Manual vs. rotary instrumentation in endodontic treatment of permanent teeth: A systematic review and meta-analysis

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Abstract: Purpose: To systematically review all studies comparing manual instrumentation with at least one rotary instrument in the preparation of the root canal of permanent human teeth. **Methods:** The electronic databases PubMed, EMBASE, LILACS, IBECS and BBO were searched. In vitro studies published until 27 of September, 2016 were included. For statistical analysis, we used the Comprehensive Meta-Analysis software (Biostat), considering P< 0.05 significant. **Results:** A total of 1,104 articles published until September 27, 2016 were obtained, with 57 meeting the eligibility criteria. The studies were grouped according to the main methodology used (computerized tomography, periapical radiography, image amplification and scanning electron microscope). Due to the wide variability of the methodologies and evaluated parameters, a subgroup analysis was performed based on the evaluated parameter. The meta-analysis revealed that rotary instruments caused a significant reduction in instrumentation time and a smaller change of the canal curvature than manual instruments. The rotary instrumentation presented better results regarding root canal transportation, ability of centralization within the canal path and shaping of the canal. Manual instrumentation performed better with regard to the smear layer and debris production, more instrumented canal surfaces and fewer dentin defects. (*Am J Dent* 2019;32:311-324).

Clinical significance: An increasing number of studies have compared the efficiency of manual and rotary instrumentation in endodontic treatment of permanent teeth. This study helps elucidate which method is more efficient in the endodontic treatment of permanent teeth.

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Introduction

Endodontic treatment aims to preserve teeth and maintain the patient's masticatory function after the dental pulp has been compromised.[1] The etiology of pulp alterations may be of physical, chemical, or biological nature.[2]

Injury to the pulp can be reversible or irreversible. A radical endodontic therapy is recommended in case of irreversible damage,[2] and treatment success is dependent on a careful root canal preparation of which the objective is to clean, disinfect and shape the canal.[3] Canal preparation can be performed by either manual instruments or automated systems with alternating or continuous rotation.[4]

The physical properties of the stainless steel Kerr (K) file have been improved over time, and currently the file has increased flexibility, torsion resistance, and cutting ability. Although widely used in root canal preparation, traditional stainless steel files present some limitations, such as high risk of canal transportation, ledge formation, perforations (especially in curved canals), and instrument fractures.[5-10] The use of the Nickel-Titanium (Ni-Ti) alloy in the file's composition provided important improvements including superelasticity, shape memory,[2] and high resistance to corrosion.[11,12] These files allow an easier canal preparation and a better preservation of the canal shape, reducing the risk of canal transportation and iatrogenic episodes. When used in automated rotary systems, Ni-Ti instruments can also decrease instrumentation time.[7,13-16] However, the high cost of the endodontic motor and the need for initial investment is a disadvantage of rotary systems.[17-21]

Several studies have evaluated the different methods of root canal instrumentation,[6,22-35] but the appropriate endodontic technique and instrument for different cases is still not well defined. Therefore, this study performed a systematic review and meta-analysis of in vitro studies comparing the efficiency of manual and rotary instrumentation in permanent teeth.

Materials and Methods

This systematic review was conducted according to the PRISMA guidelines.[36] The selected studies fulfilled the criteria established by the PICO strategy, as follows: (1) Participants: extracted permanent teeth. (2) Intervention: different types of rotary instrumentation. (3) Intervention control: manual endodontic instrumentation. (4) Outcomes: efficiency of the methods.

Registration and protocol - The study was registered at PROSPERO (number CRD42015017874) by sending the prepared study protocol to http://www.crd.york.ac.uk/PROSPERO/.

Research strategy - A search was performed in the following electronic databases: PubMed, EMBASE, LILACS, IBECS and BBO. Studies published up to September 2016 in the following languages: English, Portuguese or Spanish, were included.

The search strategy was structured with Boolean operators (AND/OR). The descriptors used were: Instrumentation, Root Canal Preparation, Manual Instrumentation and Rotary Instrumentation. The search strategy was delineated as follows: "root canal preparation"[MeSH Terms] OR ("root"[All Fields] AND "canal"[All Fields] AND "preparation"[All Fields] OR "root canal preparation"[All Fields]) AND (instrument[All Fields] OR ("instrumentation"[Subheading] OR "instrumentation"[All Fields] OR "instruments"[All Fields]) OR

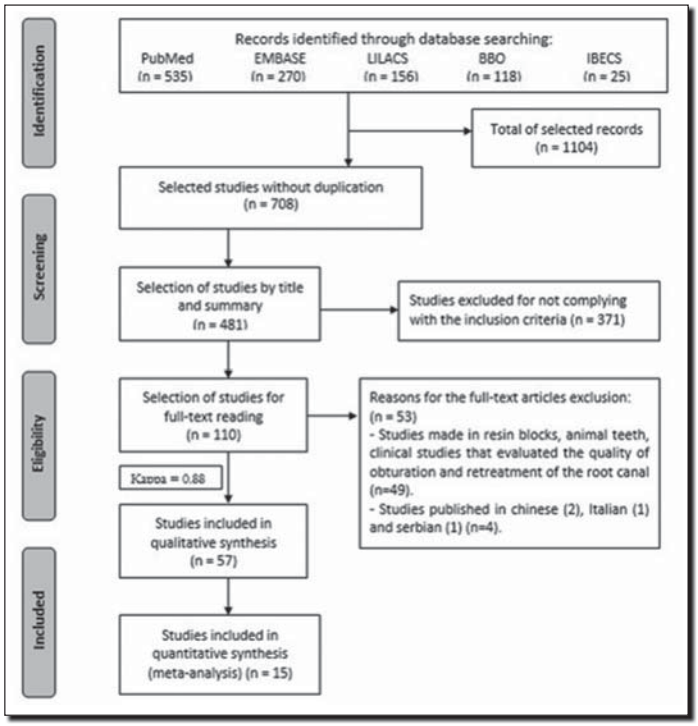


Fig. 1. Flow diagram of study selection for qualitative and quantitative syntheses.

("instrumentation" [Subheading] OR "instrumentation"[All Fields]) AND (rotary[All Fields] OR rotational[All Fields] OR handpiece[All Fields] OR handpieces[All Fields] OR "hand piece"[All Fields] OR "hand pieces"[All Fields])) AND ("hand"[All Fields] OR "manual"[All Fields] OR "mechanical"[All Fields] OR "mechanic"[All Fields] OR "mechanics"[All Fields]).

In addition, the gray literature and unpublished studies were searched electronically, and a manual search was performed to include additional research that met the eligibility criteria.

Excluded full text articles - studies that did not fulfill the inclusion criteria, made in resin blocks or in animal teeth and retreatment of the root canal; and studies published in Chinese (2), Italian (1) and Serbian (1).

Selection criteria - In vitro studies comparing manual with rotary instrumentation in endodontic treatment of root canals of permanent human teeth were included. In vivo studies, or studies carried out in animal samples, in resin blocks, in permanent teeth with open apices, or in third molars, and studies on fracture resistance or bacterial reduction after endodontic treatment were excluded. Even though in vivo studies have a greater scientific relevance, they were excluded because too few have been carried out. Also, as in vivo clinical studies might have several operators, include a variety of intraoral sites, evaluation dates and time intervals, true comparisons can be very difficult. Moreover, some clinical studies evaluate postoperative pain, which produce subjective results that are absent in laboratory studies.[37-41]

Data extraction - The collected studies were entered in Endnote Web software (www.myendnoteweb.com) and checked for duplicates.

Titles and abstracts were independently reviewed by two collaborators (MPM and HMH) for eligibility, and if the abstract was relevant, the text was read in full (Kappa= 0.88). Disagreements were resolved by a discussion with a third collaborator (DR). Figure 1 displays the detailed search sequence.

The included studies were independently examined and their main features were extracted using a standardized form in Microsoft Office Excel spreadsheet for quality evaluation and synthesis. The extracted information included: surname of the first author, year of publication, geographic region, randomization, blinding, study methodology, sample size, intervention and control conditions, evaluated parameters, study conclusion. Missing data on methodological issues were requested to the authors by e-mail.[5,7-10,16,21-24,26,28-34,42-58]

Quality analysis of the included studies - The sensitivity analysis evaluated in each study: randomization, blinding and quality of the methodology. Studies that did not specify randomization and/or blinding were also included. Studies were then classified as low risk (if randomization and/or blinding was applied), uncertain risk (the study did not clearly report randomization and/or blinding) and high risk (if randomization and blinding were not applied).

Statistical methods - Stratified meta-analysis was performed to better explore the data, given its initial heterogeneity. The Comprehensive Meta-Analysis[a] software was used, with $P< 0.05$ considered significant. Funnel plots were constructed to evaluate data heterogeneity.

Bias risk assessment - Two authors independently assessed the risk of bias in the included studies (MPM and HMH) considering the following: selection bias – randomization and allocation concealment; detection bias (blinding of participants, operators or examiners; sampling bias) control and experimental groups not well specified; methodological bias (unclear or incomplete methodology); language bias in the pre-selection of articles in languages other than English, Portuguese and Spanish were excluded.

Results

Research and selection of studies - Initially, 1104 studies were found, and after removal of duplicates 708 articles remained. Four hundred and eighty-one studies were pre-selected by titles and abstracts, but only 110 were selected for full reading, of which 53 did not meet the inclusion criteria. A total of 57 articles published from 1999 to September 2016 were included in the analysis (Fig. 1).

Characteristics of the studies - Teeth samples in the studies were single and multi-rooted teeth, with straight, curved, oval, fused and c-shaped canals (incisors, premolars and molars), extracted due to periodontal or prosthetic reasons, or available at tooth banks, with fully formed roots, without fractures, defects and obliteration of the root canal, and without any visible sign of external and internal root resorption. None of the teeth had undergone previous root canal treatment and some studies standardized the canal working length (teeth were cut shorter if needed).

Analysis of the studies - The four subgroups were determined by the main method used to evaluate the results, such as computed tomography (cone beam CT, spiral CT and micro-CT; n= 11) (Table 1), periapical radiography (conventional and digital; n= 10) (Table 2), image magnification (magnifying glass, light microscope, stereoscopic microscope, optical

Table 1. Details and conclusions of 11 included studies (in alphabetical order) - Computerized tomography. Abbreviations: R: Randomization; B: Blinding; M: Methodology; SCT: spiral computed tomography; CBCT: cone beam computed tomography; Micro-CT: computerized microtomography; CT: computed tomography; *: Instrumentation was not evaluated in this study.

Author/ Year	Geographical region	Sensitivity R	B	M	No. Sample	Intervention & control	Parameters evaluated	Conclusions
Gergi 2010	Saint Joseph University Beirut, Lebanon.	Yes	Yes	Yes	90 root canals with curvature 25-35° (n=30)	G1 Twisted files G2 System pathfile-ProTaper* G3 K-Flexofile	1. Canal transportation. 2. Centering ability. SCT	The TF system had the best performance in all measured variables.
Hartmann 2007	Lutheran University of Brazil, RS, Brazil.	Yes	Yes	Yes	60 mesiobuccal canals of maxillary molars with curvature 20-40° (n=20)	G1 K-files G2 TEP E-16R + K-files* G3 ProTaper	1. Apical canal transportation. CT	All techniques produced canal transportation but K-files produced less than the others.
Hartmann 2011	Lutheran University of Brazil, RS, Brazil.	Yes	Yes	Yes	60 mesiobuccal canals of maxillary molars with curvature 20-40° (n=20)	G1 K-Flexofile G2 TEP E-16R + K-Flexofile* G3 ProTaper	1. Apical canal transportation.	All techniques produced canal transportation.
Limongi 2007	Lutheran University of Brazil, RS, Brazil	Yes	Yes	Yes	40 mandibular incisors (n=20)	G1 K-files. G2 RaCe	1. Amount of dentin removed - CT.	There was no significant difference between techniques in all thirds of the root canal and in all canal surfaces.
Madani 2015	Babol University of Medical Sciences Babol, Iran.	Yes	-	Yes	40 mesiobuccal canals of maxillary first molars, curvature of 20-40° (n=20)	G1 K-Flexofile G2 K3	1. Apical canal transportation CBCT	Both techniques preserved the original curvature of the canal and showed similar apical transportation.
Mokhtari 2014	Tabriz University of Medical Sciences Tabriz, Iran.	Yes	No	Yes	45 mandibular first molars with curvature of 22 to 40° (n=15)	G1 BioRaCe G2 Mtwo G3 K-Flexofile	1. Canal transportation CBCT	BioRace and Mtwo in larger sizes were suitable for the apical preparation of the canal, provided that the recommended file sequences are respected.
Nagaraja 2010	Rajiv Gandhi University of Health Sciences Karnataka, India.	Yes	+/-	Yes	30 mesiobuccal root canals of maxillary molars with 10-20° curvature (n=15)	G1 NiTi K-files G2 ProTaper	1. Canal transportation 2. Remaining dentin thickness SCT	ProTaper should be used carefully in curved canals since it causes greater canal transportation and thinning of the root dentin in the middle and cervical thirds. No perfect centralization within the canal was achieved in both groups.
Stavileci 2013	University of Prishtina Prishtina, Kosovo.	Yes	Yes	Yes	60 maxillary second premolars. (n=30)	G1 K-files G2 ProTaper	1. Canal transportation 2. Centering ability Micro-CT	K-file produced more canal transportation than ProTaper The ProTaper system had a greater centralization ability than K-file.
Stavileci 2015	University of Prishtina Prishtina, Kosovo	Yes	Yes	Yes	60 maxillary second premolars (n=30)	G1 ProTaper G2 K-files	1. Untouched root canal surface. 2. Straightening of the canal after root canal preparation Micro-CT	Manual or rotary techniques completely prepared the root canal, and both caused slight smoothing of the root canal
Tasdemir 2005	Ondokuz Mayis University Samsun, Turkey.	Yes	No	Yes	20 mesiobuccal canals of maxillary first molars with curvatures of 25-35° (n=10)	G1 Hero 642 G2 K-files	1. Canal transportation 2. Centering ability SCT	Hero 642 caused less canal transportation (middle and cervical third) and had better centralization ability than K-file.
Yin 2010	Peking University Beijing, China.	No	No	Yes	24 mandibular molars with "C" shaped canals (n=12)	G1 ProTaper G2 K-files	1. Instrumentation time 2. Volume of dentin temoved 3. Uninstrumented canal Area - Micro-CT	Rotary system ProTaper preserved the canal curvature, canal preparation was fast and with few procedural errors. Manual instrumentation can provide a better cleaning of the canal surface

microscope, dental surgical microscope; n= 21) (Table 3) and scanning electron microscope (n= 15) (Table 4).

Sample sizes and tooth types - A total of 3,112 teeth were analyzed in the included studies, of which 1,743 were upper or lower molars with 10-40 degree curvatures, 24 molars with c-shaped canals, 584 upper or lower premolars, 466 upper or lower incisors and 295 single-rooted teeth (not specified). Within the four subgroups, 459 teeth were in the computed tomography group, 640 in the periapical radiography group, 1,328 in the image magnification group, and 745 in the scanning electron microscopy group.

Intervention and control - Manual instrumentation was considered the standard treatment (Control Group),[5-10,13,14,16,17,19,21-35,42-69,71,72] and included the following instruments: Manual GT,[b] Manual Protaper,[b] K-Flexofile,[b,c] K-files,[d-g] NiTi K-files,[b,h] K-Reamers/Hedstrom,[h] H-files[b,i] and S-files.[j]

Rotary instrumentation was set as the Intervention Group[5-10,13,14,16,17,19,21,23-35,42,43-72] for this systematic review and included the continuous rotary systems Protaper Universal,[b] Protaper Next,[b] GT,[b] One Shape,[b] RaCe,[d] BioRace, [d] Easy RaCe, [d] G-File,[g] Hero 642,[g] Hero Shaper, [g] Revo-S,[g] FlexMaster,[h] Alpha,[k] EndoWave,[l] GT (Series X),[m] ProFile 0.04/0.06,[b,m] Twisted Files,[n] K3 (XF),[n] K3,[n,o] LightSpeed,[p,q] Quantec[q] and Mtwo.[h,r]

Outcomes - The primary outcome was instrumentation efficiency. Within studies, one or more of the following secondary outcomes were also recorded: instrumentation time,

Table 2. Details and conclusions of 10 included studies (in alphabetical order) – Periapical radiography. Abbreviations: R: Randomization; B: Blinding; M: Methodology; Rx: Radiography; *: instrumentation not considered in this study.

Author/ Year	Geographical region	Sensitivity			No. Sample	Intervention & control	Parameters evaluated	Conclusions
		R	B	M				
Aguiar 2008	Federal University of Pernambuco Recife, Brazil.	Yes	Yes	Yes	60 mesiobuccal canals with severe curvature of mandibular first molars (n=20)	G1 Pro- Taper G2 ProTaper for hand use G3 RaCe	1. Apical canal transportation Conventional Rx.	There was no significant difference between groups, but caution must be taken with extremely curved canals.
Ahmed 2014	The Aga Khan University Hospital, Karachi.	Yes	Yes	Yes	60 mesiobuccal roots of mandibular molars with curvature of 20-40° (n=30)	G1 ProTaper G2 NiTi files	1. Changes in root canal curvature after preparation 2. Changing working length Conventional Rx.	ProTaper better maintained the working length. There was no difference in canal curvature, although ProTaper produced a smaller curvature alteration.
Alves 2012	São Leopoldo Mandic Dental Research Center, Campinas, SP, Brazil.	Yes	Yes	Yes	45 mesial canals with curvature of 25° and 35° of mandibular first and second molars (n=15)	G1 K-files G2 Mtwo G3 Pathfile *	1. Apical canal transportation Digital Rx.	There was no difference between groups and no occurrence of apical transportation or aberration in the morphology of the curved canals.
Celik 2013	Karadeniz Technical University, Trabzon, Turkey.	Yes	No	+/-	140 mesiobuccal canals of maxillary first molars with curvature of 30-40° (n=20)	G1 Twisted File G2 GT Series X G3 Revo-S G4 RaCe G5 Mtwo G6 ProTaper Universal G7 K-Flexofile	1. Canal transportation 2. Changing working length Digital Rx.	GT Series X and Twisted File showed minimal canal transportation, similar to Revo S, RaCe, Mtwo, and Universal ProTaper. NiTi rotary systems had a better centralization ability in the root canal than K-Flexofile.
D'Amario 2013	University of L'Aquila L'Aquila, Italy.	Yes	Yes	Yes	45 mesial roots of mandibular molars with curved canals of 25° and 35° (n = 15)	G1 K-files G2 G-File G3 Pathfile*	1. Changes in root canal curvature after preparation 2. Apical canal transportation 3. Instrumentation time Digital Rx.	The instruments had no influence on the occurrence of apical transportation nor did they produce a change in the canal curvature. G-File seemed to be faster and safer.
Ehsani 2011	Babol University of Medical Sciences Babol, Iran.	Yes	Yes	Yes	60 mesiobuccal canals with curvatures between 20-40° of mandibular first molars.	G1 Mtwo. (n=18) G2 RaCe. (n=20) G3 K-Flexofile. (n=17)	1. Instrumentation time 2. Changes in root canal curvature after preparation 3. Shape of the root canal Microscope 4. Canal transportation 5. Centering ability Conventional Rx.	There was no significant difference in all thirds of the canal. RaCe had a smaller number of canal aberrations and better centralization ability. Mtwo and RaCe obtained a lower instrumentation time.
Guelzow 2005	University School of Dental Medicine Berlin, Germany.	-	-	Yes	147 mesiobuccal canals of mandibular molars with curvature less than 70° (<10, <25 and> 25°)	G1 FlexMaster (n=21) G2 System GT(n=20) G3 Hero 642 (n=20) G4 K3 (n=20) G5 ProTaper (n=18) G6 RaCe (n=21) G7 K-Reamers/Hedstroem (n=20)	1. Changing working length 2. Changes in root canal curvature after preparation 3. Shape of the root canal Microscope 4. Instrumentation time Conventional Rx.	All methods preserved the original canal curvature and were safe to use NiTi systems were faster than the manual technique. ProTaper created more regular canal diameters.
Pereira 2012	Federal University of Uberlandia, Uberlandia, Brazil.	Yes	No	Yes	60 mandibular incisors with single canal. (n=20)	G1 K-Flexofile G2 ProTaper Universal hand Files G3 ProTaper Universal rotary files	1. Changes in root canal curvature after preparation 2. Apical deformation Conventional Rx.	Flexion angles in curved canals promoted the formation of an apical stop. ProTaper Universal shows less deformation of the apical stop.
Ruckman 2013	Oregon Health and Science University, Portland, Oregon.	Yes	+/-	Yes	30 single-rooted tooth with oval canals. (n=10)	G1 Self-adjusting file (SAF).* G2 ProFile 0.04 G3 K-file.	1. Evaluation of remaining contrast in canals Digital Rx.	The three techniques removed the contrast medium similarly in the 0-5 mm segment.
Vaudt 2009	University School of Dental Medicine, Berlin, Germany.	Yes	No	Yes	45 mesial roots of mandibular molars with various curvatures (<25°, 25-35°,> 35 °) (n=15)	G1 Alpha G2 ProTaper Universal G3 K-Reamers/Hedström	1. Uninstrumented area (stereomicroscope) 2. Instrumentation time 3. Changes in root canal curvature after preparation. Digital Rx.	An apical smoothing effect cannot be avoided. All systems left some non-instrumented areas in the canal but Alpha showed better results.

canal transportation, ability to remain centralized within the canal, change of root canal curvature and canal smoothness, change in working length, amount of removed and residual dentin, amount of debris and smear layer, non-prepared surfaces, dentin defects (surface fissures, cracks, fractures, etc.), canal shape or morphology (regular, round, oval, elongated, irregular), and amount of removed contrast and removed ink.

Effects of interventions

Instrumentation time - Twelve studies[7,10,13,14,16,19,21,24,45,60,64,66] evaluated instrumentation time, and all found that rotary instrumentation with different systems required less time compared to manual instrumentation (K-Flexofile, K-file, NiTi Flex, NiTi K-files and Hedstrom).

Seven of these studies compared manual instrumentation

Table 3. Details and conclusions of 21 included studies (in alphabetical order) – Image amplification method. Abbreviations: R: Randomization; B: Blinding; M: Methodology; Rot: Rotary; Rec: Reciprocation; *: instrumentation not considered in this study; **: parameter not evaluated in this study.

Author/ Year	Geographical region	Sensitivity R	B	M	No. Sample	Intervention & control	Parameters evaluated	Conclusions
Aracena Rojas 2013	Universidad de la Frontera Temuco, Chile.	Yes	Yes	Yes	52 root canals of 26 mesial roots of mandibular molars with curvature <34°	G1 ProTaper Universal (n=28) G2 Ni-Ti files (n=24)	1.Apical canal transportation Stereomicroscope	ProTaper caused less apical transportation compared to the manual technique.
Azar 2011	University of Medical Sciences, Shiraz, Iran.	Yes	Yes	Yes	70 mandibular first molars	G1 (n=20) K-files G2 (n=20) Mtwo G3 Control (n=30) .	1. Instrumentation time 2. Amount of India ink remaining of the canal Stereomicroscope	Mtwo showed acceptable cleaning capacity and results similar to K-files in less time.
Barbizam 2002	University of São Paulo Ribeirão Preto, Brazil.	Yes	No	Yes	20 mandibular central incisors with flat mesiodistal root (n= 10)	G1 K-files G2 Profile 0.04	1. Percentage of debris in the apical third Optical microscope	The manual technique was more efficient in cleaning narrow root canals, although no technique provided a completely clean canal.
Bertrand 2001	University of Nice-Sophia Antipolis, France.	Yes	No	Yes	24 root canals of mandibular molars with curvature greater than20° (n=12)	G1 K-Flexofile G2 Hero 642	1. Amount of dentin removed 2. Canal transportation Camera linked to a digital image analysis system (CUE-2, Olympus)	The original canal shape was better maintained in the apical third when using the Hero 642 instrument than the manual technique.
Bier 2009	São Paulo State University Araraquara, SP, Brazil.	Yes	Yes	Yes	260 mandibular premolars	Ga. Without instrumentation (n=40) Gb. K-Flexofile (n=20) G1 ProTaper (n=50) G2 SystemGT (n=50) G3 Profile (n=50) G4 S-ApeX (n=50)*	1. Dentin defects Stereomicroscope	K-Flexofiles and S-Apex did not produce dentin defects. ProTaper produced the most dentin defects (16%), followed Profile (8%) and lastly GT (4%).
Brkanic 2012	Dental Clinic, Medical Faculty, Novi Sad, Serbia.	No	No	Yes	140 single-rooted tooth (n=20)	G1 ProTaper G2 Profile G3 GT G4 K-3 G5 FlexMaster G6 Hand ProTaper G7 Hand GT	Maximal and residual dentin thickness Polarized light microscopy	There was no significant difference in the residual dentin thickness nor in the shape of the canal lumen in the tested instruments. NiTi instruments showed good apical preparation.
Dafalla 2010	University of Khartoum, Khartoum, Sudan.	Yes	Yes	Yes	68 curved canals of premolars. (n=34)	G1 K-files G2 Profile 0.04	1. Instrumentation time 2. Canal blockage by debris 3. Changing working length Stereomicroscope (intracanal impression).	Profile prepared root canals faster and had lower incidence of canal blocks, and small loss in working length.
Elayouti 2008	University of Tubingen, Tubingen, Germany.	Yes	Yes	Yes	90 oval root canals of mandibular incisors (43) and molars (47), with a maximum curvature of 10° (n=30)	G1 NiTi-hand files G2 ProTaper G3 Mtwo	1. Amount of dentin removed 2. Dentin remaining Stereomicroscope	No technique was able to completely prepare the surface of oval canals. Instruments with greater conicity (ProTaper and Mtwo) were more efficient than G1, but at the expense of a thinner remaining dentin thickness.
Garg 2015	Genesis Institute of Dental Sciences & Research, Ferozepur, Punjab, India.	Yes	-	Yes	1150 mandibular premolars	G1 Without instrumentation G2 K-files G3 ProTaper G4 K3 G5 Easy RaCe	1. Dentin defects Stereomicroscope	Rotating instruments had increased dentin defects compared to manual instrumentation. ProTaper caused the most dentin damage.
Hilaly 2011	Cairo University, Cairo, Egypt.	Yes	No	Yes	45 single-rooted premolars with oval canals of straight roots or with a curvature of less than 10° (n=15)	G1 H-files G2 ProTaper Universal G3 SafeSiders*	1.Untouched root canal surface 2. Amount of dentin removed Stereomicroscope	None of the three techniques completely prepared the oval-shaped root canal. H-files and ProTaper performed a reasonable instrumentation of these canals.
Kaptan 2005	Yeditepe University, Istanbul, Turkey.	No	No	Yes	80 mesial canals (buccal and lingual) of mandibular molars with curvatures of 25-40° (n=40)	G1 Hero Shaper G2 NiTiflex	1. Amount of dentin removed 2. Canal transportation 3. Direction of transportation Stereomicroscope	A greater amount of dentin was removed in the middle third of the root canal with Hero Shaper, but there was no difference in the apical and coronal thirds. There was no significant difference in canal transportation.
Kececi 2005	Suleyman Demirel University, Turkey	Yes	No	Yes	48 maxillary central incisors (n=24)	G1 K-Flexofiles G2 ProFile NiTi	1.Instrumentation time 2.Apical extrusion of sealer and/or gutta-percha** Stereomicroscope	The mean time required by the manual technique was 14 min 21 seconds and the rotary technique was 8 minutes 55 seconds.
Milani 2012	Tabriz University of Medical Sciences, Tabriz, Iran.	Yes	Yes	Yes	57 mandibular incisors without curvature. (n=19)	G1 K-Flexofile G2 ProTaper Universal G3 Without instrumentation	1.Dentin defects Dental microscope	Both techniques produced structural defects in the dentin. ProTaper, when used according to the manufacturer's instructions, produced fewer dentin defects.

Table 3 continued.

Monga 2015	Genesis Institute of Dental Sciences & Research, Ferozepur, Punjab, India.	Yes	Yes	Yes	150 mandibular premolars. (n=30)	G1 Without instrumentation G2 K-files G3 ProTaper G4 K3XF G5 WaveOne*	1. Dentin defects Stereomicroscope	Continuous rotary instruments can cause dentin cracks. However, reciprocating motion seemed to be a better option.
Nagaratna 2006	College of Dental Sciences, Davangere, India.	No	No	Yes	20 mandibular first molars. (n=10)	G1 K-files G2 Profile 0.04	1. Instrumentation time Stereomicroscope	The Profile had better results regarding the shaping of the canal, smoothness of the walls and time. There were fewer instrument failures with the K-File.
Shahriari 2009	Hamadan University of Medical Sciences, Hamadan, Iran.	Yes	No	Yes	36 mesiobuccal canals of mandibular molars with curvature <30°. (n=18)	G1 K-File G2 ProFile	1.Amount of dentin removed 2.Dentin remaining Stereomicroscope	The Profile prepared root canals with a greater conservation of the dental structure. K-Files removed greater amount of dentin.
Sipert 2006	Hospital de Reabilitação de Anomalias Craniofaciais USP, Bauru, Brazil.	No	No	Yes	20 mesiobuccal canals of maxillary molars with curvature of 25-30°. (n=10)	G1 K-files G2 RaCe	Amount of remaining dye (India ink) Magnifying glass	The results were similar with both techniques. K-files removed less amount of ink, however, this difference was significant only in the middle third of the root canal.
Taha 2010	Jordan University of Science and Technology, Irbid, Jordan.	Yes	Yes	Yes	39 mandibular premolar single-rooted with oval canals. (n=13)	G1 Hedstrom files G2 EndoWave G3 Anatomic Endodontic Technology (AET).*	1.Shape of the root canal 2. Uninstrumented area 3.Amount of remaining debris Light microscope	No technique was able to completely clean the root canal. EndoWave showed less amount of debris in the apical third.
Tan 2002	University of Melbourne, Victoria, Australia	Yes	No	Yes	30 mesiobuccal canals of mandibular molars with curvatures of 10-20ª (17) and > 25º (13). (n=10)	G1 K-files without coronal flaring G2 K-files with early coronal flaring. G3 LightSpeed	1.Canal cleanliness (pulp tissue /detritus) 2.Apical canal transportation 3. Shape of the root canal Light microscope	None of the techniques completely cleaned the entire root canal. Apical enlargement using LS was beneficial for cleaning the apical region. Both techniques using K-Files produced more defects and irregular canal shapes.
Priya 2014	Mamata Dental College Khammam, India.	-	-	Yes	100 mandibular central incisors. (n=10)	G1 Without instrumentation G2 K-file G3 ProTaper – rot G4 ProTaper– rec * G5 ProTaper Next – rot G6 ProTaper Next – rec * G7 One shape – rot G8 One shape – rec * G9 Reciproc – rot G10 Reciproc – rec *	1. Dentin defects Stereomicroscope	Manual instrumentation caused minimal dentin defects. Fewer microcracks were seen in canals instrumented with ProTaper Next, both with rotary and reciprocating motion. Reciprocating motion produced less microcracks than rotary movements.
Weiger 2003	University of Tubingen, Tubingen, Germany.	Yes	Yes	Yes	136 molar root canals with curvature <15°.	G1 FlexMaster(n=45) G2 NiTi K-files (n=45) G3 Lightspeed (n=46)	1.Changing working length 2.Instrument failure** 3.Instrumentation time 4.Canal transportation Microscope	Loss of working length: LS (4), FM (1). FM required less time, followed by LS and K-Files (almost double the time of FM). LS produced fewer canal transportation, followed by K-files and FM.

with one rotary instrument: Profile,[7,19,45] ProTaper,[10] FlexMaster,[13] Mtwo,[66] G-File.[14] Four studies evaluated two rotary instruments: FlexMaster and Lightspeed,[16] ProTaper and GT,[64] Alpha and ProTaper Universal,[21] Mtwo and RaCe.[60] One study[24] evaluated six rotary instruments: FlexMaster, System GT, Hero 642, K3, ProTaper and RaCe.

Canal transportation - The method from Gambill et al[73] was used in most studies, which applies the formula (X1-X2) - (Y1-Y2) to overlapped radiographic images taken before and after instrumentation. A result of 0 indicates that there was no canal transportation.

Ten studies evaluated canal transportation in all three thirds of the root canal, seven of which used the technique by Gambill et al.[73] Seven studies[5,6,8,9,28,54,60] found significant differences favoring rotary instrumentation (Twisted File, BioRaCe, MTwo, ProTaper, Hero 642, RaCe, GT series X and Revo-S), which caused less canal transportation than manual instrumentation (K- Flexofile and K-file). However, Nagaraja & Sreenivasa,[70] who evaluated nine different sections of the root canal, found no difference between the groups at 1-3, 4 and 9 mm sections. At the 5-8 mm section, a significantly greater canal transportation was found with the rotary instrument (ProTaper) than the manual instrument (NiTi K-files) ($P< 0.05$). Kaptan et al[44] found no significant difference between NiTi Flex and Hero Shaper, with the rotary instrument causing a slightly greater canal transportation in the apical and middle third on the outer side of the curvature and in the coronal third on the curvature's inner face. The manual instrument NiTi Flex caused transportation of the inner face of the curvature in all three thirds of the canal. Weiger et al[16] showed that Lightspeed had a significantly lower incidence compared to FlexMaster (canal transportation > 0.1 mm occurred in 76% in the FlexMaster group, 58% in the NiTi K-files group and 44% in the Lightspeed group.

Ten studies[14,17,25,26,31,43,51,56,61,64] reported canal transportation only in the apical third. Four studies[14,26,31,56] did not find significant differences between manual and rotary instrumentation; three studies[43,51,64] found less canal transportation with rotary instruments; two studies[25,61] found less with rotary instruments. However, Alves et al[17] found no canal transportation in both groups (K-file and Mtwo), only a lateral extension due to uniform wear caused by the instruments.

Centralization ability - The average centralization ratio as described by Gambill et al[73] indicated the ability of the instru-

Table 4. Details and conclusions of 15 included studies (in alphabetical order) – Scanning electron microscope. Abbreviations: R: Randomization; B: Blinding; M: Methodology; Rx: Radiography; *Instrumentation not considered in this study.

Author/ Year	Geographical region	Sensitivity R	B	M	No. Sample	Intervention & control	Parameters evaluated	Conclusions
Ahlquist 2001	Karolinska Institute, Huddinge, Sweden.	Yes	Yes	Yes	20 teeth with curved canals of 20-25°. (n=10)	G1 Stainless steel S-files G2 Profile.	1.Amount of debris 2.Smear layer	The manual technique produced cleaner root canal walls than rotary technique.
Alam 2006	Dental Faculty, BSM Medical University, Dhaka.	Yes	Yes	Yes	40 root canals with curvatures of 20-30° of 36 teeth. (n=20)	G1 NiTi Flexofile G2 FlexMaster	1.Amount of debris 2.Smear layer 3.Instrumentation time	The FlexMaster produced fewer clean walls than the manual technique, but in half the instrumentation time.
Bertrand 1999	University of Nice-Sophia Antipolis, Nice, France.	Yes	No	Yes	24 canals of mandibular molars with curvatures of 20-40°. (n=12)	G1 K-files G2 Quantec instrument	1.Smear layer 2.Amount of debris	Quantec produced cleaner walls than K-Files, especially in the middle and apical thirds.
Bhatti 2010	Christian Dental College and Hospital, Ludhiana, India.	Yes	No	Yes	120 mesiobuccal canals of mandibular molars with curvature >20º. (n=30)	G1 K-Flexofile G2 LightSpeed G3 ProTaper G4 Mtwo	1.Changes in root canal curvature. (Rx). 2. Amount of debris	ProTaper and Mtwo showed good canal cleaning. LightSpeed better maintained the initial canal curvature than the other techniques.
Çiçek 2015	Bu¨lent Ecevit University, Turkey	Yes	-	Yes	60 mesiobuccal canals of mandibular molars with mild and moderate curvature. (n=15)	G1 NiTi K-Flexofiles G2 ProTaper Universal G3 ProTaper Next G4 WaveOne*	1.Dentin defects	All techniques caused microcracks, except K-flexofiles. ProTaper Next caused fewer microcracks, followed by Universal ProTaper, the majority in the apical third.
Khadivi 2007	Islamic Azad University of Medical Sciences, Tehran, Iran.	Yes	Yes	+/-	50 mesiobuccal molar canals with 25-35 ° curvature. (n=15)	G1 K-Flexofiles G2 K3 G3 RaCe G4 Control (n=5)	1.Amount of debris 2.Smear layer	Rotary instrumentation showed better canal cleaning than manual instrumentation. No significant difference was found between K3 and RaCe.
Lin 2013	University of British Columbia, Vancouver, Canada.	Yes	Yes	Yes	36 single-rooted, straight and oval roots of maxillary premolars. (n=10).	G1 K-files G2 Profile 0.04 G3 SAF System.* G4 Control (n=6)	1.Biofilm removal	SAF significantly reduced bacteria in the apical groove. No technique was able to completely remove bacteria.
Liu 2006	Wuhan University, China.	Yes	Yes	Yes	45 maxillary and mandibular molars with radicular curvature of 25-40 °. (n=15)	G1 ProTaper G2 GT G3 K-Flexofile	1.Amount of debris 2.Smear layer 3.Apical canal transportation 4.Instrumentation time	ProTaper provided significantly better debris removal than GT, but similar than Flexofile. ProTaper instrumentation time was less than GT and FlexoFile.
Prati 2004	University of Bologna, Bologna, Italy.	Yes	Yes	Yes	48 maxillary incisors with straight or slightly curved roots.	G1 (n=10) K3 G2 (n=10) Hero 642 G3 (n=10) RaCe G4 (n=18) K-files	1.Smear layer 2.Pulpal debris 3 Inorganic debris	Rotary techniques produced results similar to a manual technique. The apical third contained the largest amount of debris and smear layer.
Porciúncula 2015	Federal University of Rio Grande do Sul, Brazil.	Yes	Yes	Yes	90 maxillary molars with curvature <40°. (n=30)	G1 K-Flexofile G2 K3 G3 NSK reciprocating handpiece + Flexofile.*	1.Smear layer formation in the apical third.	Smear layer was formed independently of the technique. Increasing the diameter of the apical section did not result in cleaning improvement of the canal walls.
Rahimi 2008	Tabriz University of Medical Sciences, Tabriz, Iran.	Yes	Yes	Yes	60 single-rooted teeth teeth with curvatures <20º. (n=20).	G1 RaCe G2 K3 G3 K-Flexofiles	1.Amount of debris 2.Smear layer	K-FlexoFile produced less debris. There was no significant difference for smear layer removal.
Reddy 2014	Navodaya Dental College & Hospital, Raichur, India.	Yes	No	Yes	50 maxillary central incisors. (n=25)	G1 NiTi K-Flexofile G2 ProTaper	1.Amount of debris 2.Smear layer	Neither instrument produced completely clean root canals. K-File produced less debris and smear layer.
Reddy 2013	St Joseph Dental College and Hospital, India.	Yes	No	Yes	60 maxillary incisors single-rooted with straight roots. (n=15)	G1 ProTaper G2 K3 G3 K-files G4 Without instrumentation.	1.Amount of debris 2.Smear layer	ProTaper showed the maximum cleaning efficiency followed by K3 in the cervical, middle and apical thirds of the root canal. None of the techniques completely cleaned the canal.
Schafer 2000	Poliklinik fur Zahnerhaltung, Munster, Germany.	Yes	Yes	Yes	120 teeth, 60 incisors with straight canals (n= 12) and 60 molars with at least one curved root 22-42º. (n=12)	G1 K-Flexofile G2 K-Flexofile, step back G2 Hedstrom G3 KaVo-Endo flash + K-flexofiles.* G4 Profile 0.04 & 0.06.	1.Amount of debris 2.Smear layer 3.Straightening of the canal (Rx)	Complete cleaning was not achieved by any of the techniques. ProFile produced better results in the instrumentation of curved canals.
Zand 2007	Tabriz Dental School, Tabriz, Iran.	Yes	Yes	Yes	75 single-rooted teeth with canal curvature <5°. (n=25)	G1 FlexMaster G2 RaCe G3 NiTi K-file.	1.Amount of debris 2.Smear layer	FlexMaster showed superior canal cleaning than RaCe and K-FLexofile. The manual instrument left more smear layer in the apical third.

ment to remain centralized in the canal [(X1-X2)/(Y1-Y2)] or [(Y1-Y2)/(X1-X2)]. A result of 1 indicates perfect centralization.

This parameter was evaluated in the three thirds of the root canal in four studies[9,28,54,60] and in 1 mm sections from the apex (1-9 mm) in the Nagaraja & Sreenivasa study.[70] All these studies used computed tomography for evaluation, except the one by Ehsani et al,[60] which used periapical radiography.

The first four studies found a better centralization ability with the rotary than the manual instrumentation. According to Nagaraja & Sreenivasa,[70] there was no significant difference between the manual (NiTi K-File) and rotary instrument (ProTaper) at all sections, but the NiTi K-File showed better centralization at the 3, 7, 8 and 9 mm and ProTaper was best at the 1, 2, 4, 5, 6 mm.

Change of root canal curvature or canal smoothing - Eight studies evaluated change in the angle of curvature, of which four[24,31,60,71] used the technique by Schneider,[74] two[14,58] the technique by Pruett et al[12] and two[21,50] used other methods.

All studies showed that rotary instrumentation (G-File, ProTaper, RaCe, Mtwo, LightSpeed and Alpha) caused a smaller change in the curvature angle than manual instrumentation (NiTi files, ProTaper manual, K-Flexofile, K-file and K-Reamers), better preserving the original anatomy of the root canal. However, Guelzow et al[24] evaluated seven rotary instruments and in six of them: FlexMaster (0.9°), Hero 642 (0.6°), K3 (0.9°), RaCe (0.7°), GT (0.5°), and ProTaper (1.2), no difference was found with the manual instrumentation with K-reamers (0.7°). Change in angle was significant between the GT and the ProTaper System (P= 0.042).

Change in working length - This parameter was evaluated in five studies, of which three found a significant difference between the groups,[6,7,71] with rotary instruments (ProTaper, Profile, Twisted file, GT, Revo-S, RaCe and Mtwo) better maintaining the original working length than the manual technique (NiTi files, K-Flexofile and K-file). However, Weiger et al[16] showed five cases of working length losses of 0.5 mm caused by the rotary instruments Lightspeed (four), and FlexMaster (one) and no loss with the NiTi K-files manual instrument. On the other hand, Guelzow et al[24] reported no significant difference between the groups (FlexMaster, GT, Hero 642, K3, ProTaper, RaCe and K-Reamers). None of the root canals were blocked with dentin debris.

Amount of removed and remaining dentin - Two studies evaluated the amount of removed and remaining dentin using a stereoscopic microscope. Elayouti et al[69] evaluated oval-shaped root canals of lower incisors and molars, showing that the Mtwo and the ProTaper rotary instruments removed more dentin than the NiTi manual files but there was no significant difference between the groups. For remaining dentin, the Mtwo instrument had 20% and the ProTaper 27% in dentin walls less than 0.5 mm. For manual instrumentation, no excessive dentin loss was observed. However, Shahriari et al[49] evaluated mesiobuccal canals of lower molars with curvature <30°, verifying that SS manual instruments removed more dentin than the Profile rotating instrument in all thirds and surfaces of the root canal (mesial, distal and buccal). The Profile instrument performed better concerning amount of remaining dentin but with a significant difference only in the coronal third and distal surface (P< 0.05).

Five studies[5,10,29,44,48] evaluated the amount of removed dentin, and three of them[5,10,29] showed that manual instruments (K-Flexofile, H-files and K-files) recorded greater dentin removal compared to rotary instruments (Hero 642, ProTaper Universal). However, Kaptan et al[44] noticed that the Hero Shaper rotary instrument removed more dentin (in mm^2) than the NiTi Flex manual instrument in the three thirds of the root canal. Limongi et al[48] concluded that during instrumentation, none of the techniques could be considered more effective than the other because each behaved differently on different thirds and surfaces of the canal.

Two studies[30,70] reported the amount of remaining dentin, with no significant difference between groups. Brkanic et al[30] analyzed remaining dentin at 1 and 3 mm from the apex, showing a greater amount of dentin remaining at the 3 mm level. Nagaraja and Sreenivasa[70] evaluated the parameter in nine levels (1-9 mm) from the apex and verified that there was no significant difference in the 1, 2, 3, 4 and 9 mm levels (P> 0.05), but at the 5, 6, 7 and 8 mm levels there was less remaining dentin with a rotary instrument (ProTaper) compared to a manual one (NiTi K-files) (P< 0.01).

Cutting ability and smear layer generation

Amount of debris - Five studies[7,43,50,68] evaluated amount of debris, four of which agreed that rotary instrumentation (Profile 0.04, EndoWave, LightSpeed, LightSpeed, ProTaper and Mtwo) had better cutting ability compared to manual (K-file, Hedstrom Files, K-Flexofile). However, Barbizam et al[42] studied the percentage of debris in the apical third of lower central incisors and found that the rotary instrument group (Profile) presented a larger area of the canal with debris (19.44±2.01%) than the manual group (K-file) (7.18±1.78%), with a significant difference between groups.

Amount of debris and smear layer - The amount of debris and smear layer was evaluated by means of two numerical scales (scores 1-5) as described by Hulsmann et al.[75] Porciúncula et al[63] studied only the amount of smear layer remaining in the apical third by scanning electron microscopy (SEM), and verified that K-Flexofile obtained lower smear layer scores compared to K3 (#30, #35 and #40). The authors showed that the instrument with the largest size has more smear layer generation than smaller instruments (P< 0.05).

Cutting ability and smear layer generation was evaluated by 11 studies[13,22,23,47,53,55,59,64,65,67,72] using SEM. Five studies[13,23,55,59,68] agreed that manual instrumentation (K-files, NiTi Flexofile, K-Flexofiles and Hedstrom) had better efficacy than the rotary instrumentation (Profile, FlexMaster, RaCe, K3, ProTaper). On the other hand, Prati et al[67] reported no significant difference in the overall results. However, a greater amount of pulp debris was found in the apical third with K3 and RaCe compared to Hero 642 and K-files. Liu et al[64] noticed that K-Flexofile caused less production of smear layer than rotary instruments. For debris removal, ProTaper had a better result than the GT system (P< 0.05), but a manual instrument was better than GT. Four other studies,[22,47,53,72] however, concluded that rotary instrumentation (Quantec, K3, RaCe, ProTaper and FlexMaster) achieved a better performance than manual instrumentation (K-files, K-Flexofiles and NiTi K-Flex).

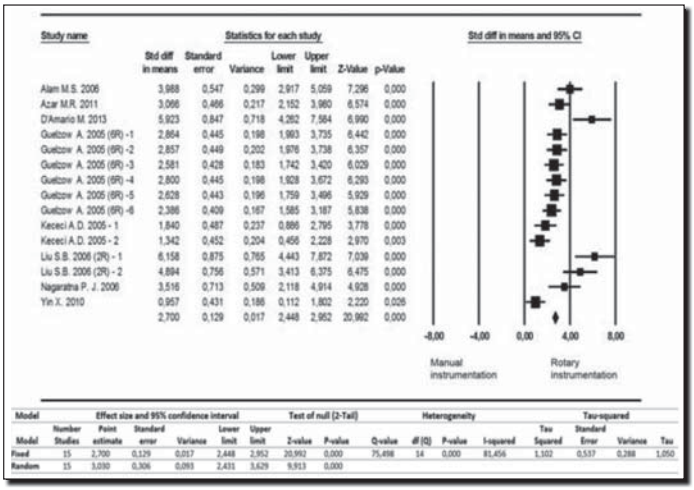


Fig. 2. Comparison of total instrumentation time with manual and rotary techniques of root canal preparation of permanent teeth.

Non-instrumented surfaces - Five studies[10,21,29,58,68] evaluated the non-instrumented surfaces of the canal. Taha et al[68] reported that there was no significant difference between techniques in general (in oval pre-molar root canals). However, the Hedstrom file showed better performance than EndoWave in the middle and coronal thirds, while in the apical third EndoWave showed a better result than Hedstrom. Two studies, in which samples were single-rooted premolars with oval canals[29] and lower molars with c-shaped canals,[10] verified that none of the instrumentation techniques resulted in a completely prepared root canal, but manual instrumentation (H-Files and K-file) had a tendency to touch more surfaces of the original canal perimeter than the rotary instrumentation (ProTaper). However, two other studies that evaluated single-rooted teeth with oval canals[21] and second upper premolars[58] showed better results for rotary instrumentation (Alpha and ProTaper) compared to manual instrumenta-tion (K-Reamers and K-file).

Dentin defects - Bier et al[27] evaluated dentin defects in lower premolars and found no complete fractures or canal defects with manual instrumentation (K-Flexofile). However, dentin defects were observed with the rotary instruments: GT (4%), Profile (8%) and ProTaper (15%). Three other studies[33-35] also did not find any defects in the dentin of teeth prepared with manual instruments (NiTi K-Flexofiles and K-files), while rotary instruments did produce dentin defects (ProTaper Universal, ProTaper Next, K3, Easy RaCe and K3XF). On the other hand, Milani et al[62] evaluated dentin defects at 3 and 6 mm from the apex of lower incisors and showed that the manual instrument K-Flexofile (6) produced more defects than the rotary instrument (ProTaper) (2), but the difference was not significant (P> 0.05).

Root canal shaping - Four studies[24,43,60,68] evaluated the postoperative cross-section of the root canal, and their final shapes were classified as round, oval, irregular or elliptical. Three studies[43,60,68] showed that rotary instrumentation (RaCe, Mtwo, EndoWave and LightSpeed) yielded fewer irregular cross-sections than manual instrumentation (K-Flexofile, Hedstrom and K-files). Guelzow et al[24] reported that the ProTaper rotary instrument produced the fewest number of irregular cross sections in the apical, middle and coronal thirds, followed by K-Reamers (manual instrument), GT, Hero 642, RaCe (rotary instruments) and the worst results were achieved with K3 and FlexMaster (rotary instruments).

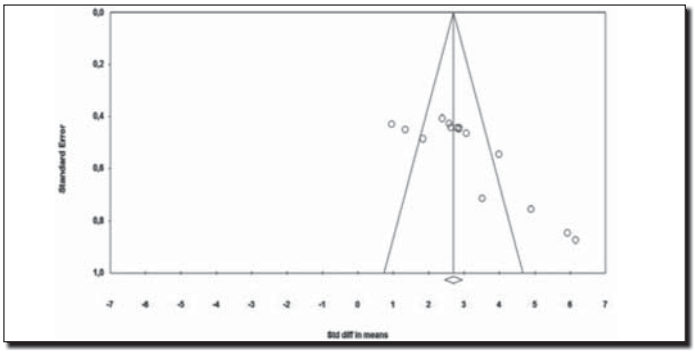
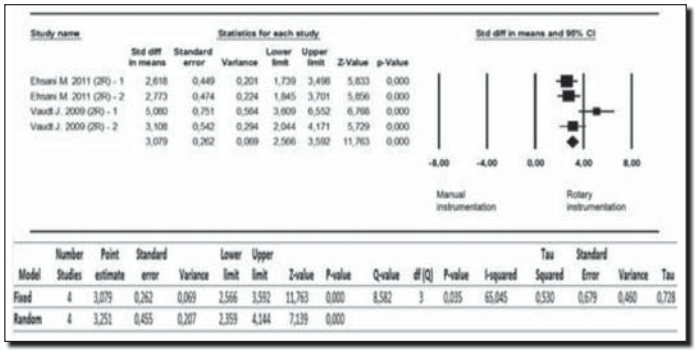


Fig. 3. Funnel plot showing the high heterogeneity of the sample in the comparison of total instrumentation time of the root canals between manual and rotary instrumentation.



Fig, 4. Comparison of instrumentation effective time of manual with rotary techniques in root canal preparation of permanent teeth.

Radiopaque contrast medium removal - Ruckman et al[32] filled the canals with a radiopaque contrast medium (Vitapex[s]) and quantified the reduction of the contrast medium in single rooted teeth with oval canals by periapical radiographs in two segments (0–5 mm and <5–10 mm from the apex). Overall the ProFile Rotary instrument (PF) 0.04 removed more material than the K-file manual instrument. In the 0–5 mm segment, the PF removed 84.2 ± 7.7% and K-File 76.5 ± 10.2% of the contrast medium (P> 0.05). In the segment >5–10 mm, the PF removed 72.3±12.0% and the K-File 60.9±11.3% of the contrast medium.

India ink removal - Two studies injected India ink into molar canals and evaluated ink removal with a scale from 0 to 3 (lower values indicate greater cleaning), after K-File manual instrumentation and RaCe and Mtwo rotary instrumentation. Sipert et al[46] sectioned in halves the mesiobuccal root of upper molars with curvature of 25-30° and analyzed the three thirds of the root. They reported that both techniques were unable to provide complete cleaning of the root canals. However, manual instrumentation (K-Files) resulted in significantly less ink left in the canal compared to the rotary instrument (RaCe) in the middle third of the canal (P< 0.05). On the other hand, the study by Azar & Mokhtare[66] found slightly better cleaning capacity with a rotary instrument (Mtwo) than with the manual instrument (K-file), but the difference was not significant (P> 0.05).

META-ANALYSIS

The meta-analysis was conducted with a total of 15 studies.[6,7,10,13,14,19,21,24,45,58-60,64,66,71] Due to the heterogeneity of the studies, the meta-analysis included only three of the evaluated criteria: instrumentation time, change of the curvature angle and loss of working length.

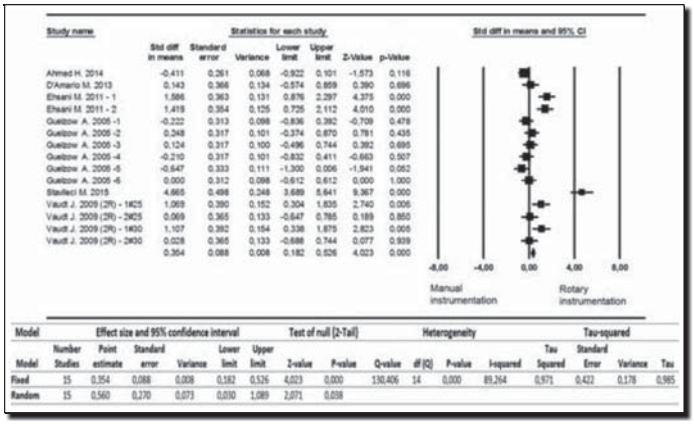


Fig. 5. Change in curvature angle of manual and rotatory instrumentation in the preparation of the root canal of permanent teeth.

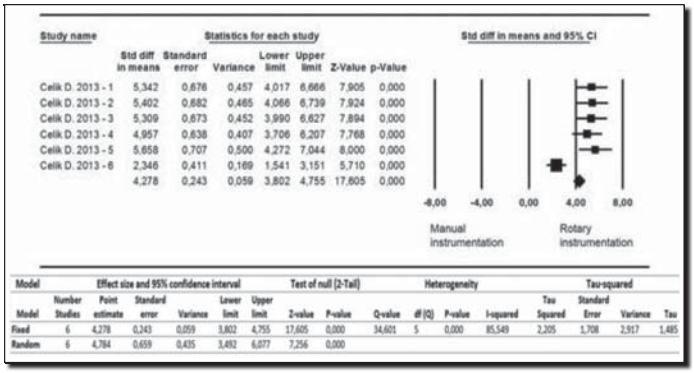


Fig. 7. Comparison of working length alteration with manual and rotary instrumentation in root canal preparation of permanent teeth.

Instrumentation time - The analysis of instrumentation time (seconds) included 10 studies.[10,13,14,19,21,24,45,60,64,66] Results showed a significant time reduction with rotary instrumentation compared to manual instrumentation of permanent teeth in both total time (including time spent with active instrumentation, instrument changes within the sequence and irrigation) and effective time (active instrumentation) (P< 0.05) (total time 95% confidence interval: 2,431-3,629; heterogeneity: Q=75.498, I2= 81.456%), (effective time 95% confidence interval, 2,566-3,592; heterogeneity: Q=8,582, I2=65,045%) (Figs. 2-4).

Curvature alteration - Six studies[14,21,24,58,60,71] were included in the comparison of curvature angle alterations and results did not show significant differences between the groups (P= 0.038). However, the rotary instrumentation caused less alterations in the canal curvature or smoothing, and better preservation of the original anatomy of the root canal than manual instruments (95% confidence interval= 0.030-1.089; heterogeneity: Q=130.4, I2=89.2%) (Figs. 5, 6).

Working length alteration - Three studies[6,24,71] were included in this meta-analysis. Results of the meta-analysis performed with the study by Celik et al,[6] in which the samples were mesiobuccal canals of upper first molars with curvature of 30-40°, revealed that rotary instrumentation caused less alterations in working length compared to manual instrumentation. However the funnel plot shows a high sample heterogeneity (Figs. 7, 8), (95% confidence interval, 3.492-6.077; heterogeneity: Q=34.6, I2=85.5%).

On the other hand, the meta-analysis generated with the studies by Guelzow et al[24] and Ahmed,[71] in which the samples were mesiobuccal roots of lower molars with curvatures <70°, and roots with curvatures between 20 and 40°, respectively, showed that in teeth with smaller root curvature, manual instrumentation caused less working length alteration than rotary instrumentation (Fig. 9), (95% confidence interval, -0.803 to -0.338; heterogeneity: Q=8.9, I2=32.6%) (Figs. 7-9).

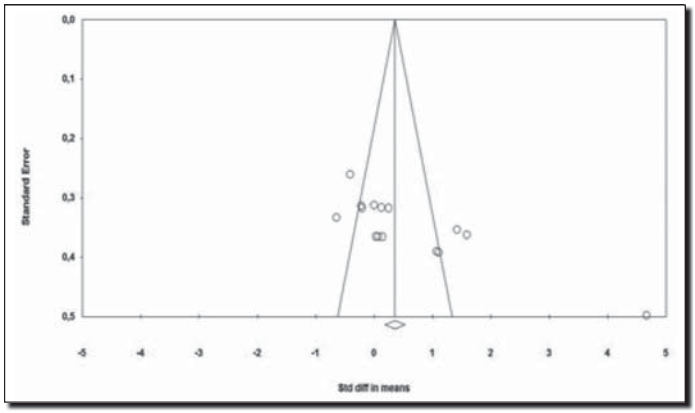
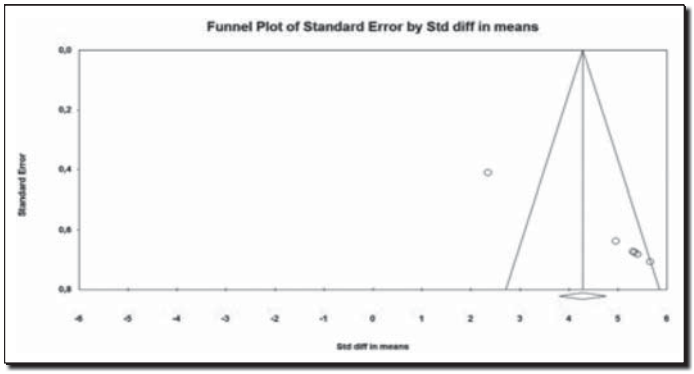


Fig. 6. Funnel plot showing the high heterogeneity of the sample in the comparison of curvature angle change of root canal of permanent teeth between manual and rotary instrumentation.



Fig, 8. Funnel plot showing high sample heterogeneity in the comparison of working length alteration between manual and rotary instrumentation in the preparation of root canals.

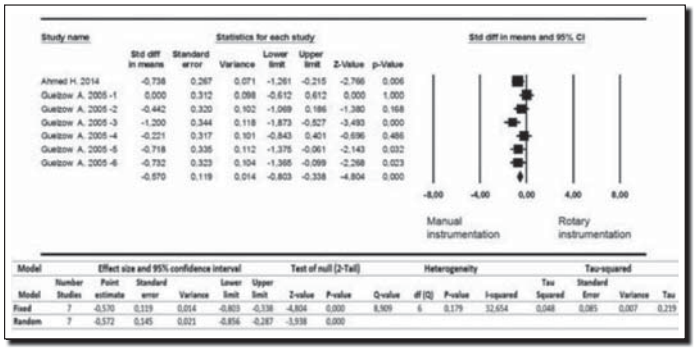


Fig. 9. Comparison of working length alteration with manual and rotary instrumentation in root canal preparation of permanent teeth.

Subgroup analysis - In order to better organize the studies included in this meta-analysis, sub-group analyses were performed based on the main methodology used by the author: computed tomography (cone beam computed tomography, spiral computed tomography and micro-computed tomography), periapical radiography (conventional and digital), magnification method (magnifying glass, light microscope, stereoscopic microscope, optical microscope, dental surgical microscope) and scanning electron microscopy.

Bias risk - A possible source of bias could be the small number of samples in some of the studies.[9,19,23,32,42,43,46,52,57,67] Another issue is the heterogeneity of the techniques applied to evaluate the following parameters: canal transportation, which was done by the formula of Gambill et al[73] or other formulas, and alteration of the root canal curvature, done by the Schneider[74] or Pruett et al[12] techniques. Because of this heterogeneity, the meta-analysis was possible with only three parameters (instrumentation time in seconds, alteration in canal curvature and loss of working length).

Discussion

The success of an endodontic treatment depends on the prudence devoted in all stages, especially in the preparation of the root canal.[3] For this procedure, a variety of manual instruments as well as rotary and reciprocating automated instruments are available in the market.[4] Although several studies on root canal instrumentation efficiency have been published, there is still no consensus as to which instrument and instrumentation technique is best. Therefore, this systematic review compared the efficiency of manual and rotary instrumentation of root canals of permanent teeth, using the main criteria evaluated by the authors of the included studies.

One of the criteria evaluated was instrumentation time. Results show a reduction in the effective time[21,60] and total time[7,10,13,14,16,19,24,45,64,66] of root canal preparation with different rotary systems compared to manual instrumentation. The study by D'Amario et al[14] that found the lowest instrumentation time among the included studies (GFile = 35.82 seconds and K-File manual instrument = 58.95 seconds) evaluated mesial roots of lower molars with curvatures of 25° and 35° treated by a single endodontist. In the work by Weiger et al,[16] which found the longest time of instrumentation (Lightspeed rotary instrument: 16 minutes and NiTi K-File manual instrument: 26 minutes), the samples were root canals of molars with curvature <15° prepared by a dentist with 4 years of experience but that had not used any technique routinely. Instrumentation time seems to be more influenced by operator experience than by sample type. In the present study, it was found that a large canal curvature does not necessarily require longer instrumentation time, depending more on the experience of the operator with the different types of techniques.[7,24,45,60]

A prior cervical enlargement tends to reduce procedural errors such as canal transportation,[18] which seems to occur regardless of the evaluation method and type of sample, and mostly in molar root canals with curvatures of up to 40°. On the other hand, the method might have partially influenced the results. The evaluation using periapical radiographic images used by several authors[6,14,17,26,60] is a two-dimensional view of the field and their interpretation can produce diagnostic errors, despite the standardization of image acquisition. Canal transportation could be better evaluated by means of computed tomography.[8,9,25,28,54,56,61,70] for producing three-dimensional images, as well as through a microscope[5,16,31,43,44,51] or a scanning electron microscope[64] for providing greater details of the cross sections and more accurate results of the actual anatomy of the root canal. However, the latter two methods are not used routinely for clinical evaluation in the dental office, which is done by periapical radiography with a good diagnostic reliability.[6,60]

Another factor that could have influenced the results for canal transportation is the great heterogeneity among the studies regarding the definition of the section of the root canal that was evaluated. Gergi et al[28] evaluated the parameter at 3, 9 and 15 mm from the apex, Mokhtari et al[8] and Ehsani et al[60] evaluated at 3, 6 and 9 mm and Kaptan et al[44] evaluated at 2, 5 and 8 mm from the apex. Celik et al[6] evaluated every millimeter from the apex (L1, L2, L3, L4, L5 and L6) and Nagaraja & Sreenivasa[70] evaluated nine different levels. Moreover, other studies have evaluated only the apical third. Despite this variation, there was a consensus among all the studies that the rotary instrumentation had superior results, with less canal transportation than the manual instrumentation. In summary, canal transportation appears to occur less frequently with the use of rotary instruments and periapical radiography is the most common endodontic evaluation method, which shows very similar results compared to other methods.

The studies that evaluated the ability of the instrument to remain centralized within the canal used image amplification and computed tomography as methods and employed root canals with 20-40° curvature[9,28,54] and a sample of upper second premolars.[54] The method used and tooth samples did not seem to affect the results, since none of the techniques showed perfect centralization. However, the rotary instrumentation was significantly more centralized in all thirds of the root canal than the manual instrumentation ($P< 0.05$).

The results demonstrated that rotary instrumentation caused a smaller change in the curvature angle than manual instrumentation. The number of instruments tested in a single study may affect the results, since the studies that found better results with a rotary instrument tested a maximum of four instruments, and the only study that presented different results included seven instruments in total. The type of tooth samples did not appear to influence the outcome, as studies used molar roots in general, except two studies that used maxillary second premolars[58] and lower incisors.[31] Other factors are the evaluation technique[12,74] and the method used, which in most cases was by periapical radiograph examination; one study used computed microtomography.[58]

Some studies[7,16,71] described loss of working length and two other studies[6,24] showed overinstrumentation. The evaluation method might have influenced the outcomes, since the three studies[6,24,71] that used periapical radiography showed some kind of alteration in working length with all included instruments, whether rotary or manual. On the other hand, the study by Dafalla et al[7] evaluated intracanal impressions through a stereoscopic microscope, and found loss of working length with a manual K-file instrument (23.5%) but not with a Profile rotary instrument. In the study by Weiger et al,[16] however, a Makroskop microscope was used, and a loss of working length was found with rotary instruments (Lightspeed and FlexMaster) and not with the manual instrument (NiTi K-files).

Regarding the amount of dentin removed, the outcomes seem to be affected by the type of sample, such as premolars with oval canals, straight roots or roots with curvatures < 10°,[29] and c-shaped mandibular molars.[10] Limongi et al[48] reported no difference between techniques (K-file and RaCe), but found different results when evaluating separately each third and each surface of mandibular incisors. Another factor that could affect

results is the evaluation method, as it seemed that a greater number of evaluated areas yielded more discrepant results.

Five studies[7,42,43,50,68] evaluated the amount of debris, 11 studies[13,22,23,47,53,55,59,64,65,67,72] evaluated amount of debris and generation of smear layer, and one study[63] evaluated only the smear layer generation. This parameter does not seem to be affected by method and sample: samples used were premolars,[7,68] mesiobuccal canals of mandibular molars with 10-20° curvatures,[43] >20º curvatures,[50] and mandibular central incisors with mesiodistally flattened root.[42] Methods used were microscopy and scanning electron microscopy. Root sections were evaluated by separate thirds or in apical thirds only. Four of the studies agreed that rotary instrumentation produced less debris compared to manual. However, Barbizam et al[42] showed greater cleaning with a manual instrument (K-file) than the Profile rotary instrument. Regarding the amount of debris and smear layer generation, eight studies[13,23,55,59,63-65,67] found that manual instrumentation had a better performance than different rotary systems. However, four of the studies[22,47,53,72] showed that rotary instrumentation resulted in less smear layer in the canal walls.

Non-instrumented surfaces were assessed by some authors. For studies that used single-rooted premolars with oval canals and mandibular molars with c-shaped canals, it was found that the manual H-file and K-file touched a larger area of the original canal than the rotary instrument ($P< 0.05$). Stavileci et al[58] presented an opposite result in maxillary premolars. Therefore, the different results found by Hilaly & Wanees,[29] which used a similar sample, seems to be influenced by the evaluation method, since Stavileci et al[58] evaluated all thirds of the root. Another study[68] evaluated all root thirds, and did not show significant differences; however the manual instrumentation with Hedstrom files showed better performance in the middle and coronal thirds, while the rotary instrument EndoWave showed a better performance in the apical third.

Dentin defects were reported in five studies,[27,33-35,62] four of which agreed that manual instrumentation did not cause any type of dentin defect while rotary instrumentation caused different defects in dentin. On the other hand, when different rotary instruments were evaluated, the ProTaper Universal caused more defects compared to other instruments (K3XF, K3 and Easy RaCe, GT, Profile and ProTaper Next). However, the study by Milani et al[62] found that manual instrumentation caused more dentin defects than ProTaper. This discrepancy does not seem to be influenced by the type of technique used for instrumentation, since the studies by Bier et al[27] and Cicek et al[33] used the balanced forces technique, while Milani et al[62] and Garg et al[34] used the step back technique, similar to Monga et al,[35] in addition to coronal enlargement. The factors that could have influenced the results were the type of sample and the sections evaluated. In the study by Milani et al,[62] the samples were lower incisors with no curvature, and this was the only study in which the teeth were sectioned at 3 mm beyond the cemento-enamel junction and dentin defects were evaluated at 3 and 6 mm from the apex. The other studies removed the crown of mandibular premolars and mesiobuccal canals of mandibular molars with mild and moderate curvature. All of these studies evaluated dentin defects at the 3, 6 and 9 mm level from the apex. Therefore, manual instrumentation can also cause dentin cracks, but more studies are needed to confirm these results.

Studies evaluating the shape of the cross-sections of the canal agreed that rotary instrumentation produced fewer irregular cross-sections than manual instrumentation. In the study by Ehsani et al,[60] the RaCe instrument showed better results than Mtwo in the coronal and middle thirds, and Mtwo showed better results in the apical third, without significant differences. The study by Guelzow et al[24] evaluated seven instruments: the ProTaper rotary system achieved better results than other instruments, followed by manual instrumentation. However, FlexMaster and K3 produced canal cross sections with more irregularities, as well as the GT Hero 642 system and RaCe. The LightSpeed rotary instrument produced round and oval root canals, and not elongated or irregular canals compared to manual instruments (with and without coronal enlargement). On the other hand, there were more irregular canals with manual K-files without prior coronal enlargement.[43] A prior coronal enlargement seems to provide better canal shaping after instrumentation, causing less irregular canals.

The results of this systematic review provide information on the wide variety of instruments used to prepare the root canal available in the market as well as their properties. In general, the rotary systems require less time compared to manual files for the preparation of root canals. Among other advantages, rotary instrumentation causes less canal transportation, has better centralization ability, produces less alterations of the canal curvature and less alterations in working length, has better debris cleaning ability, and produces more regular canal shapes than manual instrumentation. However, if the operator lacks adequate training, it can produce greater dentin removal and cause a greater amount of dentin defects, which could lead to root fractures in cases where the tooth has little residual dentin. On the other hand, manual instrumentation can be safer in relation to producing dentin defects, besides having a good cleaning capacity and producing less smear layer. Therefore, when choosing among different techniques it is important that the clinician is aware of the advantages and disadvantages of each one, in addition to following the manufacturers' instructions and considering the anatomy of the canal. Canal instrumentation of straight and single-rooted teeth is easier than teeth with severe curvatures, c-shaped or oval canals, which may require a combination of techniques. Therefore, to make the most out of the physical properties and root canal shaping abilities of rotary systems, operator training is imperative. Training is also important as it reduces instrumentation time, reducing fatigue for both the patient and the operator.

Due to the diversity in methodology and evaluated parameters of the studies included in this systematic review, there was significant heterogeneity in the results. Therefore, future studies should consider a greater standardization in the evaluation of parameters, in addition to exploring new technologies in endodontic instruments and materials. Moreover, to generate the best possible scientific evidence, randomized clinical trials should be carried out to help determine the most appropriate type of instrumentation technique for specific root canals.

In conclusion, the time required for instrumentation of root canals with rotary instruments was shorter than with manual

instruments, regardless of tooth type. The experience of the operator, however, had an important impact. Significantly better outcomes were also achieved with rotary systems regarding canal transportation, ability of the instrument to stay centralized in the canal, alteration of the canal curvature, and canal shape and smoothness. Manual instrumentation showed better performance regarding the amount of smear layer and debris, number of instrumented surfaces, and number of dentin defects. Both techniques provided similar results regarding the loss of working length and amount of removed and remaining dentin.

a. Biostat, Englewood, NJ, USA.
b. Dentsply Maillefer, Ballaigues, Switzerland.
c. Kerr, Romulus, MI, USA.
d. FKG Dentaire, La Chaux-de-Fonds, Switzerland.
e. Diadent, Almere, the Netherlands.
f. Mani, Matsutani Seisakusho Co., Takanezawa-Machi Tochigi-Ken, Japan.
g. Micro-Mega, Besançon Cedex, France.
h. Vereinigte Dentalwerke, VDW, Munich, Germany.
i. Antaeos, Munich, Germany.
j. Sjödings, Sendoline, Sweden.
k. Brasseler, Lemgo, Germany.
l. Morita, Osaka, Japan.
m. Dentsply Tulsa Dental Specialties, Tulsa, OK, USA.
n. Sybron Endo, Orange, CA, USA.
o. Kerr, San Diego, CA, USA.
p. Lightspeed Technology Inc., San Antonio, Texas, USA.
q. NT Sensor file, NT, Chattanooga, TN USA.
r. Sweden and Martina, Padua, Italy.
s. Neo Dental International Inc, Federal Way, WA, USA.

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