

Review

# Dentinal Microcracks after Root Canal Instrumentation Using Instruments Manufactured with Different NiTi Alloys and the SAF System: A Systematic Review

Kashmira Sawant<sup>1</sup>, Ajinkya M. Pawar<sup>1,\*</sup>, Kulvinder Singh Banga<sup>1</sup>, Ricardo Machado<sup>2</sup>,  
Mohmed Isaqali Karobari<sup>3,4</sup>, Anand Marya<sup>5</sup>, Pietro Messina<sup>6</sup> and Giuseppe Alessandro Scardina<sup>6,\*</sup>

<sup>1</sup> Department of Conservative Dentistry and Endodontics, Nair Hospital Dental College, Mumbai 400034, Maharashtra, India; kashmiraswnt@gmail.com (K.S.); ksbanga@gmail.com (K.S.B.)

<sup>2</sup> Clinical Practice Limited to Endodontics, Navegantes 88370-100, Santa Catarina, Brazil; ricardo.machado.endo@gmail.com

<sup>3</sup> Conservative Dentistry Unit, School of Dental Sciences, Universiti Sains Malaysia, Health Campus, Kubang Kerian, Kota Bharu 16150, Kelantan, Malaysia; dr.isaq@gmail.com

<sup>4</sup> Department of Conservative Dentistry & Endodontics, Saveetha Dental College & Hospitals, Saveetha Institute of Medical and Technical Sciences University, Chennai 600077, Tamil Nadu, India

<sup>5</sup> Department of Orthodontics, University of Puthisastra, Phnom Penh 55 180, Cambodia; amarya@puthisastra.edu.kh

<sup>6</sup> Department of Surgical, Oncological and Stomatological Disciplines, University of Palermo, 90133 Palermo, Italy; pietro.messina01@unipa.it

\* Correspondence: ajinkya@drpawars.com (A.M.P.); alessandro.scardina@unipa.it (G.A.S.)



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**Abstract: Aim:** The aim of this systematic analysis was to assess the prevalence of dentinal microcracks at various levels (3, 6, and 9 mm from the apex) after using instruments made with conventional, R-Phase, and M-Wire NiTi alloys and the SAF system. **Materials and Methods:** Electronic searches were conducted in the databases Embase, Cochrane Library, Scopus, PubMed, and Web of Science. To arrange search methods, “MeSH” terms and/or keywords typically associated with the subject were paired with the Boolean operators “AND” and “OR.” Additional searches were conducted on the websites of four separate endodontic journals. After reading the titles and excluding duplicates, 1000 of the 1343 documents originally found were eliminated. Upon reviewing the abstracts, 310 of the remaining 343 experiments were also eliminated. Based on qualifying requirements, only 13 of the remaining 33 articles were included in the qualitative review. **Results:** All systems triggered dentinal microcracks; however, when chemo-mechanical preparation was performed using Self-Adjusting File (SAF) and systems manufactured with R-phase technology—K3XF and Twisted File Adaptive (TFA)—less of these defects were found when compared to those manufactured with traditional NiTi—ProTaper Universal and Mtwo—and with M-Wire—ProTaper Next, Reciproc, and WaveOne. **Conclusions:** A lower prevalence of dentinal microcracks was observed after using SAF and endodontic systems manufactured with R-phase.

**Keywords:** NiTi instruments; dentin microcracks; Self-Adjusting File system; martensite-wire; R-phase; ProTaper Universal files; Mtwo files; ProTaper Next files; Reciproc files; WAVEONE files; TF Adaptive files; K3XF files

## 1. Introduction

Endodontic treatment is primarily performed to maintain or reestablish the health of peri-radicular tissues in the vicinity of the involved teeth [1]. In vital teeth, the pulp is removed, and the root canal is cleaned, shaped, and filled with a biocompatible material. Since the periapical tissues are not involved, the procedure is based on a “prophylactic target” to prevent the formation of a peri-radicular lesion [2]. The pulp cells in necrotic teeth are destroyed and permanently compromised, enabling microbial colonization of the root canal system (RCS) [3]. While a periapical lesion is not necessarily visible on

radiographs, it can be present [4], and treatment is done to control the endodontic infection and avoid or preserve the integrity of the peri-radicular tissues [5].

The key step in removing the pulp or controlling the endodontic infection is biomechanical preparation [6]. It is performed by operating endodontic instruments and irrigating solutions confined within the radicular space [7]. While the cleaning and shaping processes occur concurrently and thus didactically [8], it is crucial to consider the whole process as it occurs in stages. Endodontic files are mostly responsible for shaping and mechanical cleaning of the root canal, while irrigating solutions have a chemical effect on root canals' contents [3].

Stainless steel hand files were traditionally used to shape the root canal. Due to its metallurgical characteristics, the occurrence of errors and injuries was high [9]. In the late 1980s, the invention of nickel-titanium (NiTi) alloys culminated in a breakthrough in endodontics. These files have significant advantages over stainless steel files, especially in terms of instrumentation safety [10]. The existence of a fixed taper and radial lands along the length of the active section distinguished the first generation of these instruments. The first generation NiTi rotary files included Lightspeed (Lightspeed Endodontics—1992), Profile (Dentsply Tulsa—1993), Quantec (Sybron Endo—1996), and GT System (Dentsply Tulsa—1998) [11–13].

Conventional NiTi endodontic instruments contain approximately 56% nickel and 44% titanium. The finish temperature of austenite is lower than body temperature. As a result, these instruments are mostly composed of the austenite phase and exhibit super elastic properties. Traditional NiTi endodontic instruments, on the other hand, are made using a machining procedure, which can result in surface defects. These flaws are to blame for negative effects on fracture resistance, cutting performance, and corrosion resistance of the files [14].

In 2007, Sportswire LLC (Langley, OK, USA) developed a patented thermomechanical manufacturing established with the aim of producing a more flexible NiTi alloy with improved cyclic fatigue resistance. The new NiTi alloy is known as M-Wire [15]. The starting content for M-Wire thermal processing was a Nitinol formulation containing approximately  $55.8 \pm 1.5\%$  nickel,  $44.2 \pm 1.5\%$  titanium, and less than 1% trace elements [16]. Several papers have shown that M-Wire is more flexible than conventionally-treated NiTi alloys [17–19]. ProTaper Next (Dentsply-Maillefer), WaveOne (Dentsply-Maillefer), and Reciproc (VDW) are examples of systems manufactured by M-Wire.

Shortly after the launch of M-Wire in 2008, SybronEndo (Orange, CA, USA) created another manufacturing method to produce Twisted File, a revolutionary rotary NiTi system (TF). Three new technologies were used in the production of TF: R-phase heat treatment, metal wire spinning, and a special surface treatment [20]. The twisting method is carried out by converting a raw NiTi wire in an austenitic state into R-phase using a patented thermal process. R-phase has a lower shear modulus and a transition strain that is one-tenth that of martensite transformation [21]. As a result, less stress is required to induce plastic deformation in R-phase, allowing the twisting mechanism to occur. To retain its new shape [22], TF is transformed back to austenite through additional thermal procedures after twisting. K3XF and TF Adaptive are two other systems that use R-phase technology (TFA, SybronEndo, Orange, CA, USA). Unlike the instruments of the TF and TFA systems, K3XF files are created using conventional grinding processes and R-phase heat treatment after the fact. TFA instruments are used with a new adaptive motion technology that allows for either rotary or reciprocating file kinematics based on the strain exerted by the root canal walls [14].

The Self-Adjusting File system (SAF; ReDent-Nova, Ra'anana, Israel) differs from other systems for two key reasons. First, the SAF is a hollow and adjustable file that adheres to the outline of the root canal in three dimensions, with the ability to fit to its cross-section. The SAF vibrates and eliminates a uniform dentin layer from the canal walls, also in oval, flat oval, and in any irregularly-shaped root canal while in use. Rather than machining a central part of the root canal into a circular cross-section, the SAF causes a flat canal to remain flat with slightly wider dimensions. Second, the hollow file allows for continual

irrigation of the root canal during the process, with the irrigant being activated further by the vibrating motion of the file, which induces turbulence in the root canal. Irrigation is delivered by a special rinsing unit that delivers the irrigant at a flow rate of 5 mL/min (VATEA, ReDent-Nova) [23,24].

The advancement of NiTi instruments has made endodontic care even more convenient for both patients and practitioners. However, clinicians and experts continue to be concerned with root canal anomalies [25,26], radicular perforations [25,26], instrument fracture [25,26], and dentinal microcracks.

Dentinal microcracks are complete or incomplete thickness cracks that occur on the root canal walls as a result of endodontic file operation. These defects result in vertical root fracture [27] and tooth extraction [28–30]. Regardless of the NiTi file system used during chemo-mechanical preparation, dentinal microcracks have been observed.

The goal of the study is to analyze the effect of different file systems with respect to their different composition of NiTi alloys and cross-sectional shapes in dentinal crack formation during root canal instrumentation.

## 2. Materials and Methods

### 2.1. Protocol and Registration

The current study adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis—PRISMA (<http://www.prisma-statement.org>) guidelines. It was accessed on 9 August 2020. However, since no clinical records were included, it was not registered in PROSPERO (International Prospective Registry of Systematic Reviews).

### 2.2. Research Question

Centered on the “PICOS” (PRISMA-P 2016) technique, studies that compared the occurrence of dentinal microcracks resultant from endodontic files made with different NiTi alloy composition and cross-sectional geometry were included:

- P (population): extracted human teeth with complete rhizogenesis;
- I (intervention): biomechanical preparation;
- C (comparison): endodontic files made by different NiTi alloys;
- O (result): dentinal microcrack formation.
- S (study design): laboratory studies.

### 2.3. Search Strategies

Refer to Table 1.

**Table 1.** Sources of information and search strategies.

Databases	Search Strategies	Results
PubMed	(“Endodontics” OR “endodontics” OR “endodontic treatment” OR “Root canal instrumentation” OR “NiTi file system” OR “Rotary instruments” OR “Reciprocating file system”) AND (“Dentinal cracks” OR “Dentin defect”)	510
Embase	(“Endodontics” OR “endodontics” OR “endodontic treatment” OR “Root canal instrumentation” OR “NiTi file system” OR “Rotary instruments” OR “Reciprocating file system”) AND (“Dentinal cracks” OR “Dentin defect”)	354
Web of Science	(“Endodontics” OR “Endodontic Treatment” OR “Root canal instrumentation” OR “NiTi file systems” OR “Rotary instruments” OR “Reciprocating file systems”) AND (“Dentinal cracks” OR “Dentin defect”)	234
Scopus	(“Endodontics” OR “endodontics” OR “endodontic treatment” OR “Root canal instrumentation” OR “NiTi file system” OR “Rotary instruments” OR “Reciprocating file system”) AND (“Dentinal cracks” OR “Dentin defect”)	222
Hand search	<i>Australian Endodontic Journal, Iranian Endodontic Journal, International Endodontic Journal, and Journal of Endodontics</i>	23
<b>Total</b>		<b>1343</b>

#### 2.4. Data Sources

Two independent researchers (K.S. and A.P.) conducted an electronic literature search up to 10 August 2019, using MeSH terms and keywords together with the Boolean operators “OR” and “AND” to collect the relevant literature using suitable filters. The keywords “NiTi file systems”, “rotary instruments”, “reciprocating file systems”, “dentin microcracks”, “dental defects”, “dental craze lines” and “endodontics” were combined with the Boolean operators “OR” and “AND” to gather the required literature using appropriate filters. The complete search strategy with the number of articles resulted from them is presented in Table 1.

#### 2.5. Eligibility Criteria

A search of the literature was conducted to find *in vitro* studies that examined the occurrence of dentinal defects after using instruments made with conventional, R-Phase, and M-Wire NiTi alloys and SAF systems, and were published between 1 January 2012, and 10 August 2019. Based on the PICOS approach, two reviewers reviewed the full texts of the remaining papers and defined inclusion and exclusion requirements. Disputes were resolved by the decision of a third reviewer. Table 2 shows the inclusion and removal conditions.

**Table 2.** Inclusion and exclusion criteria adopted.

Inclusion Criteria
<p><i>In vitro</i> experiments conducted on extracted human teeth;</p> <p>Root canals prepared with a file with conventional NiTi metallurgy (ProTaper Universal and Mtwo systems), hollow-file (Self-Adjusting File system), M-wire metallurgy (WaveOne, ProTaper Next and Reciproc systems), and R-phase metallurgy (Twisted File Adaptive and K3XF systems) using a standard technique according to the product manual;</p> <p>Inclusion of at least two of the four comparison groups: files with conventional NiTi metallurgy (ProTaper Universal and Mtwo systems), hollow-file (Self-Adjusting File system), M-wire metallurgy (WaveOne, ProTaper Next and Reciproc systems), and R-phase metallurgy (TFA and K3XF systems);</p> <p>Prepared teeth sectioned horizontally at 3, 6, and 9 mm from the apex, with the slices examined and numbered under a stereomicroscope or a scanning electron microscope (SEM);</p> <p>Dentinal cracks are measured in slices instead of the number of teeth;</p> <p>Studies published in English.</p>
Exclusion Criteria
<p><i>In vivo</i> studies or studies not of human teeth;</p> <p>Root canals prepared with instruments other than files with conventional NiTi metallurgy (ProTaper Universal and Mtwo systems), hollow-file (Self-Adjusting File system) and M-wire metallurgy (WaveOne, ProTaper Next and Reciproc systems);</p> <p>Evaluation of the crack initiation at levels other than 3, 6, and 9 mm from the apex;</p> <p>Studies without a control group;</p> <p>Evaluation of dentinal cracks after the root canal filling procedure;</p> <p>Retreatment;</p> <p>Unavailable data.</p>

Note: If any lines, microcracks, or fractures were detected in the dentinal slice, it was defined as a “slice with cracks”. A dentinal slice devoid of any craze lines, microcracks, or fractures on the external surface of the root or the internal surface of the root canal wall was defined as a “slice without cracks”.

#### 2.6. Study Selection

Two reviewers (K.S. and A.P.) were in charge of selecting/excluding publications based on a linear review of names, abstracts, and full texts (in cases of doubt). Based on the qualifying criterion, the remaining articles were read in their entirety before making the final decision (Table 2). This whole method was carried out separately, with the assistance of a third researcher (R.M.) in the cases of questions or disputes.

### 2.7. Data Extraction

After reading the full text, two researchers (K.S. and A.P.) conducted independent sampling and data extraction to collect data from qualifying studies. Significant information was extracted and reported from the included research, including the first author, publication year, region, probability of bias, reference group, root curvature, number of tooth slices per group, identification of microcracks prior to the sample, file system used, tool used to classify dentinal microcracks, control group, and irrigant method. Owing to the methodological heterogeneity of the findings, a meta-analysis was not conducted.

### 2.8. Quality Assessment

Two researchers (K.S. and A.P.) independently assessed the possibility of prejudice in the included experiments using the Joanna Briggs' consistency evaluation of in vitro studies [31]. A third researcher (R.M.) was consulted if there were any contradictions.

The assessment tool includes the following domains:

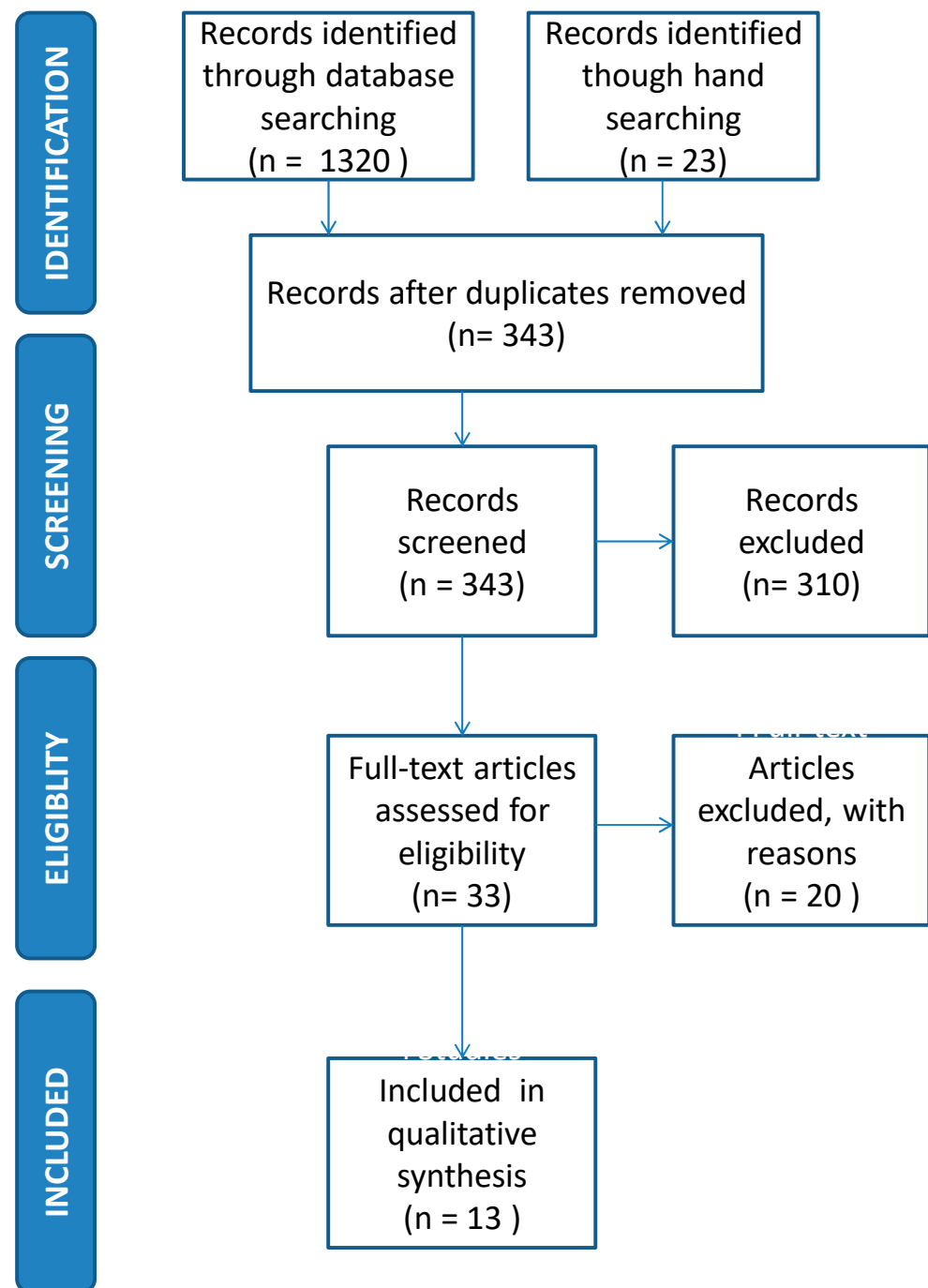
1. Congruity between the stated philosophical perspective and the research methodology.
2. Congruity between the research methodology and research question or objectives.
3. Congruity between the research methodology and the method used to collect data.
4. Congruity between the research methodology and representation, and analysis of data.
5. Congruity between the research methodology and interpretation of results.
6. Statement locating the researcher culturally or theoretically.
7. Influence of researcher on the research and vice versa addressed.
8. Representation of participants and their voices.
9. Assessment of research ethicality according to the current criteria for recent studies and if there is evidence of ethical approval by an appropriate body.
10. Assess whether the conclusion drawn in the project report flow from the analysis or interpretation of data.

Each area was assigned a Yes, No, Uncertain, or Not Available rating. According to Joanna Briggs' quality evaluation guidelines, these tests were recorded for each chosen sample. Each analysis was then classified as either an inclusion, exclusion, or obtain further detail for the systematic review.

## 3. Results

### 3.1. Study Selection Results

The PRISMA flowchart in Figure 1 shows the results of the literature scan. Initial electronic and manual searches yielded 1343 results. After reading the titles and excluding duplicates, 1000 of the 1343 documents originally found were eliminated. Since reviewing the abstracts, 310 of the remaining 343 experiments were also eliminated. Based on the qualifying criterion (Table 2), just 13 of the remaining 33 articles were included in the qualitative study.



**Figure 1.** Flowchart on number of articles selected in the systematic review based on eligibility criteria.

### 3.2. Study Features

Table 3 summarizes the characteristics of the 13 experiments chosen for quantitative analysis. All of the experiments used comparative research classes. In total, 1529 samples of mandibular teeth (incisors, premolars, and molars) were analyzed. The root curvatures ranged from 0 to 40 degrees. Prior to instrumentation, all of the teeth were scanned with a SEM or a stereomicroscope to detect prior dentinal microcracks. After the instrumentation, the same was done. A placebo group of unprepared teeth was included in both trials. In both experiments, irrigant solutions were used to prepare the root canals. In all studies, the occurrence of dentinal microcracks was assessed in slices taken from the apex at 3, 6, and 9 mm. Out of the 13 studies [32–44], 11 used devices made with conventional NiTi alloy [32–38,41–44], 2 used SAF [32,44], 13 used M-wire [32–44], and 5 used R-phase [36,38–41].

**Table 3.** Articles included in the systematic review.

No.	Article Title	Conventional NiTi		Hollow-File System		M-Wire		R-Phase		Section 3, 6, 9 mm	Technique
		PTU	Mtwo	SAF	PTN	RC	WO	TFA	K3XF		
1	In Vitro Comparative Evaluation of Dentinal Microcracks' Formation during Root Canal Preparation by Different Nickel-Titanium File Systems [32].	Yes		Yes	Yes		Yes			Yes	Stereomicroscope
2	Effect of Root Canal Preparation Techniques on Crack Formation in Root Dentin [33].	Yes					Yes			Yes	Stereomicroscope
3	Incidence of Dentinal Defects after Root Canal Preparation Reciprocating versus Rotary Instrumentation [34].	Yes				Yes	Yes			Yes	Stereomicroscope
4	Assessment of Dentinal Damage during Canal Preparation Using Reciprocating and Rotary Files [35].	Yes					Yes			Yes	Stereomicroscope
5	Dentinal Crack Formation during Root Canal Preparations by the Twisted File Adaptive, ProTaper Next, ProTaper Universal and WaveOne Instruments [36].	Yes			Yes		Yes	Yes		Yes	Stereomicroscope
6	The Effects of Different Nickel-Titanium Instruments on Dentinal Microcrack Formations during Root Canal Preparation [37].	Yes			Yes	Yes				Yes	Stereomicroscope
7	Comparison of Incidence of Dentinal Defects after Root Canal Preparation with Continuous Rotation and Reciprocating Instrumentation [38].	Yes					Yes		Yes	Yes	Stereomicroscope
8	Evaluation of Dentinal Defects during Root Canal Preparation Using Thermomechanically-Processed Nickel-Titanium Files [39].				Yes	Yes		Yes	Yes	Yes	Stereomicroscope
9	To Compare the Incidence of Dentinal Cracks after Instrumentation with Rotary, Reciprocating Twisted File Adaptive System [40].				Yes	Yes		Yes		Yes	Stereomicroscope
10	Comparison of Dentinal and Apical Crack Formation Caused by Four Different Nickel-Titanium Rotary and Reciprocating Systems in Large and Small Canals [41].	Yes					Yes	Yes		Yes	SEM

Table 3. Cont.

No.	Article Title	Conventional NiTi		Hollow-File System			M-Wire		R-Phase		Section 3, 6, 9 mm	Technique
		PTU	Mtwo	SAF	PTN	RC	WO	TFA	K3XF			
11	Effect of Reciprocating File Motion on Microcrack Formation in Root Canals: an SEM Study [42].	Yes						Yes			Yes	SEM
12	Incidence of Dentinal Cracks after Root Canal Preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper [43].	Yes						Yes			Yes	Stereomicroscope
13	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 [44].		Yes	Yes	Yes						Yes	SEM

PTU—ProTaper Universal; SAF—Self-Adjusting File; PTN—ProTaper Next; RC—Reciproc; WO—WaveOne; TFA—Twisted File Adaptive.

### 3.3. Quality Assessment

All papers related to the current study were shortlisted and screened based on names, abstracts, and finally, the entire articles were read one by one and reviewed for quality evaluation using the Joanna Briggs' quality assessment of in vitro studies' guidelines. In all, 343 papers were searched, with 330 articles being omitted for reasons such as lack of clarification of the process, research nature and results, consistency problems, and data completeness. Articles that lacked congruence between the research approach and the research query or purpose, the procedure used to gather data, data representation and analysis, and outcome interpretation were omitted (Table 4). Since the total number of experiments used in each study was limited, no statistical assessment of publishing bias (Trimand-fill, Egger's test) was carried out. Similarly, due to the scarcity of available evidence, no susceptibility or subgroup studies were carried out.



Table 4. Characteristics of the studies included in the systematic review.

No.	Title	Authors	Journal	Country	Year	Teeth	No. of Samples	Pre Instrumentation Evaluation for Cracks	Root Curvature	Control Group	File Group	Sectioning 3 mm, 6 mm, 9 mm	Examination Method	Methodology Is Well Described	Irrigant
1.	In Vitro Comparative Evaluation of Dentinal Microcracks' Formation during Root Canal Preparation by Different Nickel-Titanium File Systems [32].	Akshayraj K. Langaliya, Anjali K. Kothari, Nishantkumar R. Surti, Amiben R. Patel, Prerak R. Doshi1, and Devarshi J. Pandya	Saudi Endodontic Journal	India	2018	Mandibular premolars	84	Yes	Straight	Unprepared	ProTaper Universal, ProTaper Next and WaveOne and SAF	Yes	Stereomicroscope	Yes	Yes
2.	Effect of Root Canal Preparation Techniques on Crack Formation in Root Dentin [33].	Yazdan Shantiaee, DDS, MS, Omid Dianat, DDS, MS, Golnaz Mosayebi, DDS, Mahshid Namdari, PhD, and Patricia Tordik, DDS	PubMed	Iran	2018	Mandibular 1 <sup>st</sup> premolars	150	Yes	Curvature <25°	Unprepared	ProTaper Universal and WaveOne	Yes	Stereomicroscope	Yes	Yes
3.	Incidence of Dentinal Defects after Root Canal Preparation Reciprocating versus Rotary Instrumentation [34].	Bürklein, Tsotsis, and Schäfer	PubMed	Germany	2012	Mandibular central incisors	100	Yes	Straight (<5°)	Unprepared	ProTaper Universal, Reciproc and WaveOne	Yes	Stereomicroscope	Yes	Yes
4.	Assessment of Dentinal Damage during Canal Preparation Using Reciprocating and Rotary Files [35].	Rohit Kansal, Akhil Rajput, Sangeeta Talwar, and Ruchika Roongta	PubMed	India	2015	Mandibular premolars	120	Yes	Straight	Unprepared	ProTaper Universal and WaveOne	Yes	Stereomicroscope	Yes	Yes
5.	Dentinal Crack Formation during Root Canal Preparations by the Twisted File Adaptive, ProTaper Next, ProTaper Universal and WaveOne Instruments [36].	Karataş, Kırıcı, Arslan, Topçu, and Yeter	PubMed	Turkey	2015	Mandibular central incisors	75	Yes	Straight (<5°)	Unprepared	ProTaper Universal, Protaper Next, WaveOne and Twisted File Adaptive	Yes	Stereomicroscope	Yes	Yes
6.	The Effects of Different Nickel-Titanium Instruments on Dentinal Microcrack Formations during Root Canal Preparation [37].	Yakup, Tugrul, Burak, and Kesim	PubMed	Turkey	2019	Mandibular central incisors	120	Yes	Straight (<5°)	Unprepared	ProTaper Universal, Protaper Next, WaveOne	Yes	Stereomicroscope	Yes	Yes
7.	Comparison of Incidence of Dentinal Defects after Root Canal Preparation with Continuous Rotation and Reciprocating Instrumentation [38].	Monga, Bajaj, Mahajan, and Garg	PubMed	India	2015	Mandibular premolars	150	Yes	Straight	Unprepared	ProTaper Universal, Wave One and K3XF	Yes	Stereomicroscope	Yes	Yes
8.	Evaluation of Dentinal Defects during Root Canal Preparation Using Thermomechanically-Processed Nickel-Titanium files [39].	Kesim, Sagsen, and Tugrul	PubMed	Turkey	2017	Mandibular premolars	150	Yes	Curvature (<5°)	Prepared	Protaper Next, Reciproc, and TFA	Yes	Stereomicroscope	Yes	Yes
9.	To Compare the Incidence of Dentinal Cracks after Instrumentation with Rotary, Reciprocating Twisted File Adaptive System [40].	Kumari and Vishwas	Hand search	India	2014	Mandibular premolars	40	Yes	Straight	Unprepared	Protaper Next, WaveOne and TFA	Yes	Stereomicroscope	Yes	Yes
10.	Comparison of Dentinal and Apical Crack Formation caused by Four Different Nickel-Titanium Rotary and Reciprocating Systems in Large and Small Canals [41].	Zhou, Jiang, S. Wang, X. Wang, Zhu, and Zhang	PubMed	China	2015	Mandibular premolars and molars	180	Yes	Not specified.	Unprepared	ProTaper Universal, WaveOne and TFA	Yes	SEM	No	Yes

Table 4. Cont.

No.	Title	Authors	Journal	Country	Year	Teeth	No. of Samples	Pre Instrumentation Evaluation for Cracks	Root Curvature	Control Group	File Group	Sectioning 3 mm, 6 mm, 9 mm	Examination Method	Methodology Is Well Described	Irrigant
11.	Effect of Reciprocating File Motion on Microcrack Formation in Root Canals: an SEM Study [42].	Ashwinkumar, Krithikadatta, Surendran, and Velmurugan	PubMed	India	2013	Mandibular 1 <sup>st</sup> molars	150	Yes	Curvature (25–30°)	Unprepared	ProTaper Universal and WaveOne	Yes	SEM	Yes	Yes
12.	Incidence of Dentinal Cracks after Root Canal Preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper [43].	Karatas, Gunduz, Kırıcı, and Arslan	PubMed	Turkey	2016	Mandibular central incisors	90	Yes	Straight (<5°)	Unprepared	ProTaper Universal and WaveOne	Yes	Stereomicroscope	Yes	Yes
13.	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 [44].	Suparna Ganguly Saha, Neelam Vijaywargiya, Divya Saxena, Mainak Kanti Saha, Anuj Bharadwaj, Sandeep Dubey	PubMed	India	2017	Mandibular premolars	120	Yes	Straight canal	Unprepared	ProTaper Next, Mtwo and SAF	Yes	Stereomicroscope	Yes	Yes

#### 4. Discussion

The main aim of endodontic therapy is to clean and fill the RCS in order to preserve or regain the integrity of the periapical tissues [45]. Despite continuous developments in instruments to improve RCS cleaning [46], dentin microcracks continue to be a source of concern for clinicians and researchers [47,48] as they often contribute to the instrumented tooth fracturing and extraction [49–51]. Although, there are multiple factors that contribute to dentinal crack formation like the design of the file, flexibility of file, and stress on the tooth surface used during instrumentation.

Files considered in the study are ProTaper Universal file and Mtwo which belong to the conventional NiTi file system group. The cross-sectional design of ProTaper Universal resembles that of a reamer, with three machined cutting edges and convex core [52]. The Mtwo files cross-sectional design resembles that of the S-file [53]. It has no radial lands, progressive blade pitch from tip to shaft, positive rake angles, and a non-cutting tip. Mtwo files have two cutting edges with minimal radial contact providing maximum space for dentin removal. It is advised by the manufacture to use all files in the instrumentation sequence to the full length of the root canal [54]. ProTaper Next is fabricated utilizing M-wire technology which helps to increase file flexibility. The off-centered rectangular cross section and the unique design of the file generate enlarged space for debris [55]. WaveOne made of M-wire metallurgy have a reverse helix and 2 distinct cross-sections along the length of their active portions. From D1-D8, the WaveOne files have a modified convex triangular cross-section, whereas from D9-D16, these files have a convex triangular cross-section [56]. Reciproc also made of M-wire technology consist of s-shaped cross section, the variable taper, the cutting angles and the thermally improved raw material provides high efficiency and cutting performance. The file's tip is non-cutting for a gentle treatment near the apex [57]. Twisted File Adaptive (TFA) is made up of R-phase heat treatment, twisting of the metal wire, and a special surface conditioning [58]. As a result of this it is consider superior to traditional NiTi instruments respect to their flexibility; cyclic fatigue resistance, cutting efficiency, and their ability maintain the original canal shape with minimal transportation [59,60]. K3XF consists of modified triple and developed by R-phase heat treatment [61]. Self-adjusting files system (SAF) file system is a hollow-file system that adapts to wall of the root canal according to anatomy of the canal [62]. Although there are different design and cross sections of the files developed there is still development on dentinal cracks during root canal instrumentation.

Another important factor that contributes to dentinal cracks is improper tooth preparation. It is often seen that rough dehydration leads to fracturing, cracking and volumetric shrinkage [63]. It recommended to prepare the tooth with lubricants to replace water before root canal instrumentation for desired results to avoids necessary factors affecting the desired results [64]. Although the step of tooth preparation is an important step in root canal instrumentation it is described in detail in the studies included in the systematic review.

The aim of this systematic analysis was to assess the prevalence of dentin microcracks after using instruments made with conventional, R-Phase, and M-Wire NiTi alloys and the SAF system. A systematic review of the literature is a coordinated review focused on a pre-established approach to classify, pick, and critically examine important studies regarding a topic or doubt. The aim of systematization is to reduce the significant amounts of prejudices that are typically present in a traditional or non-systematic analysis of the literature [65]. Critically, studies that involved the use of mandibular teeth with a maximum curvature of 40 degrees and no prior dentinal microcracks were included. The studies also processed a control group and comparative classes that were used in the review. As a result, the frequency of microcracks could be determined using a SEM and a stereomicroscope, which examined cross-sections at 3 mm, 6 mm, and 9 mm from the apex.

In this systematic analysis, 1529 teeth samples were studied, with mandibular premolars and central incisors being the most commonly used teeth. Three research [33,39,42] recorded teeth with root curvature, while others reported teeth with a straight root. The

curvature specifics were not defined by Zhou et al [41]. Conventional NiTi file systems were the most commonly used, followed by M-wire file systems. All experiments that used traditional NiTi files as an experimental group used the ProTaper Universal method. WaveOne method was used in 7 studies for M-wire, with ProTaper Next and Reciproc following it. R-TFA phase's system was the most widely used.

When the occurrence of dentinal microcracks at various cross-sections was examined using SEM after using traditional NiTi file systems, a greater number of defects were found after using the ProTaper Universal method [32,34,36–38,41,43,44]. WaveOne was associated with the highest number of dentinal defects among M-wire systems [33,34,36,42]. Four M-wire studies [32,38,40,42] that used ProTaper Next have registered a rise in the number of dentinal cracks scanned. There were less dentinal microcracks after using R-phase and SAF (hollow-file system). Moreover, it should be noted that R-phase and SAF instruments were the least often included in the studies included in this systematic analysis. Kansal et al., in 2014, Saha et al., in 2017, and Kumari and Vishwas, in 2016, did not disclose any data at 6 and 9 mm cross-sections, so their conclusions might be inadequate. Zhou et al., in 2015, used all three mechanisms and found the lowest number of dentinal cracks as compared to the other findings in the study. The highest number of dentinal cracks was observed at 3 mm from the root apex, although as the distance from the apex increases, the number of microcracks decreases, with the least recorded at the 9 mm cross-section. See Table 5 for more information.

Table 5. Joanna Briggs' quality assessment criteria.

No.		Akshayraj K et al., 2018	Yazdan Shantiaee et al., 2018	Bürklein S et al., 2012	Rohit Kansal et al., 2015	Karataş E et al., 2014	Yakup Ustun et al., 2019	Prashant Monga et al., 2015	Bertan Kesim et al., 2017	R Ambika Kumari et al., 2014	Xin Zhou et al., 2015	V. Ash- winkumar et al., 2013	E. Karatas et al., 2015	Suparna Ganguly, Saha et al. 2017
1	Is there congruity between the stated philosophical perspective and the research methodology?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Is there congruity between the research methodology and research question or objectives?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3	Is there congruity between the research methodology and the method used to collect data?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Is there congruity between the research methodology and representation and analysis of data?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Is there congruity between the research methodology and interpretation of results?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6	Is there a statement locating the researcher culturally or theoretically?	No	No	No	No	No	No	No	No	No	No	No	No	No
7	Is the influence of researchers on the research and vice versa addressed?	No	No	No	No	No	No	No	No	No	No	No	No	No
8	Are the participants and their voices adequately represented?	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
9	Is the research ethical according to the current criteria for recent studies and is there evidence of ethical approval by an appropriate body?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10	Are the conclusions drawn in the project report flow from the analysis or interpretation of data?	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Unclear

All of the experiments had a control group for reference and a well-described protocol that was reported and evaluated using the Joanna Briggs' quality evaluation of in vitro studies' criterion [31]. The papers were evaluated based on their congruence between the research methodology and the research topic or purpose, the process used to gather data, data representation and analysis, and interpretation of findings. Only papers that met these conditions were included (Table 6).

**Table 6.** Number of dentinal cracks in different cross-sections.

No.	Title	File System	Files Used	No. of Specimen	Number of Dentinal Cracks at Different Cross-Sections			
					3 mm	6 mm	9 mm	Total
1.	In Vitro Comparative Evaluation of Dentinal Microcracks' Formation during Root Canal Preparation by Different Nickel-Titanium File Systems [32].	Conventional NiTi file system	ProTaper Universal	12	4	3	7	14
		Hollow-file system	SAF	12	0	0	0	0
		M-wire	ProTaper Next	12	2	2	4	8
			WaveOne	12	1	1	3	5
2.	Effect of Root Canal Preparation Techniques on Crack Formation in Root Dentin [33].	Conventional NiTi file system	ProTaper Universal	30	5	5	8	18
		M-wire	WaveOne	30	15	9	3	27
3.	Incidence of Dentinal Defects after Root Canal Preparation Reciprocating versus Rotary Instrumentation [34].	Conventional NiTi file system	ProTaper Universal	60	10	10	3	23
			Mtwo	60	7	7	6	20
		M-wire	Reciproc	60	21	15	4	40
			WaveOne	60	17	13	4	34
4.	Assessment of Dentinal Damage during Canal Preparation Using Reciprocating and Rotary Files [35].	Conventional NiTi file system	ProTaper Universal	30				16
		M-wire	WaveOne	30				5
5.	Dentinal Crack Formation during Root Canal Preparations by the Twisted File Adaptive, ProTaper Next, ProTaper Universal and WaveOne Instruments [36].	Conventional NiTi file system	ProTaper Universal	15	6	5	6	17
		M-wire	ProTaper Next	15	1	6	4	11
			WaveOne	15	6	4	5	15
		R-phase	TFA	15	1	5	7	13
6.	The Effects of Different Nickel-Titanium Instruments on Dentinal microcrack Formations during Root Canal Preparation [37].	Conventional NiTi file system	ProTaper Universal	20	4	3	1	8
		M-wire	ProTaper Next	20	4	3	0	7
			Reciproc	20	1	1	0	2
7.	Comparison of Incidence of Dentinal Defects after Root Canal Preparation with Continuous Rotation and Reciprocating Instrumentation [38]	Conventional NiTi file system	ProTaper Universal	30	0	3	2	5
		R-phase	K3XF	30	2	0	0	2
		M-wire	WaveOne	30	0	1	0	1
8.	Evaluation of Dentinal Defects during Root Canal Preparation Using Thermomechanically- Processed Nickel-Titanium Files [39].	M-wire	ProTaper Next	30	7	4	2	13
			Reciproc	30	0	1	2	3
		R-phase	TFA	30	6	4	6	16
			K3XF	30	0	1	2	3
9.	To Compare the Incidence of Dentinal Cracks after Instrumentation with Rotary, Reciprocating Twisted File Adaptive System [40].	M-wire	ProTaper Next	10	4	5	No data	
			Reciproc	10	2	2	No data	
		R-phase	TFA	10	2	1	No data	

Table 6. Cont.

No.	Title	File System	Files Used	No. of Specimen	Number of Dentinal Cracks at Different Cross-Sections			
					3 mm	6 mm	9 mm	Total
10.	Comparison of Dentinal and Apical Crack Formation caused by Four Different Nickel-Titanium Rotary and Reciprocating Systems in Large and Small Canals [41].	Conventional NiTi file system	ProTaper Universal	20	0	1	0	1
		M-wire	WaveOne	20	1	1	1	3
		R-phase	TFA	20	0	0	0	0
11	Effect of Reciprocating File Motion on Microcrack Formation in Root Canals: an SEM Study [42].	Conventional NiTi file system	ProTaper Universal	30	22	24	26	72
		M-wire	WaveOne	30	9	12	14	35
12.	Incidence of Dentinal Cracks after Root Canal Preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTape Universal instruments [43].	Conventional NiTi file system	ProTaper Universal	15	4	4	2	10
		M-wire	Reciproc	15	0	1	4	5
13.	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 [44].	Conventional NiTi file system	Mtwo	30				15
		M-wire	ProTaper Next	30				12
		Hollow-file system	SAF	30				1

The development of emerging technology used in the manufacturing of endodontic instruments seems to reduce the occurrence of dentin microcracks. NiTi files generated using M-wire and R-phase technologies had a lower incidence of dentinal microcracks, especially in the apical third.

## 5. Limitations

The literature review was undertaken using major databases; however, articles that are published elsewhere may have been overlooked. As a result, the papers used in the present systematic review were written in English, and some important evidence may have been overlooked as several papers may have been published in other languages. Only a few studies yielded inconclusive findings. The lack of standardization of cross-section length from the root apex resulted in varying cross-section lengths. The existence of selective research performed using new generation file systems was the main drawback of this systematic analysis.

## 6. Conclusions

Despite the shortcomings of this systematic review, it is possible to infer that the use of endodontic NiTi files manufactured using M-wire and R-phase technology provides a better biomechanical preparation by preventing the development of dentinal microcracks. The conclusion of the systematic review is drawn based on the limited number of publications.

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