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REVIEW ARTICLE

Canal centering ability of various file systems during endodontic treatment and re-treatment: A systematic review

Pravin G Patil[1*], Kulvinder Singh Banga[2], Sachin Metkari[1], Komal Sheth[3], Sanpreet Singh Sachdev[4], Siddhesh Latke[5]

[1]Assistant Professor, Department of Conservative Dentistry & Endodontics, Nair Hospital Dental College

[2]Professor and Head of Department, Department of Conservative Dentistry & Endodontics, Nair Hospital Dental College

[3]Assistant Professor, Department of Conservative Dentistry & Endodontics, Nair Hospital Dental College

[4]Assistant Professor, Oral Pathology and Microbiology, Nair Hospital Dental College, Mumbai

[5]Assistant Professor, Department of Dentistry, HBT Medical College and Dr. R.N. Cooper Municipal General Hospital, Juhu, Mumbai

*pravinpatil54@yahoo.com

ABSTRACT

Introduction: The canal-centering ability of an endodontic file is the ability of a file to maintain its path centered through the root canal without causing transportation. Various researchers have attempted to compare the canal-centering ability of the different file systems used routinely in endodontic practice. The present systematic review aimed to comparatively analyze the canal-centering ability of the various endodontic file systems.

Methods: A systematic search was performed using the keywords 'Canal centering ability' and 'Endodontics' across the databases Medline, PubMed, PubMed Central, Web of Science Citation Index Expanded, and Google Scholar to identify studies related to canal-centering ability of various file systems in endodontic treatment or re-treatment in English language without any restriction for the date of publication.

Results: A total of 22 studies were identified, most of which utilized human extracted teeth for analyzing the canal-centering ability. The mesial root of the mandibular first molars was most commonly used, with the mesiobuccal canal being commonly chosen to compare the canal centering ability. No significant difference was found between the canal-centering ability of reciprocating and continuous rotary file systems. The individual conclusions regarding comparisons made between respective file systems in each study have been summarized in the text.

Conclusion: The canal-centering ability of various endodontic file systems does not depend on the speed or motion of the file but is a derivative of multiple factors including geometry, composition, size, and shape of the files. Findings from the present systematic review would serve as a guide for an appropriate selection of the files to be used in cases with challenging canal morphology requiring endodontic treatment.

Keywords: Root canal treatment; Canal transportation; Biomechanical preparation.

Introduction

The principle behind chemomechanical preparation in endodontic treatment is the elimination of bacteria in the pulpal canal and the preparation of the shape and form of the canal space to receive an obturating material. However, the outcome may not always be favorable and numerous complications can occur during instrumentation of the canal that may ultimately result in failure of the endodontic therapy[1]. These include canal transportation, apical zipping, canal ledges, strip perforations, and instrument separation, all of which tend to occur due to the complex anatomy of the canals and the tendency of the instruments to return to their original shape when deformed in the canal during instrumentation.

The presence of canals that are curved or those with complex anatomy is one of the most frequent causes of these procedural errors. The straightening of the endodontic file inside the curved canal leads to the formation of a ledge or even perforation in the dentinal walls which is termed 'canal transportation' (CT)[2]. The Glossary of Endodontic Terms of the American Association of Endodontists has defined CT as 'The removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation'[3]. A CT of more than 0.3 mm is said to have the capability of hampering the sealing ability of the obturation[4]. To minimize canal transportation, a file must deviate as minimum as possible from its original axis during instrumentation within the canal, which is referred to as its 'canal centering ability' (CCA)[5].

Curved canals are frequently encountered in routine endodontic practice and thus, modern file systems are focussing on improving the flexibility and CCA of the files. Various researchers have also attempted to compare the CCA of the different file systems used routinely in endodontic practice. It is important for dental practitioners to be well-versed with the properties of various file systems available so that they can optimize their armamentarium according to the challenge posed in each particular case. An appropriate selection of the file systems will minimize complications and lead to a favorable clinical outcome of the endodontic procedure[6].

In this context, the present systematic review aimed to comparatively analyze the CCA of the various endodontic file systems. The review has an objective to determine the file systems suitable for instrumentation in canals with curved or complex anatomy. Yet another objective of the review is to determine whether factors related to endodontic files such as the number of files in a system, taper, and different motions including reciprocating and rotary, affect their CCA.

Material and Methods:

A systematic search was performed across the databases Medline (Ovid), PubMed, PubMed Central, Web of Science Citation Index Expanded, (SCIEXPANDED), and Google Scholar to identify studies related to CCA of various file systems in endodontic treatment or re-treatment. The keywords used were 'Canal centering ability' and 'Endodontics'. Articles published in the English language without any restriction for the time of publication were included.

Studies comparing the canal centering ability during biomechanical preparation of the canal or retreatment by different endodontic file systems in extracted human teeth or resin blocks were included in the present systematic review. Studies with ambiguity regarding the details of the samples used, those not incorporating the biomechanical preparation of the canals in extracted teeth or simulated models, not assessing the canal centering ability of the endodontic file systems. or not comparing the canal centering ability of two endodontic file systems were excluded from the review. Only cross-sectional studies, in-vitro studies were included while animal-based studies, review articles, case reports and case series were excluded from the review. The process of selection of articles in the present systematic review is delineated in Figure 1.

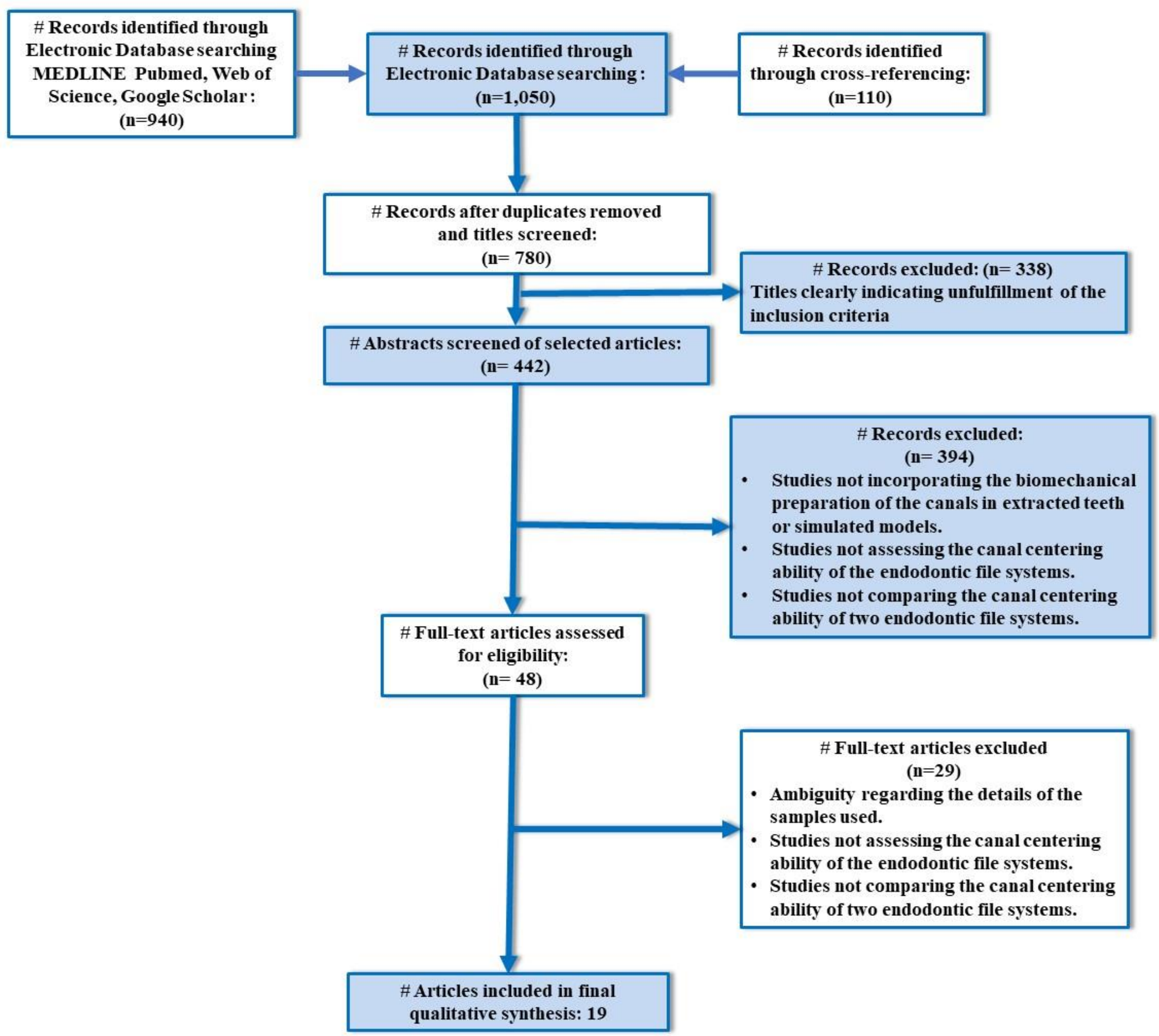

Figure 1: PRISMA Flow diagram indicating the selection process of the articles in the present systematic review.

DATA EXTRACTION:

The data were extracted in an MS Excel Worksheet which included the author and year of publication, type of study, characteristics of the sample such as tooth used and the canal prepared, the curvature of the canal, different file systems used to prepare the canals between which the comparison was made, preparation and irrigation protocols, analysis. The data was only qualitatively synthesized with respect to superiority in the canal centering ability when the various file systems were compared by the authors of different studies included in the present systematic review.

RISK OF BIAS ASSESSMENT:

The methodological quality among included studies was executed by using Cochrane collaboration risk of bias (ROB) -2 tool. The tool has various domains like random sequence generation (selection bias), allocation concealment (selection bias), blinding of personnel and equipments (performance bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias) and other biases through their signalling questions in Review Manager (RevMan) 5.3 software. The overall risk for individual studies was assessed as low, moderate or high risk based on domains and criteria. The study was assessed to have a low overall risk only if all domains were found to have low risk. High overall risk was assessed if one or more of the six domains were found to be at high risk. A moderate risk assessment was provided to studies when one or more domains were found to be uncertain, with none at high risk.

Results:

A total of 22 studies were identified the earliest of which was conducted by Yamamura et al. in 2012 and the latest by Varma et al. in March 2023[7-29]. The sample size of the studies ranged from 16 to 125 with most of the studies having sample sizes in the range of 30 to 40. Regarding the teeth used as samples, both mandibular first and second molars were used in n=8 studies, only mandibular first molars were used in n=7 studies; mandibular premolars having a single canal were used in n=3 studies, and maxillary molars were used in n=2 studies. Only one study conducted by Silva et al. in 2018 comprised 43 resin blocks that simulated root canals[15].

In n=6 studies, only the mesiobuccal canal was used to assess the CCA, while in other n=6 studies, both mesial canals were taken into consideration. Only one study by Khandelwal et al. in 2020 assessed the CCA of the files in the distal canals of mandibular first molars[19]. The studies utilizing premolars ensured that the teeth had only a single canal. The degree of curvature of the canals ranged from 10^{o} to 40^{o} with 20^{o} -30^{o} being common across almost all the studies. The initial preparation was performed to a file size ranging from 20 to 30 with varying degrees of taper; however, 25.08 was the most frequent setting.

The data extracted from all the studies included in the present systematic review including the various file systems used for comparison of their respective CCAs are summarized in Table 1. Sodium hypochlorite was the most common irrigant used during instrumentation across n=17 studies, while EDTA was used as an adjunct irrigant in n=10 studies; normal saline was used in n=3 studies, and distilled water in n=2 studies for irrigation. The concentration of sodium hypochlorite ranged from 1 to 6% across all the studies, with the concentration of 2.5% being the most commonly used (n=9 studies).

Almost all the studies (n=15) evaluated the CCA by means of Cone beam computed tomography (CBCT) while n=4 studies used micro-CT. One study each used digital microscopy (with dye) and a photographic method for the evaluation of CCA respectively.

Table 1: Summarization of the data extracted from the articles included in the present systematic review

Sr. No.	Author	Year	Sample size	Tooth	Canal	Curvature	Comparison	Instrumentation upto working length	Irrigation	Analysis by	Conclusive remarks	Ethical
1	Yamamura	2012	16	Mandibular molars	NP	20-30°	Vortex and Endo-sequence	30.04	6% hypo	micro-CT	Vortex > Endosequence	NP
2	Moghadam	2014	40	Mandibular and Maxillary molars	Mesiobuccal	15 to 30°	Twisted file and RCB	25.08	Normal saline and 5.25% hypo	CBCT	Apical third: RCB > Twisted	NP
3	Gogulnath	2015	90	Mandibular first molars	Mesiobuccal	20 to 40°	ProTaper retreatment, Mtwo R and Rendo	NP	2.5% hypo + 17% EDTA	CBCT	PTN > MTwo-R = R-Endo	NP
3	Bedier	2017	30	Mandibular 1st and 2nd molars	NP	25-40°	Neoniti and WaveOne	25.08 with 350-500 rpm and 1.5 N.cm torque	2.5% hypo	CBCT	NeoNiTi = WaveOne	NP
4	Anabarasu	2018	125	Maxillary first molars	NP	10 to 20°	Hyflex EDM, OneShape, WOG, RCB	NP	3% hypo + 17% EDTA	CBCT	Coronal third: OneShape > Hyflex = WOG = Reciproc Middle and apical third: WOG > Oneshape = Hyflex = RCB	Obtained

5	Delgoshayi	2018	30	Mandibular first molars	NP	20 to 40°	ProTaper and SafeSider	NP	2.5% hypo	CBCT	Protraper > Safesider	NP
6	Hasheminia	2018	30	Mandibular first molars	NP	15 to 30°	Reciproc, WaveOne, and EdgeFile	NP	NP	CBCT	EdgeFile > WOG > Reciproc	NP
7	Silva	2018	43	blocks of simulated resin canals	NP	40°	Reciproc Blue, WaveOne Gold and ProTaper Next	NP	Distilled water	Methylene blue dye and Handheld Digital Microscope	RCB > WOG > PTN	NP
8	Albuquerque	2019	40	Mandibular molars	Mesial	20 to 40°	protaper next, wave one gold, prodesign logic, and vortex blue	NP	2.5% hypo + 17% EDTA	micro-CT	Apical Third: LOG > PTN=WOG=Vortex Middle and Coronal third: Vortex>PTN=WOG>LOG	Obtained
9	Arruda	2019	40	Mandibular molars	Mesial	30°	ProTaper Universal system, Reciproc, ProTaper Next system	Protaper F1 (20.07).	2.5% hypo + 17% EDTA	CBCT	PTN (X2) > PTU > RCB > PTN (X3)	Obtained
10	Aydin	2019	24	Mandibular first molars	Mesial	10-20°	WOG, ProGlider and R-Pilot	NP	17% EDTA, 6% hypo, and distilled water	micro-CT	WOG = R-Pilot > ProGlider	Obtained
11	Khandelwal	2020	24	Mandibular first molars	Distal	15-30°	EndoSequence Reciprocating and WaveOne Gold	NP	NP	CBCT	EndoSequence > WOG	NP
12	Mishra	2020	40	Mandibular first molars	Mesiobuccal	25-35°	Wave One Gold and OneShape	NP	2.5% hypo	CBCT	WOG > OneShape	NP

13	Kabil	2021	50	Maxillary Molars	Mesiobuccal	25-40°	ProTaper Next, Reciproc Blue, TruNatomy, XP-Endo Shaper	20.02	2.5% hypo + 15% EDTA	Micro-CT	PTN = RCB = TruNatomy = XP-Endo Shaper	Obtained
14	Panithini	2021	30	Mandibular premolars	Single root	NP	PTN, TruNatomy and NeoNiTi.	25.06	3% hypo + 17% EDTA + 0.9% normal saline	CBCT	PTN = TruNatomy = NeoNiTi.	NP
15	Mustafa	2021	100	Mandibular molars	Mesial	25 to 30°	RaceEvo, R-Motion, Reciproc Blue, and ProTaper Gold NiTi Rotary File Systems	NP	5% Hypo + 17% EDTA	CBCT	R-Motion > RCB = RaceEvo > Protaper Gold	Obtained
16	Shojaeian	2021	30	Mandibular molars	Mesiobuccal	20 to 40°	EdgeGlidePath, One-G, and Neolix files	NP	1% hypo + 17% EDTA	CBCT	EdgeGlide Path = One-G = Neolix	Obtained
17	Aggarwal	2022	80	Mandibular first molars	Mesiobuccal	15 to 30°	Reciproc, OneShape and WaveOne	NP	2.5% saline and 3% hypo	CBCT	OneShape > WOG > RCB	NP
18	Çiftçioğlu	2022	120	Mandibular molars	Mesial	30 to 40°	PTU , HeroShaper, ProTaperRetreatment and R-Endo	30.04	5% hypo	Photographic method	PTU = HeroShaper = Protaper Re-treatment = R-Endo	NP
19	Suzuki	2022	54	Mandibular molars	Mesial	NP	WaveOne Gold system, ProTaper Next system; and ProTaper Universal	NP	2.5% hypo + 17% EDTA	CBCT	PTN > PTU > WOG	Obtained
20	Varma	2022	40	Mandibular premolars	Single canal	NP	M two R, Neoniti and WaveOne Gold	NP	NP	CBCT	Mtwo-R = NeoNiTi = WOG.	NP
21	Varma	2023	33	Mandibular premolars	Single canal	NP	Pro Taper Universal, Mtwo R, and XP endoshaper	25.08	NP	CBCT	XP endo shaper > Mtwo R > PTU	NP

All the included studies were largely comparable in methodological quality. All the included studies had moderate to high risk of bias with all the respected domains. The highest risk of bias was seen for allocation concealment (selection bias) followed by blinding of participants and personnel (performance bias). Among the included studies, Silva et al. 2018 had the high risk of bias compared to all other studies. Aggarwal et al 2022 reported the lowest risk of bias. Domains of random sequence generation (selection bias), selective reporting (reporting bias), and other biases were given the lowest risk of bias by included studies as shown in Figure 2.

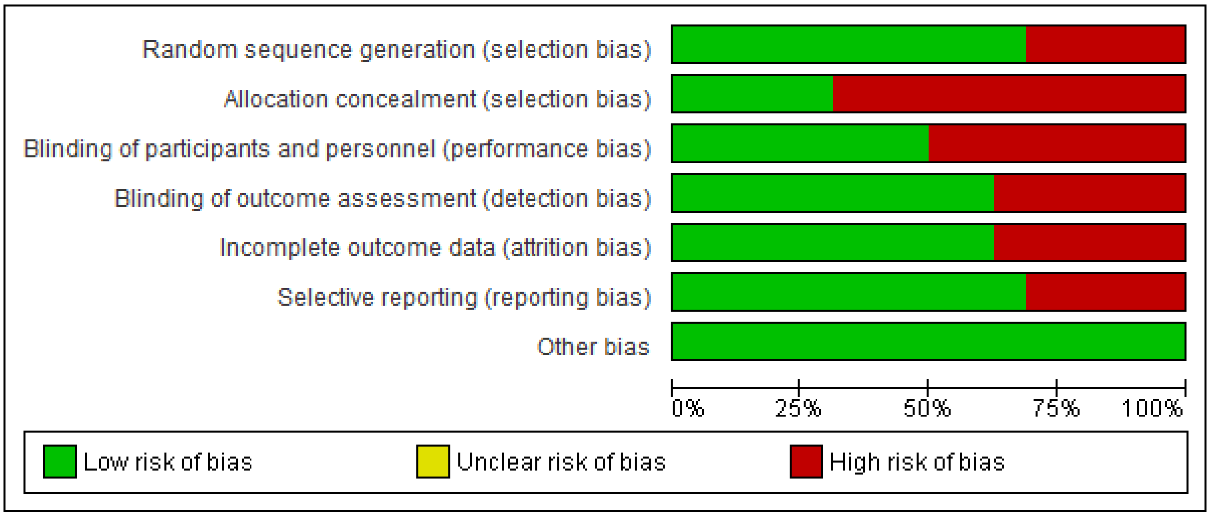

Figure 2: Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies.

Discussion:

While analyzing the CCA is possible in vivo, there would be difficulty in accurately visualizing the canal owing to the overlap of cortical plates. Additionally, there would be an ethical concern about exposing the patients to unwarranted radiation. Thus, analyzing the CCA is rationally more feasible in in-vitro study designs. Extracted teeth are most commonly used for assessment owing to their ease of procuring and availability[30], which was corroborated by our finding that 21 out of 22 studies utilized extracted teeth as their samples to analyze the CCA. While the extracted teeth create the scenario closest to that occurring under normal clinical conditions, there is still a limitation to their use. Different teeth may have different-sized canals, apical patency, compatibility with instruments, and curvatures even though the canal selected may be the same for all the cases[8].

Another popular method to simulate root canals to evaluate canal preparation is the use of resin blocks. These blocks can be prepared with canals having identical standardized morphology and dimensions[8,15]. This eliminates the outcome modifiers, standardizes the research, and adds to the credibility of the experimental model. The resin blocks offer the advantage of high reproducibility and calibration of the experimental settings. Only one study included in the present review used resin blocks as samples to simulate the root canals and evaluate their preparation by various file systems[15].

Even so, a cautionary drawback for the use of resin blocks is that their mechanical properties vastly differ from those of the dentin of a natural tooth. Thus, the preparation of the canals in resin blocks does not as closely reflect the preparation in the clinical scenario owing to the differences in the microhardness and surface texture of resin and dentin. The microhardness of dentin has been found to be about twice the value of resin blocks, thus, requiring double force to prepare the canals which generates higher internal stresses in the files being used in the former[8]. The larger particle size of the resins and the dry, coarse texture of the material interfere with the insertion and biomechanical preparatory action of the endodontic files[14,31]. Therefore, each type of sample has its own advantages and limitations and their use is open up to the researcher's judgment.

Mandibular molars are most frequently encountered with deep caries in routine clinical practice. The narrow canals of these teeth often exhibit significant curvature or are atretic which increases the difficulty of root canal treatment[32]. Such teeth would serve as the best models for assessing the CCA and were, therefore, preferred by most authors. The mesial roots of mandibular molars having two canals were selected for studies in order to maintain uniformity of the samples while comparing the CCA of two file systems (one in each canal) in n=6 studies. To reduce the variation even more, n=6 studies analyzed the CCA of different file systems in only the mesiobuccal canal of each tooth. While using both canals for comparing the CCA of different file systems offers the advantage of requiring fewer teeth, using the same canal minimizes various confounding factors and modifiers such as canal curvature, diameter, or apical opening that could possibly influence the outcome.

The studies utilizing premolars ensured that the selected teeth were single-rooted having single root canals. An advantage of using premolars is that they are frequently extracted for orthodontic purposes and are thus, obtained relatively easily[33]. Utilizing premolars as samples would be less preferred as they are less frequently encountered with irreversible pulpitis as compared to the molars. Furthermore, they tend to show a wide variation in the canal anatomy which would reduce the validity of the findings of a study[34].

It is generally the apical third of the canal that exhibits the most curvature and therefore, most of the instrument separations occur in this region[35]. There occurs a non-uniform distribution of stresses and higher forces are generated in the external surface of the curve where the instrument contacts with the canal[36]. It would only be rational to test for the CCA of file systems in the regions of most curvature in canals having an adequately challenging curvature in the first place. Thus, the researchers selected teeth with severe curvature (>20°) as dictated by Schneider's classification[37]. The CCA was studied at the apical region and at distances of 3mm to 9mm from the apex that represents the apical, middle, and cervical thirds of the canal where elbows, zips, or strip perforations tend to occur[38].

It is essential to know in-depth the root canal geometry prior to instrumentation in studies analyzing the effects of preparation techniques or instruments on the anatomy of a root canal. These parameters influence the changes caused during instrumentation more than the technique itself[39]. Conventional cross-sectioning of canals that allows direct observation of its shape under the microscope cannot be performed as it would require sectioning of the tooth and render it unsuitable for further procedures. Various other imaging methods to study canal morphology have been developed over time which include Bramante's method, longitudinal clearing of teeth, high-resolution computer tomography, cone-beam computed tomography (CBCT), and micro-computed tomography (micro-CT)[13].

Bramante's technique is the simplest and most inexpensive technique that derives analysis of the CCA by reassembly of the cross-sectional images taken from embedded roots in the muffle[40]. The pre-operative and post-operative photographs are superimposed on a computer followed by requisite measurements[41].

The CCA can be determined by radiographic imaging methods by two techniques. Pre-operative photographs of the canal can be superimposed on the post-operative ones at three different levels to determine the alterations in the canal path[13,42]. Another method involves measuring the distance between the external root surface and the inner wall of the canal at the mesial and distal aspects at three different levels at the pre-and post-operative intervals[13,43]. CBCT is the most-preferred imaging modality that provides high-resolution details of the canal in three dimensions in a non-invasive manner. It does not require damaging the samples and its low radiation poses less harm to the researcher[44].

Micro-CT has gained popularity over recent times for imaging of root canal systems across studies analyzing the root canal anatomy. It generates accurate, high-resolution, and fully quantitative data, allowing for easy 3D assessment of the root canal system along with measurement of canal changes, and avoids the potential of a radiographic or photographic transfer error[45,46]. The only major drawback of using these advanced imaging modalities is that they are time-consuming, and require expensive equipment and technical skills on the part of the researcher for three-dimensional reconstructions and measurement. Additionally, they require vast amounts of computational power for data analysis and storage space to store the derived results[26].

A multitude of file systems were compared across the various studies included in the present systematic review. The continuous rotary files included Vortex, endosequence, twister, protaper, neoniti. R-endo, m-two r, Hyflex, OneShape, HeroShaper, Protaper gold niti, Protaper Universal, Protaper Next, Safesider, Edgefile, Prodesign logic, Vortex, Proglider, OneG Neolix, Edge glidepath, XP Endo Shaper, RaceEvo, TruNatomy. On the other hand, only four reciprocating file systems were used which included Reciproc Blue, WaveOne Gold, R-Pilot, and R-Motion, with the former two being the most commonly used (n=11 and n=8 studies respectively).

Whether the motion of the files has any influence on the CCA is yet unclear owing to the contrasting evidence present in the literature. Kabil et al. reported that reciprocating instruments result in more canal transportation and less centered preparations when compared to certain rotary files in the middle third[21]. Other researchers have found reciprocating files to have better CCA as compared to the continuous rotary file systems which are suggested to be due to the reciprocating movement that disengages files from any taper lock occurring within the canal leading to reduced torsional and flexural stresses[47,48]. Several studies included in the present review have not found any significant difference between the two stating that it is highly likely that CCA is not influenced significantly by the motion of files but rather depends on its design, flexibility, and type of constituent metals.

It has been demonstrated that the canals must be instrumented to size 30/.04 to allow the irrigant to adequately clean the apical third of the root[49]. In accordance with the statement, the researchers performed initial preparation of the canal upto file size ranging from 20 to 30 with varying degrees of taper. Size 25 was the most common with varying taper of 25.04, 25.06, or 25.08. As for the irrigant, sodium hypochlorite is most commonly used in routine clinical practice with or without adjunctive 17% EDTA[50]. To closely mimic the clinical scenario, sodium hypochlorite was used as the irrigant in 80% of the studies, and 17% EDTA was used as an adjunct in about 60% of these studies. In practice, sodium hypochlorite is used in concentrations varying from 0.5 to 5%. Likewise, the concentration of sodium hypochlorite ranged from 1 to 6% across all the studies, with the concentration of 2.5% being the most commonly used.

Although all the studies included had in-vitro designs, it is still important to obtain ethical clearance[51]. However, only n=8 out of the 21 studies obtained ethical clearance from their respective committees, while the remainder did not mention any details about the same. This raises some concerns regarding the ethical considerations of the studies. The teeth with canal calcification, tortuous canals, cracks/fractures, and internal and external resorption can possibly confound the measured CCA[52]. Therefore, meticulous visual inspection of the teeth for fractures, fissures, or cracks should be performed under a surgical operating microscope in studies analyzing canal geometry which was, however, not performed in any of the studies included in the present review.

A limitation of the study is that since the different studies compared different file systems and used different canals of different teeth or used resin blocks that had properties differing from those of normal teeth, a thorough meta-analysis of the data could not be performed. The conclusive findings concerning the comparisons reported by the authors could only be produced assertively and these findings have been summarized in Table 1. Caution is advised to compare two studies using similar file systems but different study designs. Nevertheless, data presented in the systematic review can serve to guide clinicians and researchers in selecting the appropriate file systems in the future.

Conclusion:

The CCA of various endodontic file systems does not depend on the speed or motion of the file but is a derivative of multiple factors including geometry, composition, size, and shape of the files. Time and time, these factors have been modified in an attempt to improve the CCA of the file systems which would ultimately minimize the transportation caused in the routine clinical scenario. In this aspect, findings from the present systematic review would serve as a guide for an appropriate selection of the files to be used in cases with challenging canal morphology requiring endodontic treatment.

Conflicts of Interest Statement:

The authors have no conflicts of interest to declare. The authors are solely responsible for the content and writing of the paper. The authors have no affiliation with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

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References:

1. Tabassum S, Khan FR. Failure of endodontic treatment: The usual suspects. Eur J Dent. 2016;10(01):144-7.

2. Poly A, AlMalki F, Marques F, Karabucak B. Canal transportation and centering ratio after preparation in severely curved canals: analysis by micro-computed tomography and double-digital radiography. Clin Oral Investig. 2019; 23:4255-62.

3. American Association of Endodontists. Glossary of Endodontic Terms, 7th edn. Chicago: AAE, 2003.

4. Wu MK, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. J Endod. 2000;26:210-6.

5. Kandaswamy D, Venkateshbabu N, Porkodi I, Pradeep G. Canal-centering ability: An endodontic challenge. J Conserv Dent. 2009;12(1):3.

6. Jafarzadeh H, Abbott PV. Ledge formation: review of a great challenge in endodontics. J Endod. 2007;33(10):1155-62.

7. Yamamura B, Cox TC, Heddaya B, Flake NM, Johnson JD, Paranjpe A. Comparing canal transportation and centering ability of EndoSequence and Vortex rotary files by using Micro–Computed Tomography. J Endod. 2012;38(8):1121-5.

8. Khalilak Z, Fallahdoost A, Dadresanfar B, Rezvani G. Comparison of extracted teeth and simulated resin blocks on apical canal transportation. Iran Endod J 2008;3:109.

9. Moghadam NK, Shahab SH, Rostami G. Canal Transportation and Centering Ability of Twisted File and Reciproc: A Cone-Beam Computed Tomography Assessment. Iran Endod J. 2014;9(3):174-9.

10. Gogulnath D, Rajan RM, Arathy G, Kandaswamy D. A comparative evaluation of the canal centering ability of three rotary nickel-titanium retreatment systems in the mesio-buccal canals of mandibular first molars using computed tomography. J Conserv Dent. 2015;18(4):310.

11. Bedier MM, Abu El-Dahab O. Cone Beam Computed Tomographic Evaluation Of Root Canal Transportation And Centering Ability Using Rotary And Reciprocating Systems. Egypt Dent J. 2017;63(2):1913-22.

12. Anbarasu S. Comparative CBCT evaluation of dentinal crack formation, canal centering ability and apical transportation of hyflex-edm, oneshape, wave-one gold and reciproc files: An In Vitro study (Doctoral dissertation, Tamilnadu Government Dental College and Hospital, Chennai).

13. Delgoshayi N, Abbasi M, Bakhtiar H, Sakhdari S, Ghannad S, Ellini MR. Canal transportation and centering ability of ProTaper and SafeSider in preparation of curved root canals: A CBCT evaluation. Iran Endod J. 2018;13(2):240.

14. Hasheminia SM, Farhad A, Sheikhi M, Soltani P, Hendi SS, Ahmadi M. Cone-beam computed tomographic analysis of canal transportation and centering ability of single-file systems. J Endod. 2018;44(12):1788-91.

15. Silva PF, Coelho E, Alves NC, Silva SA, Pereira FC, Albuquerque DS. Canal transportation and centering ability of reciproc blue, waveone gold and protaper next in simulated curved canals. Iran Endod J. 2018;13(4):498.

16. de Albuquerque MS, Nascimento AS, Gialain IO, de Lima EA, Nery JA, de Souza Araujo PR, de Menezes RF, Kato AS, Braz R. Canal transportation, centering ability, and dentin removal after instrumentation: a micro-CT evaluation. J Contemp Dent Pract. 2019;20(7):806-11.

17. da Silva Arruda E, Sponchiado-Júnior EC, Pandolfo MT, de Carvalho Fredson MA, Garcia LD, Marques AA. Apical transportation and centering ability after root canal filling removal using reciprocating and continuous rotary systems: a CBCT study. Eur J Dent. 2019;13(04):613-8.

18. Aydın ZU, Keskin NB, Özyürek T, Geneci F, Ocak M, Çelik HH. Microcomputed assessment of transportation, centering ratio, canal area, and volume increase after single-file rotary and reciprocating glide path instrumentation in curved root canals: a laboratory study. J Endod. 2019;45(6):791-6.

19. Khandelwal A, Palanivelu A. Comparative evaluation of canal transportation and centering ability of WaveOne Gold and EndoSequence Reciprocating File systems using conebeam computed tomography. Drug Invent Today. 2020;13(2):1-5.

20. Mishra P, Sneha, Sahu Y, Malik R, Agrawal R, Mishra PK. Evaluation of Canal Transportation and centering ability of two different single file systems in combination with and without glide path technique using Cone Beam Computer Tomography: In Vitro Study. J Adv Med Dent Scie Res. 2020;8(8):127-132.

21. Kabil E, Katić M, Anić I, Bago I. Micro–computed Evaluation of Canal Transportation and Centering Ability of 5 Rotary and Reciprocating Systems with Different Metallurgical Properties and Surface Treatments in Curved Root Canals. J Endod. 2021;47(3):477-84.

22. Panithini DB, Kumar SRM, Sajjan GS, Varma MK, Satish KR, Madhavi K. A Comparative Evaluation of Canal Transportation and Centering Ability of Three Different Ni-Ti File Systems –An In Vitro CBCT Study. Open J Dent Oral Med. 2021;9(1):7-13

23. Mustafa M. Comparative Evaluation of Canal-shaping Abilities of RaceEvo, R-Motion, Reciproc Blue, and ProTaper Gold NiTi Rotary File Systems: A CBCT Study. Dent Pract. 2021;22(12):1406-12.

24. Shojaeian S, Mortezapour N, Soltaninejad F, Zargar N, Zandi B, Shantiaee Y, Bidaki A. Comparison of Canal Transportation and Centering Ability of One-G, EdgeGlidePath, and Neolix: A MicroComputed Tomography Study of Curved Root Canals. Int J Dent. 2021; 2021.

25. Aggarwal R, Aggarwal R, Aggarwal A. Evaluation of Canal Transportation and Centering Ability of Three Single File Systems. Eur J Mol Clin Med. 2022;9(3):5256-62.

26. Çiftçioğlu E, Küçükay ES. Comparative evaluation of canal transportation and centering ability of various Ni-Ti rotary systems in retreatment of curved root canals. Selcuk Dent J. 2022;9(2):385-93.

27. Suzuki EH, Sponchiado-Júnior EC, Pandolfo MT, Garcia LD, Carvalho FM, Marques AA. Shaping Ability of Reciprocating and Rotary Systems After Root Canal Retreatment: a CBCT Study. Braz Dent J. 2022;33:12-21.

28. Varma KM, Dinesh JS, Sowmya M, Kishore KN, Manthena SR, Varma P. A Multi-Dimensional Analysis of Root Canal Transportation and Centering Ability of Three

Single File Retreatment Systems: A CBCT Study. Trends Biomater Artif Organs. 2022;36(2).

29. Varma KM, Rajulapati KS, Sajjan GS, Varma KM, Devi MU, Alla RK. A Comparative Evaluation of Canal Transportation and Centering Ability with Three Different Retreatment File Systems–An In vitro CBCT Study. Uttar Pradesh J Zool. 2023;44(4):76-84.

30. DeWald JP. The use of extracted teeth for in vitro bonding studies: a review of infection control considerations. Dent Mater. 1997 Mar 1;13(2):74-81.

31. Orel L, Velea-Barta OA, Nica LM, Boscornea-Pușcu AS, Horhat RM, Talpos-Niculescu RM, et al. Evaluation of the shaping ability of three thermally treated nickel–titanium endodontic instruments on standardized 3D-printed dental replicas using cone-beam computed tomography. Medicina. 2021;57(9):901.

32. Hartmann RC, Peters OA, De Figueiredo JA, Rossi-Fedele G. Association of manual or engine-driven glide path preparation with canal centring and apical transportation: a systematic review. Int Endod J. 2018;51(11):1239-52.

33. Mahtani A, Jain RK. Frequency of premolar teeth extractions for orthodontic treatment. Bioinformation. 2020;16(12):1080.

34. Baroudi K, Kazkaz M, Sakka S, Tarakji B. Morphology of root canals in lower human premolars. Niger Med J. 2012;53(4):206-9.

35. Ansari I, Maria R. Managing curved canals. Contemp Clin Dent. 2012;3(2):237.

36. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod. 2004;30(8):559-67.

37. Kosturkov D, Radeva E, Uzunov T. Digital Determination of Curvature of Root Canals of Extracted Teeth. Acta Medica Bulgarica.; 47(1):32-5.

38. Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. J Am Dent Assoc. 1980; 101:792-794.

39. Peters OA, Laib A, Ruegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry by high-resolution computed tomography. J Dent Res.2000; 79:1405–9.

40. Bramante CM, Berbert A, Borges RP. A methodology for evaluation of root canal instrumentation. J Endod. 1987:243-5.

41. Eliasz W, Czarnecka B, Surdacka A. Apical extrusion of debris during root canal preparation with protaper next, waveone gold and twisted files. Materials. 2021;14(21):6254.

42. Kaya S, Yigit Ozer S, Adiguzel O, Orucoglu H, Deger Y, Tumen EC, Uysal I. Comparison of apical microleakage of dual-curing resin cements with fluid-filtration and dye extraction techniques. Med Sci Monit. 2015;21:937-44.

43. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996;22(7):369-75.

44. Tsiklakis K, Donta C, Gavala S, Karayianni K, Kamenopoulou V, Hourdakis CJ. Dose reduction in maxillofacial imaging using low dose Cone Beam CT. Eur J Radiol. 2005;56(3):413-7.

45. Peters OA, Paque F. Root canal preparation of maxillary molars with the self-

adjusting file: a micro-computed tomography study. J Endod. 2011;37:53–7.

46. Paque F, Peters OA. Micro-computed tomography evaluation of the preparation of long oval root canals in mandibular molars with the self-adjusting file. J Endod. 2011;37:517–21.

47. Alapati SB, Brantley WA, Iijima M, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod. 2009;35:1589–93.

48. Gao Y, Gutmann JL, Wilkinson K, Maxwell R, Ammon D. Evaluation of the impact of raw materials on the fatigue and mechanical properties of ProFile Vortex rotary instruments. J Endod. 2012;38:398–401.

49. Khademi A, Yazdizadeh M, Feizianfard M. Determination of the minimum instrumentation size for penetration of irrigants to the apical third of root canal systems. J Endod. 2006;32:417–20.

50. Iqbal A. Antimicrobial irrigants in the endodontic therapy. Int J Health Sci. 2012;6(2):186.

51. Kıraç FS. Is ethics approval necessary for all trials? A clear but not certain process. Mol Imaging Radionucl Ther. 2013;22(3):73.

52. Ali A, Saraf P, Kamatagi L, Khasnis S. Comparative assessment of canal transportation, dentin loss, and remaining root filling material by different retreatment files An in vitro cross-sectional study. Contemp Clin Dent. 2021;12(1):14.