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Review Article

Influence of Root Canal Preparation on Formation of Dentinal Microcracks: A Systematic Review

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The effect of root canal preparation technique on microcrack initiation is a controversial issue. This systematic review aimed to assess the role of root canal preparation techniques with different kinematics (manual, rotary, reciprocating, adaptive, self-adjusting file) on microcrack initiation. In vitro and in situ studies comparing the influence of at least two different root canal preparation techniques on the initiation of dentin microcracks were searched in PubMed/MEDLINE and SCOPUS up to June 5, 2018 without language and period restriction. Two authors independently reviewed all identified titles and abstracts for eligibility. Tables were generated to summarize the included studies, and the included studies were assessed for bias. Fifty-four (n=54) articles met the eligibility criteria. The results were classified according to the method used for microcrack evaluation, and most studies that used micro-computed tomography showed no formation of new cracks after root canal preparation. In general, the instrumentation techniques induced microcrack formation when the methods were destructive, irrespective of kinematics. In relation to the apex region, when the preparation working length was set as the root canal length subtracted of 1 mm, the risk of microcrack initiation reduces. The majority of the included studies had low risk of bias for all assessed domains. Our results seem to indicate that the various root canal preparation techniques considered in this study will not cause damage to the dental structure when adequately employed and the proper methodology is applied.

Key Words: endodontic treatment, dentinal microcracks, micro-computed tomography analysis, root canal preparation, systematic review.

Introduction

Hand root canal preparation techniques were successfully employed for many years, with advances (e.g. development of nickel–titanium instruments) leading to alternative mechanized systems that employ different kinematics, optimizing the procedure, enhancing shaping ability and decreasing the risk of instrument fracture during treatment (1,2). Kinematics of engine-driven Ni-Ti (nickel–titanium) instruments may be divided into rotary motion, rotational reciprocating motion, vertical vibration (Self-adjusting File system based on in-and-out motion to remove dentine and provide continuous irrigation during preparation), and rotary motion plus rotational reciprocating motion (adaptive motion) (3). Considering that these systems are operated under different kinematics and parameters of use, these factors may potentially influence the efficacy of the instrumentation and its impact on the final performance of endodontically treated teeth. Recent studies suggested that mechanized instruments may present an increased biological cost leading to additional tooth structure removal and also inducing the formation of microcracks on dentinal root canal surface (4-6).

It is known that a higher frequency of defects in a material exponentially increases the risk of stress concentration during mechanical loading and potentially impairs the mechanical performance of the restorative assembly leading to catastrophic fracture under lower loads than the conventional nominal resistance (7), and that microcracks induced by different root canal preparation techniques could compromise tooth mechanical performance during masticatory function (8). In contrast, many studies refute any causal relation between different preparation techniques and microcrack formation (9-12). Besides, the existing high heterogeneity of methodological aspects involved in the different in vitro studies including the use of various existing techniques, kinematics and parameters for root canal preparation contributes to this lack of consensus. Thus, a systematic review that considers all existing evidence on such scientific field may help to clarify such causal relation or guide future studies to adequately answer such important question.

There are two major fundamental methodologies to assess the presence of defects/microcracks on tooth structure. The first is based on destructive tests, where teeth are first visually inspected for the presence of external surface defects and dentinal defects are not rule out, then instrumented; next, slices are made, and each slice is individually analyzed considering the presence or absence of defects (4-6). Studies using this approach frequently use non-instrumented teeth as the baseline comparison

condition, and it is possible that such a processing technique could induce defects (11,13). The second approach is based on non-destructive techniques, usually employing micro-computed tomography (μCT) analysis, where the teeth are initially scanned for microcracks and are rescanned after instrumentation, and then the images superposed, which grants considerably higher accuracy, precision and more reliable data (9-13). Thus, this systematic review aimed to assess the role of endodontic instrumentation techniques with different kinematics on microcrack initiation. In addition, we discussed the accuracy and validity for microcrack detection of the different implemented methods.

Material and Methods

This systematic review followed the 4-phase flow diagram in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (14) and the review report is based on the PRISMA Statement checklist (14).

Registration

We did not pre-register the protocol of our systematic review because the PROSPERO (International prospective register of systematic reviews) does not accept to register systematic reviews of in vitro studies.

Eligibility Criteria

Inclusion Criteria

In the study were included published in vitro studies comparing the influence of at least two different root canal preparation techniques (manual, rotary, reciprocating, adaptive, self-adjusting file) on the initiation of dentin microcracks in teeth and evaluating the quantity and/or length of microcracks. Also, we included in situ studies using cadavers. We included studies independent of the implemented microcrack evaluation technique (destructive or non-destructive), the group of teeth evaluated or the definition of the presence or not of cracks. No language and publication date restrictions were imposed.

The "PICOs" questions (population, intervention, comparison and outcomes) for this systematic review were defined as follows:

Population: endodontically treated teeth

Intervention/Comparison: at least two different root canal preparation techniques (manual, rotary, reciprocating, adaptive, self-adjusting file.

Outcome: initiation of dentin microcracks.

Study design: In vitro and in situ studies

Exclusion Criteria

Articles reporting clinical evaluations and narrative/systematic reviews and other research designs such as accuracy studies of microcracks detection were excluded.

Information Sources and Search

Studies were identified by searching two electronic databases (PubMed/MEDLINE and SCOPUS) without language and period restriction. The search strategy was drafted based on the MeSH terms of PubMed/MEDLINE and related entry terms. Adapted terms were necessary for searching the SCOPUS database. The last search was run on June 5, 2018.

The following search strategies were used:

PubMed/MEDLINE: (((dentinal cracks OR dentinal microcracks OR dentinal defect OR dentinal damage OR cracks in the root dentin OR root fracture)))) AND (("Root Canal Preparation" [Mesh] OR "Root Canal Preparation" OR "Canal Preparation, Root" OR "Canal Preparations, Root" OR "Preparation, Root Canal" OR "Preparations, Root Canal" OR "Root Canal Preparations"))

SCOPUS: (((dentinal AND cracks OR dentinal AND microcracks OR dentinal AND defect OR dentinal AND damage OR cracks AND in AND the AND root AND dentin OR root AND fracture))) AND (("Root Canal Preparation" OR "Canal Preparation, Root" OR "Canal Preparations, Root" OR "Preparation, Root Canal" OR "Preparations, Root Canal" OR "Root Canal Preparations"))

Study Selection

Results of the literature searches were uploaded in the Endnote program (Thomson Reuters, New York, NY) and duplicate records were removed. Two reviewers independently screened all titles and abstracts and full-text copies of all studies that met the inclusion criteria or were classified as uncertain (when there was insufficient information in the title/abstract). The same two reviewers independently assessed the full-text copies and the discrepancies were resolved through discussion between the reviewers. A third reviewer was consulted in case of disagreement. In situations in which there was missing information or data, authors were contacted by e-mail.

Data Collection Process and Data Items

A standardized outline was developed to extract the following data:

1. Publication details: author, year of publication;
2. Endodontic treatment details: tested endodontic instrumentation techniques, root canal irrigants;
3. Methodological details: dental group, methodology used for microcrack evaluation, if that technique was based on a destructive or non-destructive method, and evaluation time (before and/or after root canal instrumentation).
4. Main findings.

All data items were initially discussed among four

reviewers involved in the study and the data collection process was completed by 2 independent reviewers and verified by two others independently.

Risk of Bias Assessment

The risk of bias of included studies was assessed based on previous studies (15,16) and considering the judgment of the following items: teeth randomization, use of teeth with similar anatomy, blinding of microcracks assessment, independent microcracks assessment and care with maintenance of dental humidity. All data items were discussed among three reviewers and the ratings (unclear, high risk and low risk of bias) were completed by one member of the team and verified by another two members independently. Publication bias was not statistically assessed.

Data Synthesis

The primary outcome was the number of new microcracks observed after the root canal preparation only considering studies evaluating microcracks formation through micro-computed tomography. We decided to use that outcome because previous studies demonstrated that the use of destructive methods could introduce new microcracks during sample preparation (11-13). However, a meta-analysis was not possible based on the heterogeneity of the research designs. As such, studies were synthesized descriptively, and tables were separated by microcrack assessment method.

The data presented on the studies that used destructive methods were collected and synthesized descriptively as complementary data. Another important aspect is that some studies focused on the initiation of cracks on the external surface of apex teeth region, and those studies were also considered separately.

Results

Literature Search

One hundred sixteen (n=116) of the 937 titles and abstracts screened were selected for full-text analysis, with 62 studies excluded and 54 studies (4-6,9-12,17-63) meeting our eligibility criteria (Fig. 1). The reasons for exclusion are reported in Figure 1.

Study Characteristics

Table 1 presents the characteristics of the included studies. Sixteen studies (31.48%) compared rotary and reciprocating preparation techniques (5,10,11,17,27-

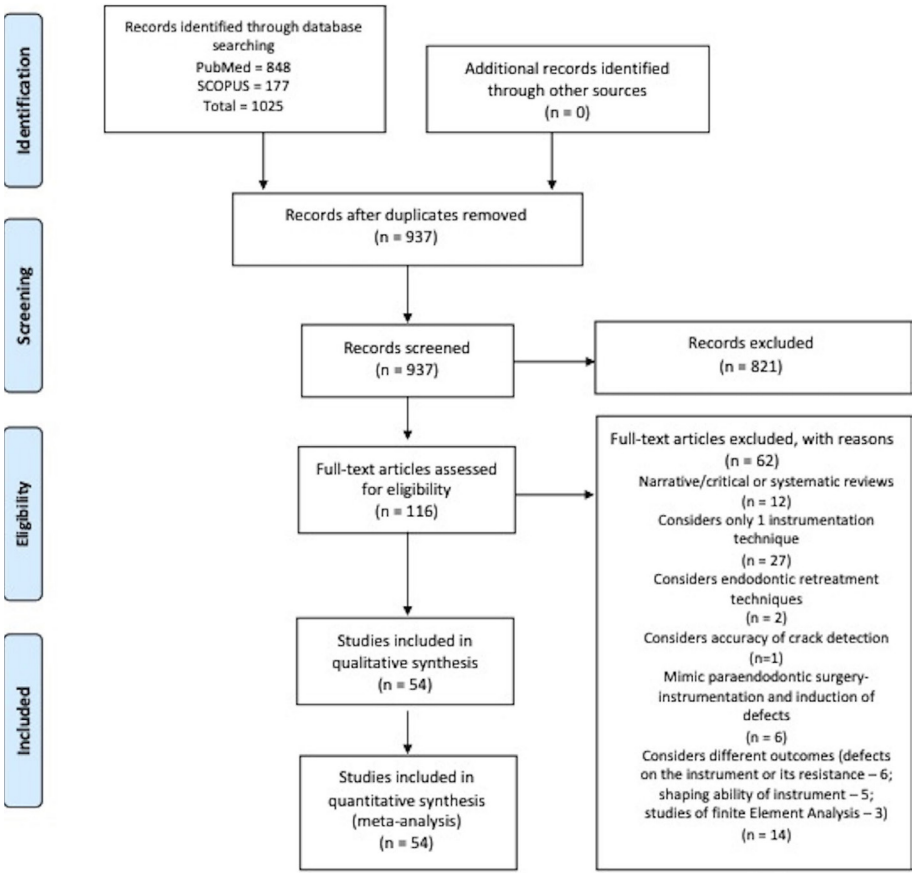

Figure 1. Preferred reporting items for systematic reviews and meta-analyses 2009 flow diagram.

Table 1. Characteristics of included studies

Reference	Method of microcrak evaluation	Comparison tested	Root canal irrigation	Teeth used
Abou El Nasr, et al. (2014). «Dentinal damage and fracture resistance of oval roots prepared with single-file systems using different kinematics.» J Endod 40(6): 849-851.	Destructive/ Stereomicroscope	Rotary, Reciprocating	2.5% NaOCl	65 roots with oval canals, with mature apices
Adorno, C. G., et al. (2009). «The effect of root preparation technique and instrumentation length on the development of apical root cracks.» J Endod 35(3): 389-392.	Non-Destructive (apex)/Digital microscope	Hand, Rotatory	1% NaOCl	40 mandibular premolars with straight roots
Adorno, C. G., et al. (2010). «The effect of working length and root canal preparation technique on crack development in the apical root canal wall. Int Endod J 43(4): 321-327.	Non-Destructive (apex)/Digital microscope	Hand, Rotatory	1% NaOCl	70 mandibular premolars with straight roots
Arias, A., et al. (2014). «Comparison of 2 canal preparation techniques in the induction of microcracks: a pilot study with cadaver mandibles.» J Endod 40(7): 982-985.	Destructive/ Microscope	Hand, Reciprocating	6% NaOCl	3 lower incisors from each of 6 adult human cadaver skulls
Ashwinkumar, V., et al. (2014). "Effect of reciprocating file motion on microcrack formation in root canals: An SEM study." Int Endod J 47(7): 622-627.	Destructive/SEM	Hand, Rotary, Reciprocating	2.5% NaOCl	150 mandibular first molars with fully formed apices
Aydin, U., et al. (2015). «Effect of ethylenediaminetetraacetic acid gel on the incidence of dentinal cracks caused by three novel nickel-titanium systems.» Aust Endod J 41(3): 104-110.	Destructive/ Stereomicroscope	Reciprocating, Twisted File Adaptive	2.5% NaOCl	70 mandibular premolars with only one straight canal
Bahrami, P., et al. (2017). «Detecting dentinal microcracks using different preparation techniques: an in situ study with cadaver mandibles.» J Endod 43(12): 2070-2073.	Destructive/ Microscope	Hand, Rotary, Reciprocating	6% NaOCl	15 human mandibles with 95 single-rooted teeth
Bayram, H. M., et al. (2017). «Effect of ProTaper Gold, Self-Adjusting File, and XP-endo Shaper instruments on dentinal microcrack formation: a micro–computed tomographic study.» J Endod 43(7): 1166-1169.	Non-destructive/ µCT	Rotatory, Self-Adjusting File	1% NaOCl	40 human mandibular premolars having single-canal, straight root, closed apex
Bier, C. A., et al. (2009). «The ability of different nickel-titanium rotary instruments to induce dentinal damage during canal preparation.» J Endod 35(2): 236-238.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	2% NaOCl	260 mandibular premolars
Borges, A. H., et al. (2018). «Influence of cervical preflaring on the incidence of root dentin defects.» J Endod 44(2): 286-291.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	1% NaOCl	180 human single-rooted maxillary central incisors with fully formed apices and straight root canals

Reference	Method of microcrak evaluation	Comparison tested	Root canal irrigation	Teeth used
Burklein, S., et al. (2013). «Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation.» J Endod 39(4): 501-504.	Destructive/ Stereomicroscope	Rotary, Reciprocating	NaOCl	100 human central mandibular incisors with mature apices and straight root canals
Cassimiro, M., et al. (2017). «Occurence of dentinal defects after root canal preparation with R-phase, M-Wire and Gold Wire instruments: a micro-CT analysis.» BMC Oral Health 17(1): 93.	Non-destructive/ µCT	Rotary, Reciprocating	2.5% NaOCl	60 permanent mandibular incisors with a single canal, with straight root canals
Cassimiro, M., et al. (2018). «Effects of Reciproc, ProTaper Next and WaveOne Gold on root canal walls: a stereomicroscope analysis.» Iran Endod J 13(2): 228-233.	Destructive/ Stereomicroscope	Rotary, Reciprocating	2.5% NaOCl	60 permanent mandibular incisors with straight roots
Ceyhanli, K. T., et al. (2016). «Comparison of ProTaper, RaCe and Safesider instruments in the induction of dentinal microcracks: a micro-CT study.» Int Endod J 49(7): 684-689.	Non-destructive/ µCT	Rotary, Reciprocating	2.5% NaOCl	30 mandibular molars with two separate mesial canals and foramina, with mature apices and similar lengths
Çiçek, E., et al. (2015). «Evaluation of microcrack formation in root canals after instrumentation with different NiTi rotary file systems: A scanning electron microscopy study.» Scanning 37(1): 49-53.	Destructive/SEM	Hand, Rotary, Reciprocating	2.5% NaOCl	60 mandibular molars. The mesial roots were used for the study
Coelho, M. S., et al. (2016). «Light-emitting diode assessment of dentinal defects after root canal preparation with Profile, TRUShape, and WaveOne Gold Systems.» J Endod 42(9): 1393-1396.	Destructive/ Dental Operating Microscope	Rotary, Reciprocating	4.125% NaOCl	80 mesial roots of mandibular molars presenting 2 canals. Only teeth presenting separate mesial and distal roots, 2 separate and patent mesial canals, and mature apices with no previous endodontic procedures
de Oliveira, B. P., et al. (2017). «Micro–computed tomographic analysis of apical microcracks before and after root canal preparation by hand, rotary, and reciprocating instruments at different working lengths.» J Endod 43(7): 1143-1147.	Non-destructive/ µCT	Hand, Rotary, Reciprocating	1% NaOCl	60 mandibular incisors with mature apices and single straight root canals
De-Deus, G., et al. (2015). «Micro-computed tomographic assessment on the effect of ProTaper Next and Twisted File Adaptive Systems on dentinal cracks.» J Endod 41(7): 1116-1119.	Non-destructive/ µCT	Rotatory, Self Adjusting File	5.25% NaOCl	175 Human mandibular first and second molars with completely separated roots. Only teeth with moderate curvature of the mesial root. 20 moderately curved mesial roots of mandibular molars were selected.

Reference	Method of microcrak evaluation	Comparison tested	Root canal irrigant	Teeth used
De-Deus, G., et al. (2017). «Dentinal microcrack development after canal preparation: a longitudinal in situ micro-computed tomography study using a cadaver model.» J Endod 43(9): 1553-1558.	Non-destructive/ µCT	Rotary, Reciprocating	2.5% NaOCl	Inclusion criteria awere the presence of non-carious maxillary first and second premolars surrounded by alveolar bone and periodontal ligament. The first and second maxillary premolars from each bone block were selected for the experimental procedures. The first premolars had 2 canals, whereas the second premolars had only 1 root canal
Devale, M. R., et al. (2017). «Effect of instrumentation length and instrumentation systems: Hand versus rotary files on apical crack formation – an in vitro study.» J Clin Diagn Res 11(1): ZC15-ZC18.	Non-Destructive (apex)/ Stereomicroscope	Hand, Rotatory	3% NaOCl	60 mandibular premolars, with straight roots and completely formed apices
Garg, S., et al. (2015). «Comparison of dentinal damage induced by different nickel-titanium rotary instruments during canal preparation: An in vitro study.» J Conserv Dent 18(4): 302-305.	Destructive/ Stereomicroscope	Hand, Rotatory	3% NaOCl	150 mandibular premolars
Harandi, A., et al. (2017). «Incidence of Dentinal Crack after Root Canal Preparation by ProTaper Universal, Neolix and SafeSider Systems.» Iran Endod J 12(4): 432-438.	Destructive/ Stereomicroscope	Rotary, Reciprocating	2% NaOCl	60 mandibular first molars with separate mesial and distal roots, only teeth with moderate root curvatures (25-30°)
Helvacioglu-Yigit, D., et al. (2015). «Evaluation of dentinal defect formation after root canal preparation with two reciprocating systems and hand instruments: an in vitro study.» Biotechnol Biotechnol Equip 29(2): 368-373.	Destructive/ Stereomicroscope	Hand, Reciprocating	5.25% NaOCl	60 mandibular anterior teeth with single, straight roots and intact root apices
Hin, E. S., et al. (2013). «Effects of self-adjusting file, Mtwo, and ProTaper on the root canal wall.» J Endod 39(2): 262-264.	Destructive/ Stereomicroscope	Hand, Rotatory, Self Adjusting File	2% NaOCl	100 mandibular premolars
Jain, A., et al. (2017). «Comparison of dentinal defects induced by hand files, multiple, and single rotary files: A stereomicroscopic study.» World Journal of Dentistry 8(1): 45-48.	Destructive/ Stereomicroscope	Hand, Rotatory	5.25% NaOCl	60 mandibular premolars free of defects with single root canal
Jalali, S., et al. (2015). «Effects of Reciproc, Mtwo and ProTaper instruments on formation of root fracture.» Iran Endod J 10(4): 252-255.	Destructive/ Stereomicroscope	Rotary, Reciprocating	2.5% NaOCl	100 human mandibular premolars with single canals
Kansal, R., et al. (2014). «Assessment of dentinal damage during canal preparation using reciprocating and rotary files.» J Endod 40(9): 1443-1446.	Destructive/ Stereomicroscope	Rotary, Reciprocating	1% NaOCl	120 human mandibular premolars with straight roots, single canal.

Reference	Method of microcrak evaluation	Comparison tested	Root canal irrigant	Teeth used
Karatas, E., et al. (2015)a. «Dentinal crack formation during root canal preparations by the twisted file adaptive, ProTaper Next, ProTaper Universal, and WaveOne instruments.» J Endod 41(2): 261-264.	Destructive/ Stereomicroscope	Rotatory, Reciprocating, Twisted File Adaptive	NaOCl	75 human mandibular central incisors with mature apices and straight root canals, single-rooted teeth with a single canal
Karatas, E., et al. (2016). «Incidence of dentinal cracks after root canal preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper Universal instruments.» Int Endod J.	Destructive/ Stereomicroscope	Rotary, Reciprocating	2% NaOCl	90 human mandibular central incisor teeth with mature apices and straight canals, single canal, mature apices and single apical foramen
Karatas, E., et al. (2015). «Incidence of Dentinal Cracks after Root Canal Preparation with Twisted File Adaptive Instruments Using Different Kinematics.» J Endod 41(7): 1130-1133.	Destructive/ Stereomicroscope	Hand, Twisted File Adaptive	NaOCl	105 human mandibular central incisors with single canals and similar lengths
Kesim, B., et al. (2017). «Evaluation of dentinal defects during root canal preparation using thermomechanically processed nickel-titanium files.» Eur J Dent 11(2): 157-161.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating, Twisted File Adaptive	1% NaOCl	150 human mandibular premolars with mature apices and a root canal curvature<5°, one straight canal
Kfir, A., et al. (2017). «Incidence of microcracks in maxillary first premolars after instrumentation with three different mechanized file systems: a comparative ex vivo study.» Clin Oral Investig 21(1): 405-411.	Destructive/ Dental Operating Microscope	Rotatory, Reciprocating, Self Adjusting File	3% NaOCl	80 human maxillary first premolars with two separate root canals, straight roots and closed mature apices
Khirtika, S. G. and S. Ramesh (2017). "Comparative evaluation of dentinal cracks and detachments after instrumentation with hand and rotary files at various instrumentation lengths: An in vitro study." J Adv Pharm Technol Res 7(3): 236-239.	Destructive/ Dental Operating Microscope	Hand instrumentation, Rotatory	1% NaOCl	36 human mandibular central incisors, single root and single canal
Khoshbin, E., et al. (2018). «The effect of canal preparation with four different rotary systems on formation of dentinal cracks: an in vitro evaluation.» Iran Endod J 13(2): 163-168.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	Reciproc (3 mL of saline); Control groups (2.5% NaOCl)	110 human single-rooted, single-canal human teeth with no apical root curvature
Kumari, M. R. and M. M. Krishnaswamy (2016). «Comparative analysis of crack propagation in roots with hand and rotary instrumentation of the Root Canal -An Ex-vivo Study.» J Clin Diagn Res 10(7): Zc16-19.	Non-Destructive (apex)/ Stereomicroscope	Hand, Rotatory	None	70 human premolars with complete apices and single, straight root and root canal
Li, M. L., et al. (2018). «A micro-computed tomographic evaluation of dentinal microcrack alterations during root canal preparation using single-file Ni-Ti systems.» Exp Ther Med 15(1): 494-499.	Non-destructive/ µCT	Hand, Rotary, Reciprocating	5.25% sodium hipochloryte	100 human mandibular first molars with completely separated roots

Reference	Method of microcrak evaluation	Comparison tested	Root canal irrigant	Teeth used
Li, S. H., et al. (2015). «Occurrence of dentinal microcracks in severely curved root canals with ProTaper Universal, WaveOne, and ProTaper Next File Systems.» J Endod 41(11): 1875-1879.	Destructive/ Stereomicroscope	Rotary, Reciprocating	1% NaOCl	60 human molars, each with at least 1 curved root and root canal
Liu, R., et al. (2013)a. «Incidence of apical root cracks and apical dentinal detachments after canal preparation with hand and rotary files at different instrumentation lengths.» J Endod 39(1): 129-132.	Destructive/ Stereomicroscope (apex)	Hand, Rotatory	2% NaOCl	240 human mandibular incisors with straight roots and single canal
Liu, R., et al. (2013). «The incidence of root microcracks caused by 3 different single-file systems versus the ProTaper system.» J Endod 39(8): 1054-1056.	Destructive (sections) Non-destructive (apex)/ Stereomicroscope	Rotatory, Reciprocating, Self Adjusting File	2% NaOCl	100 human mandibular incisors with straight roots, single canal
Milani, A. S., et al. (2012). «The effect of root canal preparation on the development of dentin cracks.» Iran Endod J 7(4): 177-182.	Destructive/ Dental Operating Microscope	Hand, Rotatory	1% NaOCl	57 human mandible incisor teeth.
Monga, P., et al. (2015). «Comparison of incidence of dentinal defects after root canal preparation with continuous rotation and reciprocating instrumentation.» Singapore Dent J 36: 29-33.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	3% NaOCl	150 human mandibular premolars with mature apices and single straight root canals with single apical foramen
Pedulla, E., et al. (2017). «Effects of 6 single-file systems on dentinal crack formation.» J Endod 43(3): 456-461.	Destructive/ Stereomicroscope	Rotary, Reciprocating	3% NaOCl	64 human mandibular central incisors with mature apices single rooted teeth with a single straight canal
Pop, I., et al. (2015). «Synchrotron light-based µCT to analyse the presence of dentinal microcracks post-rotary and reciprocating NiTi instrumentation.» Clin Oral Investig 19(1): 11-16.	Non-destructive/ µCT	Rotary, Reciprocating	1% NaOCl	14 human mandibular and maxillary first molars with mature apices
Priya, N. T., et al. (2014). «»Dentinal microcracks after root canal preparation» a comparative evaluation with hand, rotary and reciprocating instrumentation.» J Clin Diagn Res 8(12): Zc70-72.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	1% NaOCl	100 human mandibular central incisors with single root and single patent canal
Rose, E. and T. Svec (2015). «An Evaluation of Apical Cracks in Teeth Undergoing Orthograde Root Canal Instrumentation.» J Endod 41(12): 2021-2024.	Destructive (apex)/Dental Operating Microscope	Hand, Rotary, Reciprocating	6.15% NaOCl	40 mandibular first and second premolars of pig jaws with single root
Saha, S., et al. (2017). «Evaluation of the incidence of microcracks caused by Mtwo and ProTaper next rotary file systems versus the self-adjusting file: A scanning electron microscopic study.» J Conserv Dent 20(5): 355-359.	Destructive/SEM	Rotatory, Self Adjusting File	2.5% NaOCl	120 human mandibular premolar teeth with straight roots single canals.

Reference	Method of microcrak evaluation	Comparison tested	SRoot canal irrigation	Teeth used
Shori, D. D., et al. (2015). «Stereomicroscopic evaluation of dentinal defects induced by new rotary system: «ProTaper NEXT».» J Conserv Dent 18(3): 210-213.	Destructive/ Stereomicroscope	Hand, Rotatory	NaOCl	60 human single-rooted premolars
Stringheta, C. P., et al. (2017). «Micro–computed tomography versus the cross-sectioning method to evaluate dentin defects induced by different mechanized instrumentation techniques.» J Endod 43(12): 2102-2107.	Non-destructive/ µCT	Rotary, Reciprocating	2.5% NaOCl	40 mesial roots of first and second mandibular molars, fully formed roots, roots with independent foramina, curvatures between 10 and 30, and an initial foramen diameter corresponding to a #15 K-type file
Topçuoğlu, H. S., et al. (2016). «Effect of glide path and apical preparation size on the incidence of apical crack during the canal preparation using Reciproc, WaveOne, and ProTaper Next systems in curved root canals: A stereomicroscope study.» Scanning 38(6): 585-590.	Non-Destructive/ Stereomicroscope	Rotary, Reciprocating	2.5% NaOCl	140 human mandibular first molar with two separate mesial canals, and two separate apical foramina
Ustun, Y., et al. (2015). «The effects of different nickel-titanium instruments on dentinal microcrack formations during root canal preparation.» Eur J Dent 9(1): 41-46.	Destructive/ Stereomicroscope	Hand, Rotary, Reciprocating	2.5% NaOCl	120 human mandibular incisor teeth with straight roots (<5°), with single canals
Yoldas, O., et al. (2012). «Dentinal microcrack formation during root canal preparations by different NiTi rotary instruments and the self-adjusting file.» J Endod 38(2): 232-235.	Destructive/ Stereomicroscope	Hand, Rotatory, Self Adjusting File	2.5% NaOCl	140 human mandibular first molars
Zhou, X., et al. (2015). «Comparison of dentinal and apical crack formation caused by four different nickel-titanium rotary and reciprocating systems in large and small canals.» Dent Mater J 34(6): 903-909.	Destructive/SEM	Hand, Rotatory, Twisted File Adaptive	1% NaOCl	180 large canals in the premolars and 100 small canals in the molar
Zuolo, M. L., et al. (2017). «Micro-computed tomography assessment of dentinal micro-cracks after root canal preparation with TRUShape and Self-adjusting File Systems.» J Endod 43(4): 619-622.	Non-destructive/ µCT	Rotatory Reciprocating, Self Adjusting File	5.25% NaOCl	40 straight mandibular incisors

µCT - Micro–computed Tomography

30,32,36,40,41,43,50,55,60,63), 12 (22.22%) compared manual, rotary and reciprocating techniques (21,23,25,26,31 ,33,47,49,54,56,57,61) and 8 studies (14.81%) tested manual and rotary techniques (18,19,34,35, 39,48,52,53,59). The most commonly used irrigating solutions were 2.5% sodium hypochlorite (n=14) (6,10, 11,17,21,22,28-31,40,58,60,61) and 1% sodium hypochlorite (n=13) (18,19,24,26,33,41 ,45,46,50,53,55, 56,62). Mandibular incisors were used in 17 studies (31.48%) (5,12,20,27-29,33,37,44,46,51-53,56,61) and mandibular premolars in 16 studies (29.63%) (4,18,19,22,24,25,34,35,38-41,45,54,58,63). Most studies (n=38) used destructive techniques for microcracks evaluation (4-6,12,17,20-23,25-27,29,31,32,35-47,50-54,56-59,61). Twenty-nine (29) studies (53.7%) evaluated the microcracks using a stereomicroscope (5,6,17,22,25-27,29,34-45,47,48,50,52,54,56,59-61) and only 11 studies (20.37%) used the µCT (9-12,24,28,30,33,49,55,63).

Micro-Computed Tomography Studies

Table 2 features the results of studies that used µCT to evaluate the microcracks (n=11). Seven studies (63.64%) demonstrated no formation of new cracks after root canal preparation (9-12,24,28,33), and the following studies revealed formation of new cracks after root canal preparation: Li et al. (49) showed that the OneShape system (rotary system) resulted in increased microcracks; Ceyhanli et al. (30) compared two rotary systems (ProTaper Universal and RaCe) and one reciprocating system (Safesider) and the results revealed that all systems increased the number of microcracks, and ProTaper Universal generated more microcracks than the RaCe system; Pop et al., (55) tested ProTaper Universal (rotary) and WaveOne (reciprocating) and both systems induced microcracks. Jamleh et al. (63) also considered ProTaper (rotary) and WaveOne (reciprocating) systems and the latter showed a trend of introducing fewer microcracks (11 teeth shown microcracks of 20 evaluated with WaveOne, meanwhile 20 of 20 shown microcracks with the ProTaper).

Destructive Methods

Table 3 features the results of the studies that used destructive methodologies to evaluate the microcrack initiation (n=38) (4-6,12,17,20-23,25-27,29,31,32,35-47,50-54,56-59,61). In summary, the majority of these studies induced microcrack formation (23 studies in an undeniable way, 11 in a partial way, where some specific kinematics did not induce microcracks), thus only four studies rejected the hypothesis of microcrack initiation through root canal preparation (20,24,32,57).

It is important to highlight that among these four studies that rejected the influence of root canal instrumentation, Coelho et al. (32) did not observe microcracks formation after all instrumentation kinematics considered (Profile on rotary motion, TRUShape on rotary motion and WaveOne Gold on reciprocating motion), while Arias et al. (20) (considering Profile GT by hand motion, WaveOne on reciprocating motion) and Bahrami et al. (23) (considering Stainless steel K-Flexo files by hand motion, TRUShape on rotary motion, WaveOne Gold on reciprocating motion) observed absence of any defect and Rose & Svec did not observe microcrack formation considering WaveOne on reciprocating motion, ProTaper on rotatory motion and GT files by hand motion (57).

Among the studies that partially support an instrumentation technique influence, hand (6,25,31,35,47,54,61), SAF (4,6,51) or TFA (62) kinematics were the employed techniques when no microcracks were observed. Moreover, Bier et al. (25) observed the use of a rotary instrument which did not induce microcracks (S-ApeX system), whereas the use of ProTaper, ProFile and SystemGT all on rotary motion lead to microcrack initiation.

Apex Region

Table 4 features the results of the studies that considered the external apex region of teeth instrumented under different kinematics (n=8) (18,19,34,48,51,52,57,62). Five of these studies compared hand and rotary instrumentation (18,19,34,48,52); one compared hand and rotary and reciprocating (57); one compared rotary, reciprocating and TFA(57); and one rotary, reciprocating and SFA (51).

In summary, these types of in vitro studies showed a positive relationship between instrumentation and defect introduction (irrespective of the employed kinematics - 6 supported microcrack formation (18,19,34,48,52,62), 1 only showed one system (51) (Protaper on rotary motion), and 1 completely discarded microcrack formation for any system (57) (considering Profile GT on hand motion, ProTaper Universal on rotary motion and WaveOne on reciprocating motion).

Another important factor considered in the majority of these studies was the working length (WL) for instrumentation; only Liu et al. (51) and Rose & Svec (57) did not consider this factor. It seems consensual that when WL is set on total root canal length (RCL) or over this measurement the risk of microcrack initiation is increased, while when at least 1 mm WL for instrumentation is subtracted from the RCL the potential for microcrack initiation is decreased, irrespective of instrument kinematics. The only exception noticed was in Devale et al. (34), wherein the WL set on RCL and RCL-1mm depicted similar microcrack formation using hand instruments, although they also depicted a significant decrease in such occurrence for the other considered systems (Race and K3 rotary instruments).

Risk of Bias

The majority of the included studies had a low risk of bias with regard to the following items: teeth randomization (66.6%), blinding of outcome assessment (55.5%), independent assessment (59.2%) and control of teeth moisture (94.4%), and all studies presented low risk of bias with regard to using teeth with similar anatomy (Fig. 2). The review of the authors' judgments on each risk of bias item for each included study are presented in Figure 3.

Discussion

Our systematic review is the first to our knowledge that synthesizes all studies assessing the influence of different root canal preparation techniques on microcrack initiation, in endodontically treated teeth. Clear evidence was found refuting any alleged influence of root canal preparation leading to microcrack initiation, as the majority of studies that used a reliable and accurate methodology showed no relationship between these factors (9-12,24,28,33).

The lack of consensus on the effect of the instrumentation technique on microcrack development was mainly motivated by the influence of the evaluation methods acting as confounders (11). Destructive methodologies such as stereomicroscope demonstrated that root canal preparation techniques lead to microcracks formation that were not present before the instrumentation (5,6,11,17,21,22,25-27,29,31,35-38,40,41,43,44,50,53,54,56, 61,62,64). In contrast, most of studies using µCT analysis demonstrated no new microcrack formation after root canal preparation (9-12,24,28,33). The reason why this difference occurs is that µCT is the most reliable and accurate method.

A recent systematic review (65) evaluating the incidence of dentinal microcracks during the use of reciprocating and rotatory systems considering only destructive methods (teeth sectioned and examined with stereomicroscope or

Table 2. Results of studies that used micro-computed tomography to evaluate the microcracks

Author	Preparation technique	System	Results	
			Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Bayram et al., 2017	Rotary, Self-Adjusting File	ProTaper Universal (rot), ProTaper Gold (rot), Self-Adjusting File, XP-endo Shaper (rot)	Yes	No
Cassimiro et al., 2017	Rotary, Reciprocating	ProTaper Next (rot), K3XF (rot), WaveOne Gold (rec)	Yes	No
Ceyhanli et al., 2016	Rotary, Reciprocating	ProTaper Universal (rot), RaCe (rot), Safesider (rec)	Yes	ProTaper Universal (Rot) system generated more post-instrumentation dentinal microcracks than the RaCe system (Rot)
de Oliveira et al., 2017	Manual, Rotary, Reciprocating	ProTaper Universal for Hand Use (manual), HyFlex CM (rot), Reciproc (rec)	Yes	No
De-Deus et a., 2015	Rotary, Adaptive	ProTaper Next (rot), Twisted File Adaptive (TFA)	Yes	No
De-Deus et a., 2017	Rotary, Reciprocating	Reciproc (rec), ProTaper Universal (rot)	Only in ProTaper Universal group	No
Jamleh et al. 2015	Rotary, Reciprocating	ProTaper (rot), WaveOne (rec)	No	WaveOne (Rec) showed a trend of introducing fewer microcracks than ProTaper (Rot)
Li et al., 2018	Manual, Rotary, Reciprocating	WaveOne (rec), OneShape (rot), Reciproc (rec), K-file (manual)	Yes	The OneShape system (Rot) resulted in increased microcracks
Pop et al., 2015	Rotary, Reciprocating	ProTaper (rot), WaveOne (rec)	Yes	Both systems induced microcracks
Stringheta et al., 2017	Rotary, Reciprocating	Reciproc (rec), ProTaper Next (rot), WaveOne Gold (rec), ProDesign Logic (rot)	Yes	No
Zuolo et al., 2017	Rotary, Reciprocating, Self-Adjusting File	TRUShape (rot), Self-Adjusting File, BioRace (rot), Reciproc (rec)	Yes	No

rot - rotary; rec - reciprocating; TFA - twisted file adaptive; - No formation of new microcracks; + Formation of new microcracks

Table 3. Results of studies that used destructive methodologies to evaluate the microcracks

Author	Preparation technique	System	Non-prepared teeth as baseline comparison	Results	
				Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Arias et al., 2014	Hand, Reciprocating	Profile GT (hand), WaveOne (rec)	Yes	Yes	No indicatives of formation of microcracks in comparison to non-instrumented teeth
Aydin et al., 2015	Reciprocating, TFA	Reciproc (rec), WaveOne (rec), TFA (adaptive motion)	Yes	No: non instrumented teeth show absence of microcracks	Formation of microcracks regardless of instrumentation system used.
Ashwinkumar et al., 2014	Hand, Rotary, Reciprocating	NiTi K-files (manual); ProTaper (manual); ProTaper (rot); WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	ProTaper rotary files were associated with significantly more microcracks than ProTaper hand files and WaveOne Primary reciprocating files. Ni–Ti hand K-files did not produce microcracks at any levels inside the root canals.
Bahrami et al., 2017	Hand, Rotary, Reciprocating	Stainless steel K-Flexo files (hand), TRUShape (rot), WaveOne Gold (rec)	Yes	Yes	No indicatives of formation of microcracks in comparison to non-instrumented teeth. (There was no relationship between the shaping kinematics (hand preparation, WaveOne reciprocation, and rotary TRUShape) and the frequency of microcracks)
Bier et al., 2009	Hand, Rotary	Flexofiles (hand), ProTaper (rot), ProFile (rot), SystemGT (rot), S-ApeX (rot)	Yes	No: non instrumented teeth show absence of microcracks	Hand instrumentation and rotary instrumentation with S-ApeX system show absence of microcracks. However, the use of other rotary NiTi instruments resulted in formation of microcracks.
Borges et al., 2018	Hand, Rotary, Reciprocating	Stainless steel K-files (hand), ProTaper Universal (rot), ProTaper Next (rot), ProFile (rot), Reciproc (rec), WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	All instruments lead to the formation of microcracks, regardless of the enlargement or not of the cervical portion.
Burklein et al., 2013	Rotary, Reciprocating	Mtwo (rot), ProTaper (rot), Reciproc (rec), WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	Formation of microcracks regardless of instrumentation system used. (At the apical level of the canals, reciprocating files produced significantly more incomplete dentinal cracks than full-sequence rotary systems)
Cassimiro et al., 2018	Rotary, Reciprocating	ProTaper Next (rot), Reciproc (rec), WaveOne Gold (rec)	Yes	No: non instrumented teeth show absence of microcracks	Formation of microcracks regardless of instrumentation system used. (The Reciproc file generated the lowest incidence of defects, and the highest incidence occurred 6 and 9 mm from the root apex)
Çiçek et al., 2015	Hand, Rotary, Reciprocating	Stainless steel K-Flexo files (hand), ProTaper Universal (rot), ProTaper Next (rot), WaveOne (rec)	No	No: hand instrumented teeth show absence of microcracks	All instruments caused microcracks except for hand file. (The highest percentage of microcrack was recorded in 3 mm section for all groups)
Coelho et al., 2016	Rotary, Reciprocating	ProFile (rot), TRUShape (rot), WaveOne Gold (rec)	Yes	Yes	No indicatives of formation of microcracks in comparison to non-instrumented teeth.

Author	Preparation technique	System	Non-prepared teeth as baseline comparison	Results	
				Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Garg et al., 2015	Hand, Rotary	Stainless steel K-files (hand), ProTaper (rot), K3 (rot), Easy RaCe (rot)	Yes	No: non instrumented teeth show absence of microcracks	No indicatives of formation of microcracks using hand files. Indicatives of formation of microcracks using rotary instruments with intensity dependent on the system (ProTaper> K3 > Easy RaCe).
Harandi et al., 2017	Rotary, Reciprocating	ProTaper Universal (rot), Neolix (rot), SafeSider (rec)	Yes	No: non instrumented teeth show absence of microcracks	Formation of microcracks regardless of instrumentation system used.
Helvacioglu-Yigit et al. (2015)	Hand, Reciprocating	Stainless steel K-files (hand), WaveOne (rec), Reciproc (rec)	Yes	No: non instrumented teeth show absence of microcracks	Formation of microcracks regardless of instrumentation system used.
Hin et al., 2013	Hand, Rotary, SAF	Stainless steel K-Flexo files (hand), ProTaper (rot), Mtwo (rot), SAF (5000 in-and-out vibrations per minute)	Yes	No: non instrumented teeth show absence of microcracks	Instrumentation of root canals with SAF, Mtwo, and ProTaper results on damage to root canal dentin. (SAF has a tendency to cause less dentinal cracks as compared with other files)
Jain et al., 2017	Hand, Rotary	Stainless steel K-files (hand), Hero Shaper (rot), OneShape (rot)	No	Yes	All instruments results on formation of microcracks, whereas hand files induced lesser amount.
Jalali et al., 2015	Rotary, Reciprocating	Mtwo (rot), PTU (rot), Reciproc (recip)	Yes	No: non instrumented teeth show absence of microcracks	All three engine-driven systems created dentinal defects, whereas Reciproc caused less cracks.
Kansal et al., 2014	Rotary, Reciprocating	ProTaper (rot), ProTaper F2 file (rec), WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	Dentinal cracks are produced irrespective of motion kinematics, whereas reciprocating motion introduced less defects.
Karatas et al., 2015	Hand, TFA	K-files (hand), TFA (adaptive motion), TFA (rot), TFA (rot/rec)	Yes	No: non instrumented teeth show absence of microcracks	All the kinematics used caused dentinal crack formation. (TFA with rotary and reciprocating motion under specific parameters (210CW–30CCW) and hand files introduced statistically less defects)
Karatas et al., 2015a	Rotary, Reciprocating, TFA	ProTaper Universal (rot), ProTaper Next (rot), WaveOne (rec), TFA (adaptive motion)	Yes	No: non instrumented teeth show absence of microcracks	All the kinematics used caused similar dentinal crack formation.
Karatas et al., 2016	Rotary, Reciprocating	ProTaper Universal (rot), ProTaper Gold (rot), ProFile Vortex (rot), F360 (rec), Reciproc (rec)	Yes	No: non instrumented teeth show absence of microcracks	All systems produced dentinal cracks where F360 introduced less defects been statistically similar to non-instrumented teeth.
Kesim et al., 2017	Hand, Rotary, Reciprocating, TFA	Stainless Steel K-files (hand), K3XF (rot), ProTaper Next (rot), Reciproc (rec), TFA (adaptive motion)	No	Yes	Hand files, K3XF and Reciproc introduced statistically fewer defects.
Kfir et al., 2017	Rotary, Reciprocating, SAF	ProTaper (rot), WaveONe (rec), SAF (5000 in-and-out vibrations per minute)	Yes	Yes	Rotary and Reciprocating systems lead to microcrack formation. (SAF was not statistically different from non-instrumented teeth which show a small occurrence of microcrack)

Author	Preparation technique	System	Non-prepared teeth as baseline comparison	Results	
				Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Khirtika and Ramesh, 2017	Hand, Rotary	Hand instrumentation (hand), ProTaper Universal (rot), Protaper Next (rot), Mtwo (rot)	No	Yes	All groups show microcrack formation, whereas the least defects were observed in canals with hand instrumentation.
Khoshbin et al., 2018	Hand, Rotary, Reciprocating	Stainless steel K-files (hand), ProTaper (rot), Mtwo (rot), Reciproc (rec), Neolix (rot)	Yes	No: non instrumented teeth show absence of microcracks	Hand instrumented teeth show no microcrack formation. All rotary systems created dentinal cracks whereas Neolix caused the least number of cracks.
Li et al., 2015	Rotary, Reciprocating	ProTaper Universal (rot), ProTaper Next (rot), WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	All 3 NiTi files can cause dentinal microcracks. The ProTaper Next system induces lesser defects.
Liu et al., 2013	Rotary, Reciprocating, SAF	OneShape (rot), ProTaper (rot), Reciproc (rec), SAF (5000 in-and-out vibrations per minute)	Yes	No: non instrumented teeth show absence of microcracks	SAF instrumented teeth show no microcracks. Reciproc produced less dentinal defects than ProTaper and OneShape.
Liu et al., 2013	Hand, Rotatory	K3 (rot), ProTaper (rot), Flex K Files (hand)	Yes	Not reported	Rotary instruments caused more dentinal defects than hand instruments
Milani et al., 2012	Hand, Rotary	Stainless steel K-Flexo files (hand), ProTaper Universal (rot)	Yes	No: non instrumented teeth show absence of microcracks	Hand instrumentation lead to more crack formation.
Monga et al., 2015	Hand, Rotary, Reciprocating	Stainless steel K-files (hand), ProTaper (rot), K3XF (rot), WaveOne (rec)	Yes	No: non instrumented teeth show absence of microcracks	Hand instrumented teeth show no microcracks. Continuous rotating and reciprocating instruments produce dentinal crack formation, whereas reciprocating movement introduced less defects.
Nasr and Kader, 2014	Rotary, Reciprocating	WaveOne (rec), ProTaper (rot), ProTaper (rec)	Yes	No: non instrumented teeth show absence of microcracks	Wave one system introduced less defects than ProTaper.
Pedulla et al., 2017	Rotary, Reciprocating	One Shape (rot), F6 SkyTaper (F6ST) (rot), HyFlex EDM (rot), WaveOne (rec), Reciproc (rec), WaveOne Gold (rec)	Yes	No: non instrumented teeth show absence of microcracks	Instrumentation lead to microcrack formation whereas HyFlex EDM caused less defects.
Priya et al., 2014	Hand, Rotary, Reciprocating	Stainless steel K-file (hand), ProTaper (rot), ProTaper (rec), ProTaper Next (rot), ProTaper Next (rec), OneShape (rot), OneShape (rec), Reciproc (rot), Reciproc (rec)	Yes	No: non instrumented teeth show absence of microcracks	Least defects were seen in canals with hand instrumentation. (Among engine driven instrumentation ProTaper Next files showed least cracks when set in rotary or reciprocating motion. Full sequence systems showed less cracks than single file systems and reciprocating motion was found to be better for both full sequence and single file systems)
Rose & Svec, 2015	Hand, Rotary, Reciprocating	WaveOne (rec) ProTaper (rot), GT files (hand)	Yes	No: non instrumented teeth show absence of microcracks	No formation of microcracks

Author	Preparation technique	System	Non-prepared teeth as baseline comparison	Results	
				Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Saha et al., 2017	Rotary, SAF	Mtwo (rot), ProTaper Next (rot), SAF (5000 in-and-out vibrations per minute)	Yes	No: non instrumented teeth show absence of microcracks	Instrumentations lead to microcrack formation whereas SAF introduced fewer defects.
Shori et al., 2015	Hand, Rotary	Hand Files (hand), ProTaper Universal (rot), Hero Shaper (HS) (rot), ProTaper Next (rot)	No	Yes	Hand files lead to the lower microcrack formation than rotary systems. (ProTaper Netx rotary system induce less dentinal defects than ProTaper and Hero Shaper)
Ustun et al., 2015	Hand, Rotary, Reciprocating	Stainless steel K-Flexofile (hand), ProTaper F2 (rec), Reciproc (rec), ProTaper (rot), ProTaper Next (rot)	Yes	No: non instrumented teeth show absence of microcracks	All experimental groups showed microcrack formations in statistically similar intensity.
Yoldas et al., 2012	Hand, Rotary, SAF	Hand file (hand), Hero Shaper (HS) (rot), Revo-S (RS) (rot), Twisted File (TF) (rot), ProTaper (PT) (rot), SAF (5000 in-and-out vibrations per minute)	Yes	No: non instrumented teeth show absence of microcracks	Hand and SAF instrumented teeth show no microcracks. Other NiTi instruments tend to induce various degrees of dentinal damage during root canal preparation.
Zhou et al., 2015	Rotary, Reciprocating, TFA	Protaper Universal (rot), Twisted File (TF) (rot), WaveOne (rec), TFA (adaptive motion)	Yes	No: non instrumented teeth show absence of microcracks	TFA instrumented teeth show no microcracks. TF system introduced fewer defects than ProTaper Universal and WaveOne.

Rot: rotatory; Rec: reciprocating; TFA: twisted file adaptive; SAF: self-adjusting file.

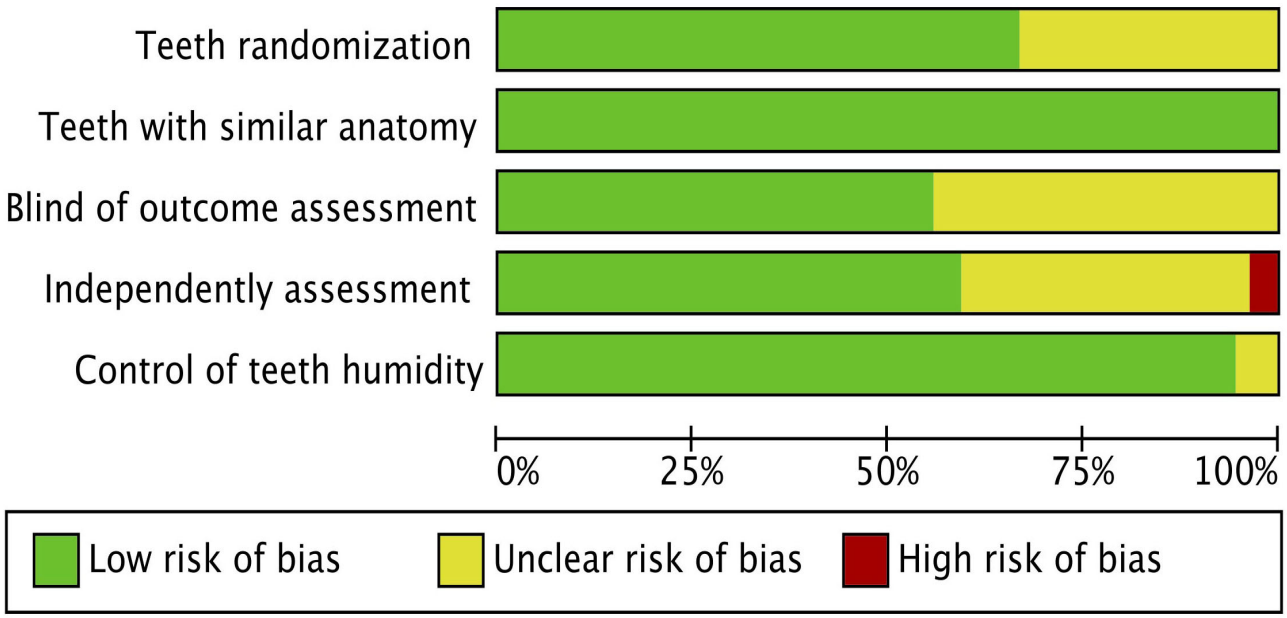

Figure 2. Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Table 4. Results of studies that considered only the apex region to evaluate the formation of microcracks

Author	Preparation technique	IL	System	Methodology for microcrack detection	Results	
					Microcracks on baseline	Instrumentation inducing, forming or propagating cracks
Adorno et al., 2009	Hand, Rotary	RCL, RCL-1mm	Stainless steel files (hand), Profile (rot)	NDM: visual inspection of photographs of apex surface on a digital microscope at 100× before and after instrumentation	No	Crack formation on apex surface was associated with the IL and not the instrumentation technique. IL equal to RCL resulted in more more cracks.
Adorno et al., 2010	Hand, Rotary	RCL, RCL-1mm	Stainless steel K-files (hand), Profile (rot)	Mixed analysis (DM and NDM): visual inspection of photographs of apex surface on a digital microscope at 100× before and after instrumentation. Then, slices were made to evaluate 1 mm deep and 2 mm deep the integrity of root surface)	No	Crack formation on apex surface was associated with the IL and not the instrumentation technique. IL equal to RCL resulted in more more cracks. The rotary technique produced more cracks prolonged into root canal surface up to 1mm deep (<2 mm deep).
Devale et al., 2017	Hand, Rotary	RCL, RCL-1mm	Stainless steel K-files (hand), RaCe (rot), K3 (rot)	NDM: visual inspection of photographs of apex surface on a stereomicroscope at 100× before and after instrumentation	No	There was no significant significance between stainless steel hand files and rotary files for crack formation. IL had a significant effect on crack formation when rotary files were used but not for hand files.
Kumari and Krishnaswamy, 2016	Hand, Rotary	RCL, RCL-1mm	Stainless Steel files (hand), ProTaper Universal (rot), ProTaper Next (M wire) (rot)	DM: apex surface was polished, photographed and images were examined on a stereomicroscope at 20× before and after instrumentation	No	All samples depict crack formation after instrumentation. Hand files caused more cracking than rotary files, the smallest number of cracks for ProTaper Next. When the IL was set 1 mm short, all systems showed fewer cracks
Liu et al., 2013	Rotary, Reciprocating, SAF	RCL	OneShape (rot), ProTaper (rot), Reciproc (rec), SAF (5000 in-and-out vibrations/min)	NDM: visual inspection of photographs of apex surface on a stereomicroscope at 20× before and after instrumentation	No	Only instrumentation with Protaper system showed apex microcrack formation.
Liu et al., 2013a	Hand, Rotary	RCL, RCL-1mm, RCL-2mm, RCL+1mm	Stainless Steel K-flexo files (hand), K3 (rot), ProTaper (rot)	DM: visual inspection of photographs of apex surface on a stereomicroscope at 20×, instrumentation, re-evaluation and sectioning for checking microcrack extension	No	Rotary instruments caused more dentinal defects than flexible hand instruments; instrumentation short of RCL educed the risk of dentinal defects.
Rose and Svec, 2015	Hand, Rotary, Reciprocating	RCL-1mm	Profile GT (hand), ProTaper Universal (rot), WaveOne (rec)	DM: instrumentation was performed in teeth of pigs still positioned in the hemisected jaws with preservation of whole surrounding tissues. Thereafter, tissue was removed and the apex was exposed, sectioned and examined under dental operating microscope	No	No crack formation was found for non-instrumented teeth or teeth instrumented with different systems. In situ periradicular tissue supporting the roots may prevent cracking or dentinal damage.
Zhou et al., 2015	Rotary, Reciprocating, TFA	RCL-1mm, RCL+1mm	Protaper Universal (rot), Twisted File (TF) (rot), WaveOne (rec), TFA (adaptive motion)	DM: Apex surface was observed with a stereomicroscope to confirm absence of cracks. After instrumentation, the apical region was sectioned and examined by scanning electron microscopy at 50 and 100×)	No	There were no significant differences among the conditions studied regarding apex microcrack formation, although small canals predisposed more crack formation than larger canals and RCL+1mm led to more defect introduction.

Rot: rotatory; Rec: reciprocating; TFA: twisted file adaptive; SAF: self-adjusting file; IL: instrumentation length, RCL: root canal length; DM: Destructive methology; NDM: Non-destructive methodology.

scanning electron microscopy - SEM) demonstrated that the ProTaper technique resulted in more dentinal microcracks

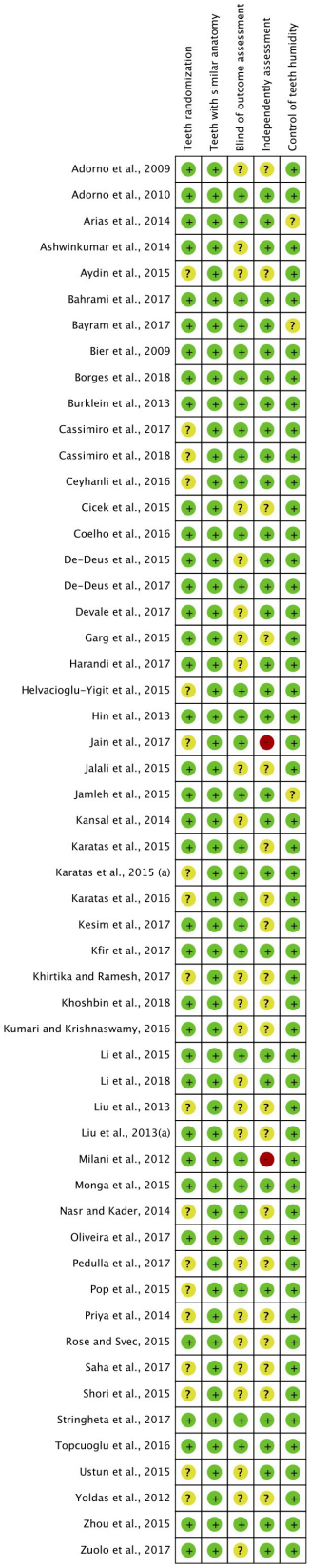

Figure3. Review authors' judgments about each risk of bias item for each included study.

compared to other systems. Our results, considering only non-destructive methods, revealed that regardless of kinematic used most of studies demonstrated no formation of new cracks after root canal preparation. In addition, the problems related to the use of destructive techniques are that they do not consider the potential injury caused by the single interplay of different sources of stress on root canal dentin in the different treatment moments. Issues such as the effect of the NaOCl substance used during irrigation, the mechanical preparation itself, the sectioning methodology (11), the inherent dehydration caused by the difficulty of maintaining of an adequate condition during the time spent in executing such methodology (66), and the mandatory alcohol series dehydration that precedes scanning electron microscopy analysis are not considered. Also, destructive methods only allow assessing limited levels of the root canal length (11).

Micro-computed tomography analysis assesses all of the root canal length, allowing the accurate positioning of dentinal microcracks. The three-dimensional reconstruction can be performed at different stages of endodontic treatment permitting that the pre-existing microcracks can be observed as it is a non-destructive method (13, 67). In regards to the effect of dehydration on microcrack initiation, Shemesh et al. (66) states that even studies which use µCT analysis are susceptible to be biased/confounded by such a factor. In this sense, it may be highlighted that almost all studies included in the present systematic review allegedly took precautions to maintain teeth hydration.

Four studies using µCT (30,49,55,63) demonstrated that instrumentation systems increased the number of microcracks. The variation of results could be associated to differences in the methodological aspects, the quality of tool used and the familiarity of the operator with hand techniques. For example, De-Deus et al. (67) pointed out several aspects that could interfere in the results of the study by Ceyhanli et al. (30): only 10 sections of each specimen were evaluated (<1.5% of the total of obtained images) which did not permit the evaluating all of the root canal length; the results could be related to false-positive findings because the used method did not permit distinction between microcracks and artefact/noise; and details about scanning and reconstruction were not reported, thus making it difficult to reproduce the study. Jamleh et al. (63) evaluated root surface strain and for that they attached a strain gauge to root surface, which required a clean dry surface. Additionally, they also executed staining methods using vacuum to detect cracks on tooth, which also is known to require extensive dehydration and could introduce defects and promote the presence of cracks (68). Besides, in another recent study, De-Deus et al. (69) using teeth from cadavers revealed absence of preexisting

dentinal microcracks in non-endodontically treated teeth demonstrating that the microcracks observed previous to endodontic treatment was considered an experimental phenomenon.

Another important consideration is the influence of the working length set for root canal preparation, irrespective of the implemented technique. Studies are almost unanimous that the subtraction of 1 mm to the root canal length should be performed to avoid damage (microcrack initiation) to the apex region, for all considered preparation techniques. However, a report of microcrack formation absence in the apex region exists in the literature and yet remains to be tested; i.e. the influence that the surrounding tissues may exert on teeth during instrumentation. Rose and Svec, was the only study that used a methodological approach where teeth were instrumented still attached to hemisected jaws under preservation of whole surrounding tissues, and this was the main reason claimed by the authors to explain the absence of any microcracks in any evaluated system (57).

Strengths of our study include rigorous methods for study selection and data extraction including the risk of bias assessment. Also, most included studies presented low risk of bias in all domains. As a limitation of the present study, assessment of the impact of publication bias in the results of the systematic review was not possible. Although it seems clear that the root canal preparation technique is probably not related to microcrack development, the impact of various restorative strategies after endodontic treatment on formation of microcracks remains largely unknown. Also, the compliance of strict protocols from tooth extraction until final analysis should be taken and completely reported when published. In conclusion, our results indicate that the various root canal preparation techniques considered in this study will not cause damage to the dental structure when adequately employed.

Resumo

O efeito da técnica de preparo do canal radicular na iniciação e/ou propagação de microfissuras dentinárias é um tema controverso. Essa revisão sistemática teve como objetivo avaliar o papel das técnicas de preparo do canal radicular com diferentes cinemáticas (manual, rotatória, reciprocante, adaptativa e self-adjusting file) na iniciação e/ou propagação de microfissuras dentinárias. Estudos in vitro e in situ comparando a influência de pelo menos duas técnicas diferentes de preparo do canal radicular foram identificados no PubMed/MEDLINE e SCOPUS até 05 de junho de 2018 sem restrição de idioma e tempo. Dois autores revisaram de maneira independente todos títulos e resumos para elegibilidade dos estudos. Tabelas foram criadas para sumarizar os estudos incluídos e os estudos foram avaliados quanto ao risco de viés. Cinquenta e quatro (54) estudos enquadraram-se nos critérios de elegibilidade. Os resultados foram classificados de acordo com o método utilizado para avaliação das microfissuras. A maioria dos estudos que utilizaram micro-tomografia não demonstraram formação de novas microfissuras após preparo do canal radicular. Em geral, técnicas de instrumentação induziram formação de microfissuras quando os métodos de avaliação foram destrutivos, independente da cinemática. Em relação a região do ápice, quando comprimento de trabalho foi definido como o comprimento do canal menos 1 mm, o risco de indução de microfissuras é reduzido. A maioria dos estudos incluídos apresentaram baixo risco de viés para todos os domínios apresentados. Nossos resultados parecem indicar que as diferentes técnicas de preparo do canal radicular não causam danos a estrutura dental quando adequadamente utilizadas e a metodologia adequada é utilizada.

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