IEJ
Iranian Endodontic Journal

Structural Analysis of NiTi Endodontic Instruments: A Systematic Review

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ARTICLE INFO

Article Type: **Systematic Review**

Received: 13 Feb 2020
Revised: 21 May 2020
Accepted: 05 Jun 2020
Doi: *10.22037/iej.v15i3.28083*

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ABSTRACT

Introduction: Irregularities and defects on NiTi endodontic instruments originating from the manufacturing process can lead to the structural collapse and fracture of these instruments during treatment. To assess the cause of instrument wear and fracture, as well as increasing fracture incidence, destructive and non-destructive methods have been used for the analysis of surfaces and internal structures of new and used NiTi instruments. The aim of this systematic review was to undertake a detailed analysis of the methods used to evaluate the surface and internal microstructure of endodontic instruments. **Methods and Materials:** The scientific literature was comprehensively and systematically searched in the MEDLINE (PubMed), Web of Science, Cochrane Library, Scopus, and LILACS/BBO databases for studies published up to June 9, 2019. The eligibility criteria was based on the PICO (Patient, Intervention, Comparison, and Outcome) strategy with the question "What is the best method for structural analysis of endodontic files?" Two aspects were considered for inclusion in this study: (*i*) endodontic instruments and (*ii*) methods for structural analysis of NiTi instruments. . The systematic review was performed according to the PRISMA statement. **Results**: Based on the inclusion criteria, 94 articles were selected. The results showed that although specific methods have been used for qualitative and/or quantitative structural analysis of NiTi instruments, no study addressed both the surface and internal structure of the instruments at the same time. According to this review, the need to compare the methodologies used in the selected articles has been identified; however, each type of method used has its own limitation on the analysis of both the surface and the internal structure of the instruments. **Conclusions:** The comparison between the different types of methodologies used in the studies revealed the reliability and the limitations of the methods employed for structural analysis of endodontic instruments; thus assisting us in determining their validity.

Keywords: Atomic Force Microscopy; MicroCT; NiTi Instrument; Optical Profilometery; Surface Properties

Introduction

With the purpose of effectively preparing the root canal while respecting its anatomy, the nickel-titanium (NiTi) alloy, instrument design, and manufacturing processes have been under study and constant development. The mechanical properties of NiTi, such as superelasticity and shape memory, provide flexibility and fatigue resistance to instruments [1, 2]. Root canal preparation with NiTi rotary or reciprocating instruments better maintain the appropriate canal centrality and provide more predictable outcomes than stainless steel files [3].

The fracture of instruments inside the root canal from torsional overload or flexural fatigue in the apical third of the canal can threaten the success of the treatment and be a major concern [4].

Approaches to increasing the effectiveness and safety of NiTi rotary files include enhancement in the manufacturing process and the use of new alloys that offer superior mechanical properties [5]. Recently, a series of thermo mechanical processes have been used to improve the microstructure of NiTi used in rotary files. For this purpose, alloys modified by phase transformation from an increase in their austenite transformation temperature have

been developed, resulting in controlled memory (CM) instruments, which are extremely flexible while keeping the memory typical of other NiTi instruments [5, 6].

Besides the maintenance of the canal's anatomy and having a small risk of fracture, endodontic files should be effective for dentin removal. Thus, parameters such as cross-sectional mass and design, helical and rake angle, number and depth of flutes, and tip design should also be considered. In addition, irregularities on the surface of instruments may result in fracture during clinical use [3] due to cracks that initiate from superficial defects [7]. Importantly, fractures can occur without any visible defect or previous deformation [8].

The concomitant evaluation of the surface and core of instruments (structural analysis) using existing methodologies [8-15] requires the sample to be destroyed [8, 10, 11]. Thus, a single instrument cannot be used and consequently, the risk of bias exists.

The aim of this study was to identify the methods employed for the structural analysis of endodontic instruments by a systematic review of the literature.

Table 1. Eletronic data base and search strategy

PUBMED
((((Root Canal preparation [mesh] OR Root Canal treatment [Mesh] OR root canal* [tiab] OR canal* [tiab] or Endodontics [Mesh] or Endodontic* [Tiab] or Root Canal Therapy [Mesh Term])))) AND ((Microscopy Electron, Scanning[meSH terms] OR Scanning Microscopies Electron [tiab] OR SEM [tiab] OR Optical Imaging [meSH terms] OR Imaging Optical[tiab] OR Profilometry surface [tiab] OR Microscopy, Atomic Force[meSH terms] OR Microscopies Force[tiab] OR Force Microscopies Scanning [tiab] OR AFM[tiab] OR MICROSCOPIC IMAGES [tiab] OR Rotary Instrument* [tiab] OR Surface properties [meSH terms] OR Surface Property [tiab] OR Properties Surface [tiab] OR Surface Changes [tiab] OR Equipment Failure[meSH terms] OR Equipment Defect [tiab])))) AND ((Dental Instruments [meSH terms] OR Dental Instrument*[tiab] OR Dental Alloys [Mesh] OR Dental alloy[tiab] OR Alloy Dental [tiab] OR Nickel [meSH terms] or Nickel [Tiab] OR Nickel-Titanium[tiab] OR NiTi [tiab] OR Titanium [meSH term] or Titanium [Tiab] OR stainless steel [meSH term] OR stainless steel [Tiab]))
SCOPUS
(“Dental Instruments” OR “Dental alloy” OR nickel OR “Nickel-Titanium” OR “stainless steel”) AND (“Scanning Microscopies Electron” OR sem OR “Imaging Optical” OR “Profilometry surface” OR “Microscopies Force” OR “Force Microscopies Scanning” OR afm OR “Microscopic Image” OR “Rotary Instuments” OR “ Surface Property” OR “Surface Change” OR “Equipament Failure” OR “Equipament Defect”) AND (“root canal” OR canal* OR endodontic*)
WEB of SCIENCE
(("root canal" OR canal* OR endodontic*)) AND (("Scanning Microscopies Electron" OR sem OR "Imaging Optical" OR "Profilometry surface" OR "Microscopies Force" OR "Force Microscopies Scanning" OR afm OR "Microscopic Image" OR "Rotary Instruments" OR "Surface Property" OR "Surface Change" OR "Equipment Failure" OR "Equipment Defect")) AND (("Dental Instruments" OR "Dental alloy" OR nickel OR "Nickel-Titanium" OR niti OR titanium OR "stainless steel"))
LILACS and BBO
tw:(tw:(mh:"dental instruments" OR "dental instruments" OR "instrumentos dentários" OR "endodontics file" OR "limas endodônticas" OR mh:"Dental Alloys" OR "Dental alloy" OR "ligas dentárias" OR mh: "Nickel" OR "Nickel" OR "Nickel-Titanium" OR "NiTi" OR mh: "titanium" OR "titanium" OR mh: "stainless steel" OR" stainless steel") AND tw: (mh:"Microscopy Electron, Scanning" OR "Scanning Microscopies Electron" OR "microscópio eletrônico" OR "SEM" OR mh:"Optical Imaging" OR "Imaging Optical" OR "Profilometry surface" OR "Perfilometria optica" OR mh: "Microscopy, Atomic Force" OR "Microscopies Force " OR "Force Microscopies Scanning " OR "AFM" OR "MICROSCOPIC IMAGES" OR "microscópio de força atômica") OR (mh: "Surface properties" OR "mudanças superficiais" OR "Properties Surface" OR "Surface Changes" OR mh: "Equipment failure" OR "Equipment defect") AND tw:(mh: "Root Canal preparation "OR "Root Canal preparation" OR "Instrumentação do canal" OR mh: "Root Canal treatment" OR "Root Canal treatment" OR mh: "Root Canal Therapy" OR "Tratamento Endodôntico" OR "Root canal" OR "canal" OR mh: "Endodontics" OR "Endodontic" OR "Endodontia")) AND (instance:"regional") AND (db: ("LILACS" OR "BBO" OR "IBECS") AND type:("article"))
COCHRANE LIBRARY
#1 MeSH descriptor: [Dental Instruments] explode all trees #2"Dental Instruments" #3 (#1 or #2) #4 "Endodontic files" or "Endodontics file" or "Endodontic file" #5 MeSH descriptor: [Dental Alloys] explode all trees #6 "Dental alloy" or "Alloy Dental" #7 (#5 or #6) #8 MeSH descriptor: [Nickel] explode all trees #9 "nickel" #10 (#8 or #9) #11 MeSH descriptor: [Titanium] explode all trees #12 Titanium #13 (#11 or #12) #14 MeSH descriptor: [Stainless Steel] explode all trees #15 "stainless steel" #16 (#14 or #15) #17 (#3 or #4 or #7 or #10 or #13 or #16) #18 MeSH descriptor: [Microscopy, Electron, Scanning] explode all trees #19 "Scanning Microscopies Electron" or SEM #20 (#18 or #19) #21 MeSH descriptor: [Optical Imaging] explode all trees #22 "Imaging Optical" or "Profilometry surface" #23 (#21 or #22) #24 MeSH descriptor: [Microscopy, Atomic Force] explode all trees #25 "Microscopies Force" or "Force Microscopies Scanning" or AFM or "Microscopic images" #26 (#24 or #25) #27 MeSH descriptor: [Surface Properties] explode all trees #28 "Surface Property" or "Properties Surface" or "surface changes" #29 (#27 or #28) #30 MeSH descriptor: [Equipment Failure] explode all trees #31 "Equipment Defect" #32 (#30 or #31) #33 (#20 or #23 or #26 or #29 or #32) #34 MeSH descriptor: [Root Canal Preparation] explode all trees #35 "root canal" or "canal" #36 MeSH descriptor: [Endodontics] explode all trees #37 "Endodontic" or "Endodontics" #38 (#36 or #37) #39 MeSH descriptor: [Root Canal Therapy] explode all trees #40 (#34 or #35 or #38 or #39) #41 (#17 and #33 and #40)

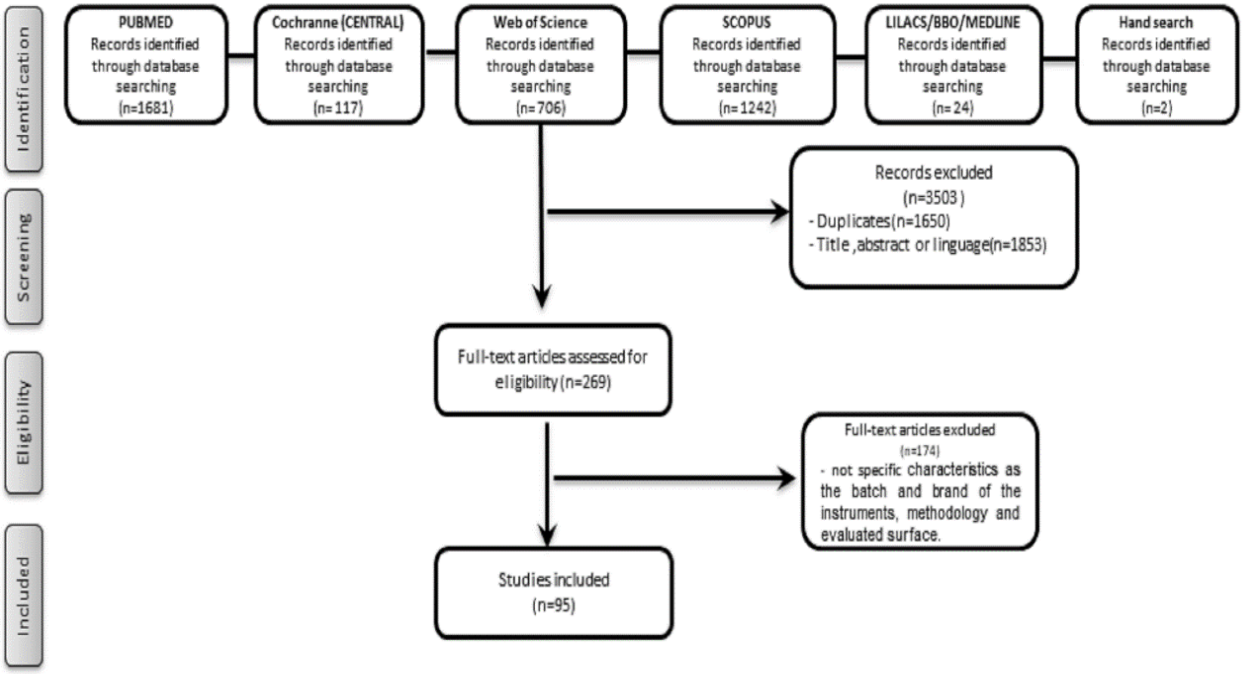

Figure 1. Flow diagram of the screening and selection process, according to the PRISMA Statement with studies included in qualitative assessment is shown

Material and Methods

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement, the recommendation of the Cochrane Collaboration and included studies in accordance with the "PICO" format [16], in which: Population (P) was "Endodontic instruments", Intervention (I) was "Analysis methods [scanning electron microscopy (SEM), atomic force microscopy (AFM), optical imaging]", Comparison (C) was "ability to analyze" and Outcome (O) was "Defects (surface properties, equipment failure)".

Information sources and search strategy

A search was performed in the Cochrane Library, Medline/PubMed, VHL (Virtual Health Library-Lilacs and Brazilian Dentistry Library (BBO), and Web of Science databases up to June 9th, 2019 (Table 1). Adaptations were made to adopt the same terms on all search engines in combination with database-specific filters, when available. The grey literature was accessed *via* "the System for Information in the Grey Literature in Europe" (Open-Grey), Thesis and Dissertations, and Google databases. The reference lists of important primary studies were hand-searched for additional relevant publications. No restriction was placed on the publication date or languages. Specific search strategies were developed for each database with the guidance of a librarian (DM). A complementary search was done in the reference lists of included studies.

Study selection

The studies were selected according to the eligibility criteria based on the PICO strategy. Two aspects were considered for study inclusion: (i) endodontic instruments and (ii) analysis methods. The exclusion criteria were clinical studies, case reports, review articles, retrospective articles, editorials, opinions, surveys, guidelines, conferences, commentary articles, and *in vivo* animal studies. Articles that did not evaluate surface characteristics were also excluded.

All titles and abstracts initially retrieved in the search were analyzed and selected by the eligibility criteria. The identified records were imported into EndNote Web Software and the duplicate articles were excluded. The titles and abstracts were read independently by two reviewers (M.Z.S and I.B.B.), and the articles that were compatible with the inclusion criteria were selected for full-text reading to confirm their eligibility. Any disagreement on the eligibility of studies was solved through discussion and consensus, and in case of disagreement, a third reviewer (P.S.) decided whether the article should be included.

Data extraction and quality assessment

Data were extracted, tabulated, and reviewed with Microsoft Office Excel 2013 by two reviewers, independently. The data extracted included the year of publication and author(s), brand and lot number of endodontic instruments, analysis methods, area assessed (internal and/or external), time assessed, (before and/or after use), fracture analysis (yes and/or no), and study

Table 2. Main characteristics of the selected articles

Reference	File brand name and manufacturer	Methodology used	Evaluated surfaces	Time of evaluation	Fracture analysis	Lot ID	Structural analysis
Al Jabbari *et al.* [17]	Flex-Master Ni-Ti files (VDW; Munich, Germany)	Micro-CT	Internal External	Before use	No	Yes	Yes
Al Jabbari *et al.* [18]	EasyShape system (Komet Dental, Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany)	SEM	Internal External	Before use	Yes	Yes	Yes
Alapati *et al.* (2003) [19]	Profile (Dentsply- Maillefer , Ballaigues Switzerland); Lightspeed (Kerr Corporation Brea, CA,USA)	SEM	External	Before and ater use	No	No	Yes
Alapati *et al.* [20]	ProFile GT instruments (Dentsply-Maillefer, Ballaigues, Switzerland)	SEM	Internal	Before and after use	Yes	No	Yes
Alexandrou *et al.* [21]	Profile (Densply/Maillefer, Ballaigues, Switzerland); Flexmaster (Endodontic Synergy, VDW, Munich, Germany	SEM	External	Before and after use	No	No	Yes
Alexandrou *et al.* [22]	Mani NRT 30/0.4 (MANI Inc, Toshigi-Ken, Japan)	SEM	External Internal	Before and after use	Yes	No	Yes
Al-Sudani D [23]	Hyflex CM (Coltene-Whaledent, Allstetten, Switzerland)	Micro-CT	External	Before and after use	No	No	Yes
Ametrano *et al.* [24]	Protaper NiTi Rotary (Dentsply Maillefer, Ballaigues, Switzerland)	AFM	External	Before and after use	No	No	Yes
Aminsobhani M. [25]	Race (FKG Dentaire, La-Chaux-de Fonds, Switzerland); Twisted File (SybronEndo, Orange, CA, USA); Mtwo (VDW, Munich, Germany); Protaper Next x2 (Dentsply Maillefer, Ballaigues,Switzerland)	SEM	Internal	After	Yes	No	Yes
Barbosa *et al.* [26]	K3 (SDS Kerr, Glendora, CA)	SEM	Internal	After use	Yes	No	Yes
Barbosa *et al.* [27]	K3 (SDS Kerr, Glendora, CA)	SEM	External	Before Use	No	No	Yes
Barbosa *et al.* [28]	WaveOne (Dentsply Maillefer, Ballaigues,Switzerland), Reciproc (VDW, Munich, Germany)	3D NonContact Opt. Profilometry	External	Before and after use	No	No	Yes
Barbosa *et al.* [15]	WaveOne (Dentsply Maillefer, Ballaigues,Switzerland), Reciproc (VDW, Munich, Germany)	MicroCT	External Internal	Before and after use	Yes	No	Yes
Bennett *et al.* [29]	ProTaper Universal (Dentsply Maillefer, Ballaigues,Switzerland) and ProTaper Next (Dentsply Maillefer, Ballaigues,Switzerland)	SEM	External Internal	Before and after use	Yes	No	Yes
Biz *et al.* [30]	ProFile .04 (Dentsply Maillefer, Ballaigues,Switzerland); Pow R .02 (Moyco Union Broach, York, USA); Quantec Series 2000 (Analytic Endodontic, Glendora, USA)	SEM	Internal	Before use	Yes	No	Yes
Boessler *et al.* [31]	Protaper (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	Before use	No	No	Yes
Bonaccorso *et al.* [32]	RaCe (FKG Dentaire, La-Chaux-de Fonds, Switzerland)	SEM	External	Before and after use	No	No	Yes
Bonaccorso *et al.* [33]	RaCe (FKG Dentaire, La-Chaux-de Fonds, Switzerland)	SEM	External	Before and after use	No	No	Yes
Bui *et al.* [34]	Profile (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	Before and after use	Yes	No	Yes
Buono VT *et al.* [35]	Pro Taper Universal (Dentsply Maillefer, Ballaigues, Switzerland),	SEM	External Internal	After use	Yes	No	Yes
Chakka, MK *et al.* [36]	ProTaper for hand use (Dentsply Maillefer, Ballaigues, Switzerland), ProTaper Rotary files (Dentsply Maillefer, Ballaigues, Switzerland); Endowave rotary files (J. Morita Europe GmbH Dietzenbach Germany	Stereomicroscope	External	After use	No	No	Yes

Chang *et al.* [37]	K3 NiTi Rotary ((SybronEndo, Orange, CA))	SEM	External	After use	No	No	Yes
Cheung *et al.* [38]	HERO Shaper size 25; (MicroMega, Besanc¸, France)	SEM	Internal	After use	Yes	No	Yes
Cheung *et al.* [39]	ProFile Rotary (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	Internal	After use	Yes	No	Yes
Cheung *et al.* [40]	ProTaper system (Dentsply Maillefer Ballaigues, Switzerland))	SEM	External Internal	After use	Yes	No	Yes
Cheung *et al.* [41]	ProTaper S1(Dentsply Maillefer, Ballaigues, Switzerland)	SEM	Internal	After use	Yes	No	Yes
Chi *et al.* [42]	ProTaper Universal F2 files (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Internal	After use	Yes	No	Yes
Condorelli GG *et al.* [43]	RaCe NiTi instruments (FKG, La Chaux de Fonds Switzerland)	SEM	External Internal	After use	Yes	No	Yes
Ferreira *et al.* (2017) [44]	WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) Reciproc (VDW, Munich, Germany)	3D NonContact Opt. Profilometry	External	Before and after use	No	No	Yes
Ferreira *et al.* [45]	WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) Reciproc (VDW, Munich, Germany)	3D Optical Profilometry	External	Before and after use	No	No	Yes
Gambarini *et al.* [46]	TFA SM (Kerr Endodontics, Glendora, Orange, CA, USA)	Stereomicroscope SEM	External Internal	After use	Yes	No	Yes
Grande *et al.* [47]	Ni–Ti endodontic instrument systems were tested: ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) and Mtwo (Sweden & Martina, Due Carrare, Italy).	SEM Micro-CT	External Internal	After use	Yes	No	Yes
Gu Y *et al.* [48]	Twisted Files (R-phase) (SybronEndo, Orange, CA, USA), WaveOne (M-wire) (Dentsply Maillefer, Ballaigues, Switzerland), Hyflex CM, or V Taper 2H (CM-wire) with the same apical size and taper (25/0.08)	Micro-CT SEM	External Internal	After use	No	No	Yes
Hanan *et al.* [49]	A non-random convenience sample of reciprocating files of WaveOne (Dentsply/Maillefer, Ballaigues, Switzerland) and Reciproc (VDW GmbH, Munich, Germany)	SEM	External	Before and after use	No	No	Yes
Herold *et al* [50]	EndoSequence Profile (Brassler USA, Savannah, GA)	SEM	External	Before and after use	No	No	Yes
Huang *et al.* [51]	ProFile (Dentsply/Maillefer, Ballaigues, Switzerland) Twisted file ((SybronEndo, Orange, CA, USA)	SEM	Internal	After use	Yes	No	Yes
Iacono *et al.* [52]	HyFlex EDM (Coltene-Whaledent, Allstetten, Switzerland)	SEM	External	Before and after use	No	No	Yes
Inan U *et al.* [53]	ProTaper (Dentsply Maillefer, Ballaigues, Switzerland)	AFM	External	Before and after use	No	No	Yes
Inan U, Aydin C. [54]	ProTaper D3(Dentsply Maillefer, Ballaigues, Switzerland), R-Endo R3 (Micromega, Beçancon, France), and Mtwo R (VDW, Munich, Germany)	SEM	Internal	After use	Yes	No	Yes
Inan U, Gonulol N [55]	Mtwo (VDW, Munich, Germany)	SEM	Internal	After use	Yes	No	Yes

Kaul R. *et al.* [56]	ProFile, (Dentsply Maillefer, Ballaigues, Switzerland) RaCe (FKG, La Chaux de Fonds Switzerland) and Twisted File (SybronEndo, Orange, CA, USA)	SEM	External	Before and after use	No	No	Yes
Kim *et al.* [57]	TF 25/0.06 (SybronEndo, Orange, CA, USA), RaCe 25/0.06 (FKG, La Chaux de Fonds Switzerland), ProTaper F1 (Dentsply Maillefer, Ballaigues, Switzerland), and Helix #25/0.06 (DiaDent, Chongju, Korea).	SEM	External Internal	Before and after use	Yes	No	Yes
Kim *et al.* [58]	#10 K hand files; the PathFile System (Dentsply Maillefer, Ballaigues, Switzerland)	3D Optical Profilometry	External	After use	No	No	Yes
Kottoor J *et al.* [59]	ProTaper, (Dentsply Maillefer, Ballaigues, Switzerland) Twisted File (SybronEndo, Orange, CA, USA)	SEM	External Internal	Before and after use	Yes	No	Yes
Kum *et al.* [60]	K3 (SybronEndo, Orange, CA)	SEM	External Internal	Before and after use	Yes	No	Yes
Liu,JF *et al.* [61]	Profile (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	Before use	No	No	Yes
Lopes,H *et al.* [62]	Bio Race (FKG, La Chaux de Fonds Switzerland)	SEM	External Internal	Before and after use	Yes	No	Yes
Lopes,HP *et al.* [63]	Bio Race (FKG, La Chaux de Fonds Switzerland)	SEM 3D Optical Profilometry	External	Before and after use	No	No	Yes
Luzi *et al.* [64]	ProTaper rotary NiT (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	Before and after use	No	No	Yes
Magalhaes *et al.* [65]	Reciproc (RC/R25) and WaveOne (WO/Primary) (Dentsply Maillefer, Ballaigues, Switzerland) both types size 25, 0.08 taper.	SEM	External	Before and after use	No	No	Yes
Marending M *et al.* [66]	Lightspeed instruments (Kerr Corporation Brea, CA, USA)	SEM	External	Before and after use	No	No	Yes
Martins RC *et al.* [67]	ProFile NiTi Rotary 20/04, 25/04, 20/06 (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	Before and after use	No	No	Yes
Melo *et al.* [68]	K3 rotary (SybronEndo, Orange, CA)	SEM	Internal	After use	Yes	No	Yes
Nair *et al.* [69]	M Two (VDW) and ProTaper F1 file ((Dentsply Maillefer, Ballaigues, Switzerland)).	AFM	External	Before and after sterelization	No	No	Yes
Novoa *et al.* [70]	ProTaper S1(Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External	After immersion in NaOcl	No	No	Yes
O'hoy *et al.* [71]	Profile 20/04 (Dentsply Maillefer, Ballaigues, Switzerland) GT (Dentsply Tulsa Dental, Tulsa, OK.), Quantec (Analytic Endodontic, Glendora, USA), Lightseep (Kerr Corporation Brea, CA, USA)	SEM	External	After the cleaning cycle	Yes	No	Yes
Patel, D. *et al.* [72]	RaCe (FKG, La Chaux de Fonds Switzerland), HyFlex rotary instruments, Mechanical GP (Coltene-Whaledent, Allstetten, Switzerland)	SEM	External	Before and after use	No	No	Yes
Peng, B. *et al.* [73]	ProTaper files (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Internal	Before and after use	Yes	No	Yes
Pereira ESJ *et al.* [74]	ProTaper Universal F2 (PTU - SE) (Dentsply Maillefer, Ballaigues, Switzerland), ProTaper Next X2 (PTN - MW) (Dentsply Maillefer, Ballaigues, Switzerland) Typhoon (TYP) (Clinician's Choice Dental Products, New Milford, CT, USA), Hyflex (HF) (Coltene-Whaledent, Allstetten, Switzerland) and Vortex Blue (VB)	SEM	External	Before and after use	No	No	Yes

Pirani C. *et al.* [75]	HyFlex EDM (Coltene-Whaledent, Allstetten, Switzerland)	SEM	External	Before and after use	No	No	Yes
Pirani C. *et al.* [76]	WaveOne Primary (Dentsply Maillefer, Ballaigues, Switzerland) and Reciproc R25 (VDW, Munich, Germany).	SEM AFM	External Internal	Before and after use	Yes	No	Yes
Pirani, C. *et al.* [77]	WaveOne Primary (Dentsply Maillefer, Ballaigues, Switzerland) and ProTaper Universal F2 (Dentsply Tulsa Dental, Tulsa, OK.)	SEM	External Internal	Before and after use	Yes	No	Yes
Rapisarda E. *et al.* [78]	ProFile Files (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Internal	Before and after use	Yes	No	Yes
Rapisarda E. *et al.* [79]	ProFile .04 taper #25(Dentsply Maillefer, Ballaigues, Switzerland) instruments were subjected to ionic implantation with were subjected to ionic implantation with bands	SEM	External	Before and after use	No	No	Yes
Saghiri, M. A. *et al.* [80]	ProTaper1 F1 NiTi instruments (Maillefer-Dentsply, Baillagues, Switzerland)	SEM	External Internal	After use	Yes	No	Yes
Sağlam, B. C. *et al.* [81]	ProTaper rotary NiTi files (Dentsply Maillefer, Ballaigues, Switzerland)	SEM AFM	External	Before and after use	No	No	Yes
Sağlam, B. C., & Görgül, G. [82]	ProTaper Retreatment files (Dentsply Maillefer, Ballaigues, Switzerland), R-endo files (MicroMega, Beçancon, France), and Mtwo retreatment files (VDW, Munich, Germany)	SEM AFM	External	Before and after use	No	No	Yes
Sattapan B *et al.* [83]	Quantec Series 2000 (Analytic Endodontic, Glendora, USA)	SEM	External	Before and after use	Yes	No	Yes
Shen Y. *et al.* [84]	ProFile Vortex (Dentsply Maillefer, Ballaigues, Switzerland) and Vortex Blue instruments (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Internal	After use	Yes	No	Yes
Shen, SM *et al.* [85]	G-PACKS (SybronEndo, West Collins, Orange, CA, USA)	SEM	External	Before and after use	Yes	No	Yes
Shen, Y. *et al.* [86]	ProFile and ProTaper (both of Dentsply Tulsa Dental)	SEM	External	Before and after use	Yes	No	Yes
Shen, Y. *et al.* [87]	ProTaper (Dentsply Maillefer, Ballaigues, Switzerland), ProTaper for Hand Use (Dentsply Maillefer, Ballaigues, Switzerland), and K3 (SybronEndo, Orange, CA)	SEM	Internal	After use	Yes	No	Yes
Shen, Y. *et al.* [88]	ProFile (Dentsply Tulsa Dental, Johnson City, TN)	SEM	Internal	After use	Yes	No	Yes
Shen, Y. *et al.* [89]	(ProFile series 29 (Dentsply Tulsa Dental Products, Tulsa, OK), ProFile (Dentsply Tulsa Dental Products), and ProTaper (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	Internal	After use	Yes	No	Yes
Shen, Y. *et al.* [90]	RaCe (FKG, La Chaux de Fonds Switzerland)	SEM	External	Before and after use	Yes	No	Yes
Shen, Y. *et al.* [91]	EndoSequence (ES), ProFile (PF) (Dentsply Maillefer, Ballaigues, Switzerland), ProFile Vortex (Vortex) (Dentsply Maillefer, Ballaigues, Switzerland), Twisted Files (TF) (SybronEndo, Orange CA, USA), Typhoon (TYP) (Clinician's Choice Dental Products, New Milford, CT, USA) and TyphoonCM (TYP CM) (Clinician's Choice Dental Products, New Milford, CT, USA)	SEM	External	Before use	No	Yes	Yes

Shen, Y. *et al.* [92]	ProFile Vortex instruments (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Interna	After use	Yes	No	Yes
Spanaki-Voreadi AP *et al.* [93]	ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland)	SEM	External Interna	Before and after use	Yes	No	Yes
Stefanescu, T. *et al.* [94]	Bio-RaCe (FKG, Le Chaux-of-Fonds, Switzerland)	SEM	External	After use	Yes	No	Yes
Stefanescu, T. *et al.* [95]	A BioRace® (FKG, Le Chaux-of-Fonds, Switzerland)	SEM	External	After use	Yes	No	Yes
Subha, N., & Sikri, V. K. [96]	ProFile, ProTaper Rotary, ProTaper Hand (Dentsply Maillefer, Ballaigues, Switzerland) and K3 Endo (SybronEndo, Orange, CA)	SEM	External	After use	No	No	Yes
Svec, T. A., & Powers, J. M. [97]	ProFile® (Dentsply, International, Inc., Tulsa, OK) 0.04 taper rotary files, 25 mm long in ISO size 20 (lot 082799840),	SEM	External	Before and after use	No	Yes	Yes
Topuz, O *et al.* [98]	RaCe (FKG, La Chaux de Fonds Switzerland)	AFM	External	Before and after immersion in NaOcl	No	No	Yes
Tripi, TR *et al.* [8]	GT Rotary instruments (Dentsply Tulsa Dental, Tulsa, OK.) before and after	SEM	External	Before and after use	No	No	Yes
Troian, C. H. *et al.* [99]	RaCe (FKG, La Chaux de Fonds Switzerland) and K3 NiTi rotary systems K3 (SybronEndo, Orange, CA)	SEM	External	Before and after use	Yes	No	Yes
Uslu, G., Özyürek, T., & Yılmaz, K. [100]	HyFlex CM and HyFlex EDM (Coltene-Whaledent, Allstetten, Switzerland)	3D Optical Profilometry.	External	Before and after use	No	Yes	Yes
Valois CR *et al.* [101]	K-file Dentsply (K-Dentsply): Dentsply Maillefer Instruments SA, Ballaigues, Switzerland. K-file Moyco (K-Moyco): Moyco, Union Broach, York, USA. K-file Nitiflex (Nitiflex): Dentsply Maillefer Instruments SA, Ballaigues, Switzerland. Greater Taper (GT-hand) (Dentsply Tulsa Dental, Tulsa, OK). Quantec (Analytic Endodontic, Glendora, USA)	AFM	external	Before use	No	Yes	Yes
Valois CR, Silva LP, Azevedo RB [102]	Greater Taper (Dentsply Tulsa Dental, Tulsa, OK.) ProFile (Dentsply Maillefer, Ballaigues, Switzerland),	AFM	External	Before and after use	No	Yes	Yes
Vieira EP *et al.* [103]	Pro Taper Universal (Dentsply Maillefer, Ballaigues, Switzerland),	SEM	External	Before and after use	No	No	Yes
Vieira EP *et al.* [104]	Pro Taper Universal (Dentsply Maillefer, Ballaigues, Switzerland),	SEM	External	After	No	No	Yes
Wei X *et al.* [105]	Pro Taper Universal (Dentsply Maillefer, Ballaigues, Switzerland),	SEM Stereomicroscope	Internal	After	Yes	No	Yes
Yamazaki-Arasaki A *et al.* [106]	Protaper Universal (Dentsply Maillefer, Ballaigues, Switzerland)-K3 (SybronEndo, Orange, CA)-Twisted Files (SybronEndo, Orange, CA, USA)-Biorace (FKG, La Chaux de Fonds Switzerland)	AFM	External	Before and after use	No	No	Yes
Yamazaki-Arasaki AK *et al.* [107]	Protaper Universal (Dentsply Maillefer, Ballaigues, Switzerland) K3 (SybronEndo, Orange, CA) Twisted Files (SybronEndo, Orange, CA, USA) Biorace (FKG, La Chaux de Fonds Switzerland)	SEM	External	Before and after use	No	No	Yes
Ye J, Gao Y. [108]	No, only m-wire	SEM	External	Before and after use	No	No	Yes

Table 3. Quality assessment of the selected articles according to the modified CONSORT checklist of items for reporting in vitro studies of dental materials

Reference	**Abstract**	**Introduction** Background	**Introduction** Objectives	**Methods** Intervention	**Methods** Outcomes	**Methods** Sample Size	**Methods** Randomization	**Methods** Allocation	**Methods** Implementation	**Methods** Blinding	**Methods** Statistical methods	**Results**	**Discussion**	**Other Information** Funding	**Other Information Protocol**
Al Jabbari *et al.* [11]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No
Al Jabbari *et al.* [109]	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	Yes	No
Alapati *et al.* [7]	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Alapati *et al.* [3]	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	Yes	No	No
Alexandrou *et al.* [110]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Alexandrou *et al.* [111]	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Al-Sudani D [112]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Ametrano *et al.* [113]	No	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No
Aminsobhani M. [114]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Barbosa *et al.* [115]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Barbosa *et al.* [116]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Barbosa *et al.* [14]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Barbosa *et al.* [15]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	No
Bennett *et al.* [117]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Biz *et al.* [118]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Boessler *et al.* [119]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Bonaccorso *et al.* [120]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Bonaccorso *et al.* [121]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Bui *et al.* [122]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
Buono VT *et al.* [123]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	No
Chakka MK *et al.* [124]	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Chang *et al.* [125]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Cheung *et al.* [126]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Cheung *et al.* [127]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Cheung *et al.* [128]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	Yes	No	No
Cheung *et al.* [129]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Chi *et al.* [130]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Condorelli GG *et al.* [131]	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No
Ferreira *et al.* [13]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Ferreira *et al.* [132]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Gambarini *et al.* [2]	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	No
Grande *et al.* [133]	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	No	No
Gu Y *et al.* [134]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Hanan *et al.* [1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Herold *et al.* [135]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Huang *et al.* [136]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Iacono *et al.* [137]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Inan *et al.* [138]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Inan, Aydin [139]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Inan *et al.* [140]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Kaul *et al.* [141]	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	No

Kim *et al.* [142]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Kim *et al.* [143]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Kottoor *et al.* [144]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Kum *et al.* [145]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Liu *et al.* [61]	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Lopes *et al.* [146]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Lopes *et al.* [147]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Luzi *et al.* [148]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No
Magalhaes *et al.* [149]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Marending *et al.* [150]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Martins [151]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Melo *et al.* [152]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	No	No	Yes	No
Nair *et al.* [153]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Novoa *et al.* [154]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
O'hoy *et al.* [155]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Patel *et al.* [156]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No
Peng *et al.* [157]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Pereira *et al.* [158]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Pirani *et al.* [159]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Pirani *et al.* [76]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Pirani *et al.* [77]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Rapisarda *et al.* [160]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Rapisarda *et al.* [161]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Saghiri *et al.* [80]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Sağlam *et al.* [162]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Sağlam & Görgül [163]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Sattapan *et al.* [4]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Shen *et al.* [164]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Shen *et al.* [5]	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Shen *et al.* [165]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Shen *et al.* [166]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Shen *et al.* [167]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	Yes	No
Shen *et al.* [168]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Shen *et al.* [169]	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Shen *et al.* [170]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No
Shen *et al.* [171]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Spanaki *et al.* [172]	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Stefanescu *et al.* [94]	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	No
Stefanescu *et al.* [95]	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Subha & Sikri [10]	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	No
Svec, & Powers [97]	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Topuz *et al.* [9]	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No
Tripi *et al.* [8]	Yes	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Troian *et al.* [173]	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No	No	No
Uslu *et al.* [12]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Valois *et al.* [101]	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No
Valois *et al.* [174]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Vieira *et al.* [175]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Vieira *et al.* [176]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	No	No
Wei *et al.* [177]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No
Yamazaki-Arasaki *et al.* [178]	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Yamazaki-Arasaki *et al.* [179]	Yes	Yes	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No
Ye , Gao [6]	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	No	No	No

outcomes. The quality assessment was performed using a modified CONSORT checklist of items for reporting in vitro studies of dental materials [180]. In case of disagreement, a third reviewer (P.S.) decided whether the article should be included. The items presents in this checklist enabling assessment of the standard of reporting in the different sections of a paper.

Results

Search results

A wide search was carried out and the selection of studies was judicious in order to include only those that demonstrated assessments of the integrity of the instruments before, after or before and after use.[13, 15, 109, 113, 132]. The electronic screening yielded 3771 entries and 269 studies were evaluated for eligibility, after which 174 non-eligible articles were excluded for the reasons indicated in the flow diagram [16] (Figure 1). Based on the inclusion criteria, 95 articles were selected.

Study characteristics

Table 2 shows the 95 selected studies and their characteristics such as the batch number (12 out of 95 studies) and brand of instruments, methodology, and evaluated surface. The studies are listed by alphabetical order of authors' names.

The selected studies have in common the presence of structural analysis of the instruments with previously determined methodologies, published in qualified journals that corroborate the quality of the studies within their respective areas. Among the eligible articles, 55 evaluated the external structure of instruments, and the methodologies employed did not destroy samples. On the other hand, 14 articles evaluated only the internal structure of instruments and 26 evaluated external and internal surfaces. Of the 40 papers that evaluated the internal surface, 4 studies [11, 15, 133, 134] used a micro-CT, which does not cause sample loss.

Quality Assessment

In Table 3, the eligible articles were submitted to an assessment of quality using a modified CONSORT checklist of items for reporting in vitro studies of dental materials [180]. It was observed that of the 95 selected articles, 7 did not have a structured summary of trial design, 6 studies did not present an introduction with specific objectives and hypotheses, 76 studies did not clarify how sample size was determined, only 19 studies explained or the method used to generate a random allocation sequence, 41 did not clearly present statistical methods used to compare groups for primary and secondary outcomes, 33 articles did not present the results in detail and 17 present a structured discussion, with trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses.

Discussion

This study focused on the investigation of methodologies described in the literature to evaluate NiTi endodontic instruments. The methodologies used to evaluate NiTi endodontic instruments indicate that the fracture of instruments inside the root canal is due to defects that are not visible [10]. The surface properties of NiTi files are essential for mechanical performance. Consequently, it is relevant to investigate the surface properties of new and used NiTi files to avoid unexpected file fractures [12].

The preventive disposal of instruments before reaching the limit of their service life can avoid accidents. However, the exact service life of instruments is not well defined yet. Therefore, study methodologies that allow both a quantitative and qualitative definition of the service life of endodontic instruments are required.

Surface characteristics of NiTi instruments exposed to cyclic fatigue tests have been evaluated by SEM or AFM [1, 163]. As SEM disadvantages, the risk of damaging the samples during their preparation and the impossibility of a quantitative analysis of instruments surface should be considered [1]. On the other hand, AFM produces high-resolution images, providing quantitative and qualitative data. However, the samples require an ultra-flat and rigid surface and, consequently, the scanning probe does not cause deformation on the surface [174].

The non-contact optical profilometery analysis is a non-destructive method used to evaluate surfaces quantitatively and qualitatively and it does not require sample preparation. Despite the advantages of the method, the area evaluated is very restricted and cannot be used to evaluate internal structures [12-14, 132].

The above methods, although efficient for the proposed objectives, are not capable of evaluating the samples on the external surface and internally at the same time. Therefore, non-destructive methodologies that can be used to evaluate the sample in its entirety should be considered. Thus, the computerized micro-tomography (micro-CT) can be a useful method. However, when assessing the quality of the selected studies, methodological deficiencies were observed, making it impossible to obtain a reliable result from the method.

The advantage of micro-CT in relation to SEM, AFM, and non-contact optical profilometery analysis is its ability to evaluate the core of an object at the various time-points of the test before the fracture of the object [15, 133, 134].

Conclusions

This study identified the need to compare the methodologies in the selected articles to achieve a coherent conclusion. The comparison would indicate the reliability of the methods employed for structural analysis of endodontic instruments, thus determining the validity of the studies.

Conflict of Interest: 'None declared'.

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Please cite this paper as: Barbosa IB, Ferreira FG, Scelza P; Adeodato C, Caldas IP, Gonçalves FP; Masterson D, Zaccaro Scelza M. Structural Analysis of NiTi Endodontic Instruments: A Systematic Review. Iran Endod J. 2020;15(3): 124-39. Doi: 10.22037/iej.v15i3.28083.