INSTITUTO UNIVERSITÁRIO EGAS MONIZ

MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

METHODS USED TO EVALUATE SHAPING ABILITY OF ROTARY ENDODONTIC FILES – STATE OF THE ART

Trabalho submetido por

Ranya Elemam

para a obtenção do grau de Mestre em Medicina Dentária.

Setembro de 2021

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Trabalho orientado por

Prof. Doutora Ana Mano Azul

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DEDICATION

To my beloved family for their everlasting love, support, encouragement, and continuous prayers.

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RESUMO

O objetivo deste projeto é efetuar uma revisão da literatura científica acerca da capacidade de preparação das limas rotatórias, para responder à seguinte questão:

Qual a melhor técnica, com base nos parâmetros de capacidade de transporte e centralização, para avaliar a capacidade de preparação de limas rotatórias?

A pesquisa foi realizada nas bases de dados PubMed, MEDLINE, Embase, ScienceDirect, Scopus e B-on. Estudos publicados em inglês de janeiro de 2010 a fevereiro de 2021, que especificavam a capacidade de centralização e a capacidade de modelagem das limas rotativas, foram incluídos.

65 estudos foram incluídos na revisão de uma amostra cumulativa de 615 estudos. 48 estudos usaram dentes extraídos, enquanto 17 estudos usaram canais radiculares simulados em blocos de resina. 38 estudos usaram tomografia micro-computadorizada e tomografia computadorizada de feixe cónico (MCT+CBCT), enquanto 26 estudos usaram imagens digitais duplas (DDIR+DDIP) e análise de *software*, e apenas um usou radiografia e MCT.

A capacidade de conformação da instrumentação do canal radicular torna-se essencial com a introdução de novos instrumentos no mercado. O método MCT e os seus tipos inovadores tornam-se superiores na avaliação da qualidade da instrumentação do canal radicular, uma vez que podem fornecer imagens tridimensionais.

PALAVRAS-CHAVE: preparação do canal radicular; transporte do canal, Capacidade de Centralização, Capacidade de modelagem, Níquel-Titânio, Rotativo.

ABSTRACT

The aim of this project is to review and analyze the literature that studied the shaping ability of endodontic rotary files to answer the question: What is the most accurate method used to assess the shaping ability of rotary endodontic files based on the canal transportation and centering ability parameters?

Search was performed using PubMed, MEDLINE, Embase, ScienceDirect, Scopus, e B-on databases. Studies published in English from January 2010 to February 2021, that specified centering ability and shaping ability of the rotary files, were included.

65 studies were included in the review from a cumulative sample of 615 studies. 48 studies used extracted teeth, while 17 studies used simulated root canals in resin blocks. 38 studies used Micro-Computed Tomography and Cone-Beam Computed Tomography (MCT+CBCT) while 26 studies used Double Digital Images Radiographs / Photographs (DDIR+DDIP) and software analysis, and only one used both DDIR and MCT.

Shaping ability of the root canal instrumentation becomes essential with the introduction of new instruments to the market. MCT method and its breakthrough types become superior in evaluating the quality of root canal instrumentation since they can provide 3-dimentional picture.

KEYWORDS: Root canal preparation, Canal transportation, Centering ability, Shaping ability, Nickel-Titanium, Rotary.

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LIST OF ACRONYMS

CAD	Computer-Aided Design
CBCT	Cone-Beam Computed Tomography
CM	Controlled Memory
CT	Computed Tomography
D	Deviation
2D	2 Dimensions
3D	3 Dimensions
DDIP	Double Digital Images Photographs
DDIR	Double Digital Images Radiographs
HF	HyFlex
IR	IRace
MCT	Micro-Computed Tomography
Mm	Millimeter
M-Wire	Martensitic-Wire
NCM	Newton Centimeter
NITI	Nickle Titanium
RPM	Revolutions Per Minute
PTN	ProTaper Next
PTU	ProTaper Universal
R-Phase	Rhombohedral phase
SAF	Self-Adjusting File

1 INTRODUCTION

The main objective of endodontic treatment is to remove micro-organisms, necrotic pulp tissue debris, well shape and prepare the root canal system in order to allow the entrance of irrigation and to place medications and obturation materials (1).

1.1 Endodontic Background

Bacteria and their by-products are major etiological factors in the initiation and progression of pulpal inflammation and apical periodontitis (2). Therefore, a vital objective of root canal treatment is the removal of bacteria and their substrates from the root canal system. Prevention or treatment of apical periodontitis is the major purpose of root canal procedure so that the periradicular tissues are not vulnerable to attack from microbes within the tooth (3). Mechanical preparation in endodontic therapy requires the application of irrigants and medicaments to form a bacteria free canal while simultaneously shaping the canal for root filling process. It is the most perplexing step during root canal therapy procedure; and the most challenging (4). It is also considered an essential part of the whole root canal treatment procedure due to the fact that it determines the efficacy of subsequent phases afterwards (5). Objectives of ideal root canal instrumentation procedures are well addressed. They include a well-shaped root canal that is continuously tapered, preserving the original shape of the canal, free of any iatrogenic damage to the canal system and/or to the root structure while maintaining the original apical foramen position (i.e. no transport) (6). The capability to keep the instruments centered inside the canal is crucial to accomplish those objectives and provides an accurate enlargement to the root canal without any deliberate weakening of the root structure.

Endodontic instruments that enlarge and prepare root canals must meet the basic requirements to prevent the effect of transportation and centering in order to ensure successful root canal treatment (5, 7, 8). Tooth and its root canal anatomy varies in cross-section, shape, thickness of dentin, and foramen size. The possibility of procedural errors presented in curved canals are increased with those anatomical variation, especially transportation, since most endodontic instruments are straight and capable to create lateral forces in curved canals (9). Previously, the instrumentation objectives were reached minimally when using stainless steel files since they are very rigid and their rigidity increases with larger instrument sizes (9). However, the introduction of Nickel-Titanium (Ni-Ti) instruments, with their unique property of super elasticity, permit entering in curved canals with less stress (10). The elasticity allows bending ability to the instruments to follow the anatomical curvature of the canal (11), which diminishes stress and torsion forces within the canal leading to minimal transportation (10).

Evaluating the shaping ability of endodontic files was comprehensively considered through endodontic literature for its necessity and challenges, especially in curved canals. Numerous parameters were used for this assessment, such as evaluating the tendency of the instruments to induce canal transportation, instrument's ability to allow prepared canal to stay centered, loss of working length, measurements of dentine thickness, and alteration in post instrumentation figures (7-9). In addition, various devices and methods were utilized, which include silicon impression, muffle system, and radiograph superimposition techniques. These techniques were effectively documented in endodontic research. Yet, limitations are well-recognized encouraging the search for new methods with advanced capacities that permit both quantitative and qualitative three-dimensional assessments of the root canal (12).

Some research studies which investigated rotary endodontic files revealed that NiTi preserved original canal shape better than stainless steel files (10, 13, 14). The advantages of NiTi rotary instruments are well recognized; however, their characteristic affects their shaping ability: the selection of any system would affect the ability to shape the root canal, particularly with curved canals (15). Manufacturers integrated different designs to reduce apical transportation while accomplishing good file function in more rapid and more predictable canal preparation (16). Their production history will be the subject of the review of literature in next section 1.2.

1.2 History of Nickel-Titanium (NiTi) Instruments

Nickel-Titanium instruments are produced from NiTi alloy which comprises 56% nickel and 44% titanium. This type of instrument was first introduced to dentistry by Walia et al. in 1988 (17). However, its first use in endodontic design was commercially available in the 1990's (18, 19). This alloy type has two unique distinctive features. The shape memory and the superior elasticity. These files are three times more elastic and flexible than stainless steel files and has greater clockwise and anti-clockwise torsion fracture resistance than stainless steel hand files (17). The first-generation of the NiTi file systems had passive cutting radial lands, constant tapers of their active cutting blades and several files within the system. Those characteristics permitted the file to be centered inside the canal. GT files (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) is one type of this category (18). The advancement of NiTi files has substantially improved the quality of root canal shaping and has reduced the incidence of iatrogenic errors during root canal preparation (5). In early 1992, NiTi files were introduced to students in the college of dental medicine at the University of South California, which caused a wave of development (17). NiTi instruments nowadays are presented in a range of forms (files, pluggers, spreaders, etc). The second generation of NiTi rotary files was available in the market in 2001 (19). In comparison with the previous category of the first generation, this group have active cutting edges and less numbers of files. Examples to this group include the EndoSequence (Brasseler USA), and BioRaCe (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland), ProTaper (Dentsply Tulsa Dental Specialties, OK, USA).

At present, with more than two decades of use, the design of the NiTi instruments has experienced considerable changes and enhancements in NiTi metallurgy resulted in third generation production, where manufacture involves heating and cooling methods that drastically improved the files cyclic fatigue and reduce fragility of NiTi instruments in curved canals (20). Types included within this group are the Twisted File (Axis|SybronEndo, Orange, USA), HyFlex (Coltène, Whaledent AG, Altstatten, Switzerland), GTX (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA), Vortex (Dentsply Tulsa Dental Specialties, Tulsa, OK), and WaveOne (Dentsply Tulsa Dental Specialties, OK, USA). Fourth Generation production involves the innovation of reciprocation technology, which has been included to the advanced group of NiTi files (21). This group of instruments is based on the single-file technique. WaveOne (Dentsply Tulsa Dental Specialties, OK, USA), Reciproc (VDW, GmbH, Munich, Germany), and Self-adjusting file (SAF; ReDent-Nova, Raanana, Israel) are example of this group instruments (21, 22). The fifth generation of the rotary endodontic files implemented a different approach where the center of mass and/or the center of rotation are offset. The reason of this characteristic design was to decrease the engagement between the file and dentin wall and improves the file flexibility (23). Types of files with this technology are Revo-S, One Shape® (Micro-Mega®, Besançon, France), and the PTN ProTaper Next (PTN) file (Dentsply Tulsa Dental Specialties/ DentsplyMaillefer).

The most advanced adjustments of nickel–titanium alloy is the M-wire NiTi design, which is made by thermal treatment process to NiTi wire blanks(24). The M-wire alloy is a mixture of approximately equivalent amounts of R-phase (i.e., pre-martensitic or an intermediate phase between austenitic and martensitic phase) and austenite NiTi; a conventional super elastic NiTi which has an austenite structure (20, 25). M-wire NiTi comprises significant amounts of martensite that does not undergo phase transformation causing a metallurgical microstructure that demonstrates strengthening to the alloy (26). It has been claimed that these instruments improve file flexibility and resistance to cyclic fatigue whilst preserving cutting efficiency (27).

NiTi rotary instruments present substantial benefits in endodontic clinical sitting and delivery care for their unique flexibility and time-saving properties. In addition, the wide range of their designs and cross-sectional patterns take the lead to many experimental studies that scientists performed to evaluate their clinical performances. When a new instrument is developed, many characteristics need to be investigated such as cleaning ability, shaping ability, safety aspects and effects on root canal configuration (7, 28-30). When shaping ability of instrument was evaluated, many evaluating parameters were reported in the literature, yet transportation is the most frequently used. It has become evident that rotary nickel–titanium instruments are able to maintain the canal shape even in severely curved canals and that preparation with these instruments is substantially faster than hand instrument preparations (31-33). However, such evaluations are important to clinicians and researchers; because their consideration is valued in the selection of a particular rotary NiTi instrument for clinical practice (34). The shaping quality of instrumentation and root canal transportation induced by rotary files will be the subject of the review of literature in section 1.3.

1.3 Shaping Ability

Shaping ability of files means the capability of the endodontic files to shape the root canal, specially curved canals without inducing aberrations. This is normally achieved by evaluating if the file is straightening the curvature of the canal, its ability to be centered, or its ability to maintain the canal centered with less displacement or transportation.

When examining the quality of root canal preparation created by endodontic instruments and /or techniques, numerous elements of special interest to the scientists were well addressed in the literature, mainly instruments' cleaning ability, shaping ability and safety concerns (7).

Cleaning and shaping phase of the endodontic procedure comprises two processes that are connected to each other. Mechanical preparation to change the shape of the root canal system supports the cleaning by direct removal of bacteria and its by-products from the root canal system; additionally allows the irrigation materials and its active agents involved in the disinfection process to penetrate deeper into the root canal system (35). When an operator shapes the root canal, s/he has to follow ideal objectives. Schilder (6) recommended clear design objectives when shaping the root canal so that cleaning is easily facilitated, and obturation will be aided to produce an optimal seal. These objectives are summarized as follows:

- Taper – a continuously tapered preparation shape should be formed.
- Canal axis – The position of the canal axis should be sustained in the center of the root with no deviation.
- Foramen – The original position of the foramen should be maintained, and it should not be enlarged.

Shaping ability of endodontic files should reflect those objectives for that ideal canal, i.e., preparation involves negligible canal transportation with optimally centered preparations (36).

Many evaluation parameters were used in the literature when shaping ability of instruments was investigated. These parameters included change in the root canal cross-sectional area, degree of canal transportation, centering ability, minimum remaining dentine thickness in the mesial and furcal directions, taper and flow of "the prepared root", smoothening of the canal walls, change in curvature angulation, centering ratio, working time, fracture of instruments, canal aberrations, and working length (37). Yet, transportation and centering ability are used more frequently in most of the study, thus, they were considered in this review.

1.4 Canal Transportation

Canal Transportation, according to the Glossary of Endodontic Terms of the AMERICAN ASSOCIATION OF ENDODONTISTS, is defined as follows: 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; may lead to ledge formation and possible perforation. (38).

1.4.1 How Transportation Occurs

All root canal instruments were found to have a tendency to straighten inside the canal irrespective to the type of alloy of the file used (5, 7, 39-41). The cutting edges of files are enforced against the outer side of the curved canal wall, which is the concave part of the canal in the apical third position of the root canal and pushed against the inner side wall at the middle or coronal thirds of the root canal, which is the convex area, that originates an asymmetrical dentin removal (5, 41). As a result, the apical part of the root canal areas seems over prepared in the path of the convexity of the canal, and greater amounts of dentin are removed at the concavity along the coronal plane leading to the creation of canal transportation or straightening of the canal (5, 41). Figure 1 shows transportation (in red color) in simulated root canal.

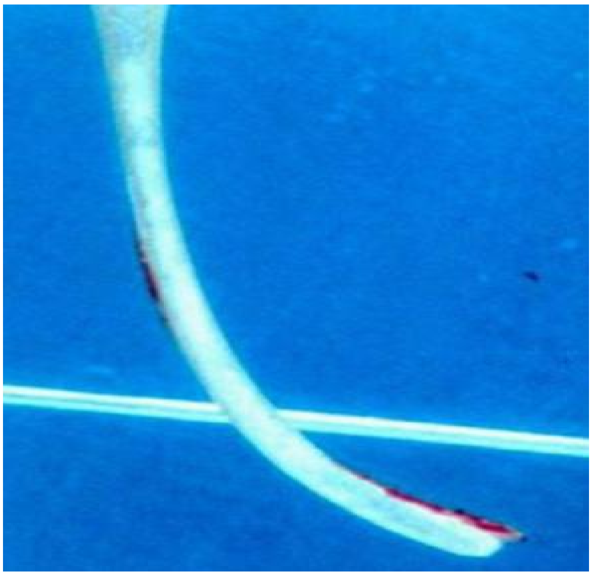


Figure 1: Root canal transportation: Adapted from SCHÄFER et al., 2006 (42)

1.4.2 Consequences of Root Canal Transportation

The alteration of the original path of the root canal may result in damage of the apical foramen and loss of apical stop (7). Consequently, this will take the lead to extrusion of debris, irrigants, filling materials out of the canal and subsequently will cause an irritation of the periapical tissues (42).

The shape of the transported root canal has special features, where the outer part of the canal curvature appears over prepared producing an elliptical figure at the apical endpoint which is termed zipping (42). It is additionally known as 'hourglass shape,' a 'teardrop,' or a 'foraminal rip'(5, 8, 41). When zipping incidence happens, it leads to an unfavorable outcome on the apical seal of root canal specially if cold lateral compaction technique was used (43). Figure 2 illustrated simulated root canals before and after preparation (A, B) and showed a creation of zip and elbow (7).

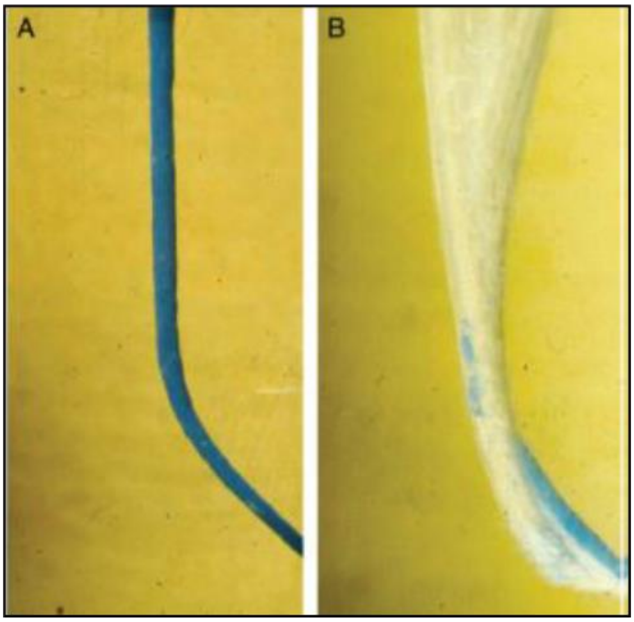


Figure 2: Zip and elbow: Adapted from Hülsmann et al., 2005 (7)

The narrow aspect of the root canal which occurs between the over prepared material removal area alongside the outer wall apically and the over increase of the inner wall of the curvature coronally and is called elbow. This is typically appearing at the point of maximum curvature.

Consequently, this leads to a lesser amount of taper of the root canal shape and will create insufficient cleaning and obturation of the apical part of the root canal (7, 8). Perforation is an additional outcome, in which Apical perforation arises due to the sharp cutting tips of the used files (5, 7). Strip perforation happens in the middle of the coronal third of the canal and displays as a perforation that is most often a consequence of over preparation along the inner side of the wall of the curvature (7, 44). Ledging is equally a result of root canal transportation when the working length cannot be reached (31). It arises in any part along the way in the canal, but mainly in the middle or the apical part of root canals as a raised up area on the start point of the outer side of the curvature (7).

1.4.3 Factors Affecting the Occurrence of Root Canal Transportation

A high prevalence of procedural errors has been reported to be connected to root canal anatomy (5, 7). Degree and radius of root canal curvature are the most responsible factors for the inducing of stress on the instruments while in use. The more severely curved the canal and the more shorter the radius of its curvature, the higher is the risk of transportation incidence (45). Added risk factor for canal transportation is the endodontic file design; the instruments that have an altered non-cutting tip are better in maintaining the original canal path of the root canal system compared with instruments with conventional tips (46). Depth of flutes, core diameter, cross-section and spirals per unit length also have a great impact on the ability of the instrument to maintain the original canal curvature (10). It was reported that the cross-sectional design has a superior effect than the taper or size of an instrument on the stresses created under either torsion or bending conditions (47).

Instruments' type of metal also effects on the occurrence of transportation; files which are made from stainless steel create more transportation than instruments made from nickel titanium (NiTi). However, NiTi files, which are thermo-mechanically proceeded, produce minimal canal transportation. However, the brand new group of NiTi instruments, such as those made of new alloys (CM-wire, M-wire), shows insignificant transportation (46).

Recently, various innovative (NiTi) rotary systems claim improvements in their performance and their shaping ability feature.

However, centering ability during instrumentation to avoid the occurrence of canal deviation is still in concern and that instruments, which can produce optimally centralized preparation, is not yet available (23, 48-51). The search for the instrument that is most efficient and greatly successful in shaping the root canal without incidence of transportation may moderately justify the recent dramatic flood of new files with varied materials and designs presented in the market (39). Some studies, which investigated rotary endodontic files, showed that NiTi instruments have the ability to maintain original canal shape and path better than stainless steel files (10, 14, 52). This was credited to the exceptional property of super elasticity that NiTi files have, which allowed using them in curved canals with less lateral forces and less transportation (10).

1.5 Centering ability

Centering ability is defined as: The ability to keep the instruments centered to provide an accurate enlargement, without excessive weakening of the root structure (13). The canal-centering ratio is the difference between the instrumented and non-instrumented canals, which measures the ability of an instrument to stay centered (53).

2 DEVELOPMENT

2.1 Purpose and Approach

The purpose of this project is to investigate and analyze the literature that examined the shaping ability of endodontic rotary files to find the best method used for this assessment based on canal transportation and centering ability parameter A literature search is done for relevant published studies on methods used in the evaluation of the shaping ability of rotary files in the context of endodontics using PubMed, MEDLINE, Embase, ScienceDirect, Scopus, e B-on database search. In primary stage, studies were selected according to titles and abstracts, and upon collection, they were fully reviewed to ensure that they meet the inclusion/exclusion criteria. Afterwards, evidence-based tables were constructed with the following information: Author's name, year of publication, type of samples (extracted teeth, simulated blocks), evaluation method (DDIR and computer analysis, DDIP, and computer analysis, MCT, CBCT) and parameters (transportation / centering ability). After gathering all studies and removing duplicates and irrelevant data, the remaining studies were retrieved, and their reference lists were checked to identify any other articles/textbooks relevant to the topic that might have provided additional information.

Inclusion criteria are included in-vitro and ex-vivo studies that used different materials and/or techniques. Studies should mention transportation or centering ability parameters and evaluating preparation quality based on shaping ability of rotary files. Searches were limited to studies written in English with human extracted teeth or experimental blocks and published between January 2010 and February 2021.

The exclusion criteria consisted of studies that failed to meet the inclusion criteria. If a study did not define transportation/ centering ability as parameters nor did it report shaping ability to evaluate rotary files, it was excluded. All systematic review, literature review, case series, study reports and studies that expressed opinions, were only read but not included within the analysis. Studies that allocated cleaning rather than shaping and/or dealt with identification of bacterial species, material science or clinical setting were also excluded. Lastly, studies in which keywords do not match the subject of the search as well as non-English language studies have also been excluded.

2.2 Results and Analysis

The search through PubMed, MEDLINE, Embase, ScienceDirect, Scopus, e B-on database searches has yielded a huge number of studies (615). After the exclusion of duplicates, studies in which key words do not match the subject of the search, case reports and non-English language studies were also excluded. 360 published Studies relevant on instrumentation of root canals were collected.

Studies that evaluated shaping ability were screened further. Titles and abstracts were additionally evaluated, the relevance of each study to the criteria was determined. The full texts of the selected studies were then obtained and reviewed of which only 65 (18 %) were kept as shown in figure 3.

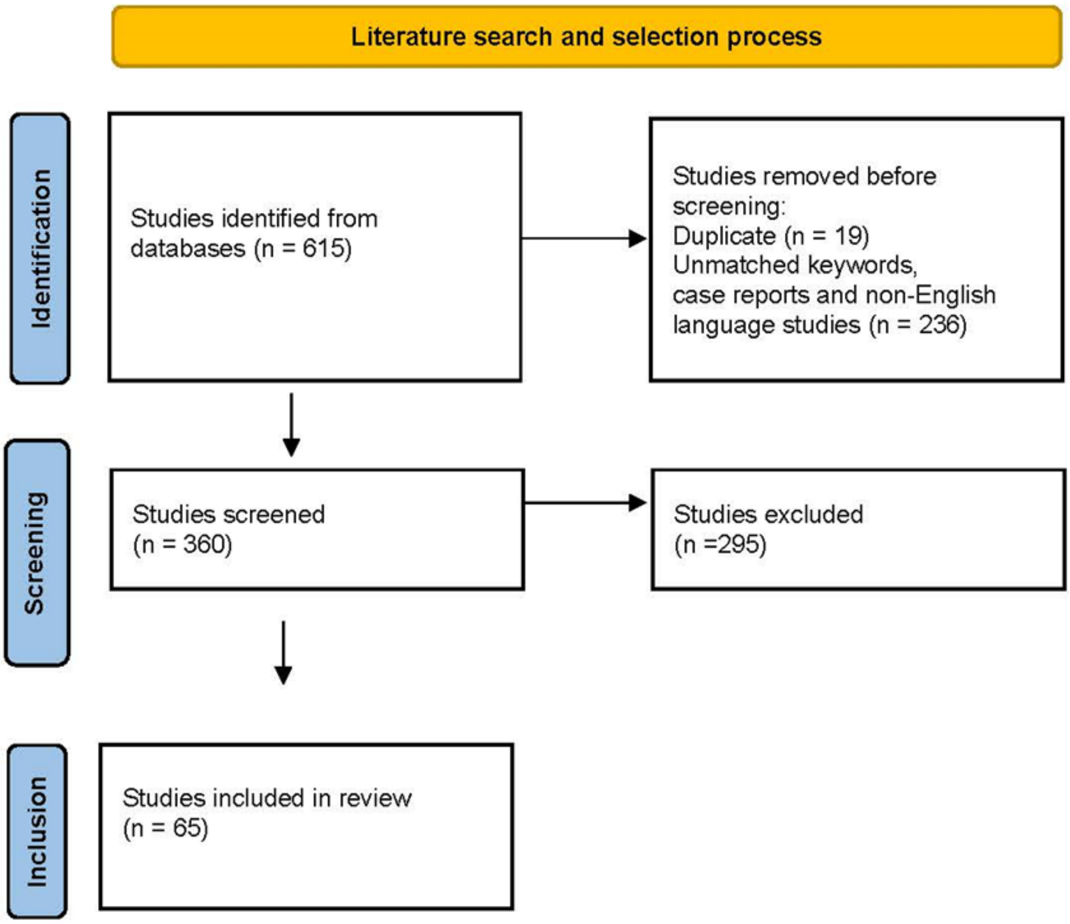


Figure 3: Literature search and selection process

From the selected studies, the following data were extracted and included in the Data table: Author name, year of publication, samples type, methods used to evaluate transportation or centering ability (Micro-Computed Tomography (MCT), Cone-Beam Computed Tomography (CBCT), Double Digital Images Photographs (DDIP) with either the Adobe Photoshop, the Fiji, the Image-Pro Plus or with the AutoCAD software, Double Digital Image Radiographs (DDIR) with either MCT, the Adobe Photoshop or with the AutoCAD software) as shown in Table 1.

Table 1: Studies included in reverse chronological order

No.	Year	Author/Reference	Type of Samples	Methods	Parameters
1	2021	María de las Nieves Pérez Morales [82]	Mandibular molars	MCT	Canal transportation and centering ability
2	2020	Christina Razcha [81]	Mandibular molars	MCT	Canal transportation and centering ability
3	2020	P. O. F. Fernandes [80]	Mandibular molars	MCT	Canal transportation
4	2020	Burçin Arıcan Öztürk [124]	Single rooted	CBCT	Canal transportation and centering ability
5	2020	P. H. Htun [96]	Mandibular premolars	MCT	Canal transportation
6	2020	Mariana Mena Barreto Pivoto-João [79]	Mandibular molars	MCT	Centering ability
7	2020	Franziska Haupt [78]	Mandibular molars	MCT	Canal transportation and centering ability
8	2020	Emina Kabil [88]	Maxillary molars	MCT	Canal transportation and centering ability
9	2020	Maria de las Nieves Perez Morales [94]	Maxillary premolars	MCT	Canal transportation and centering ratio
10	2019	Peet J. van der Vyver [87]	Maxillary molars	MCT	Canal transportation and centering ratio
11	2019	Zeliha Uğur Aydın [77]	Mandibular molars	MCT	Canal transportation and centering ability
12	2019	Yousif Iqbal Nathani [95]	Mandibular premolars	CBCT	Canal transportation and centering ability
13	2019	Keiichiro Maki [112]	Simulated resin blocks	DDIP & Adobe Photoshop	Centering ability
14	2019	Daniel José Filizola de Oliveira [76]	Mandibular molars	MCT	Canal transportation
15	2018	Martin Vorster [75]	Mandibular molars	MCT	Canal transportation and centering ability
16	2018	M. M. Kyaw Moe [74]	Mandibular molars	MCT	Canal transportation and centering ratio

No.	Year	Author/Reference	Type of Samples	Methods	Parameters
17	2018	Mohamed Medhat Kataia [111]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
18	2018	Seyed Mohsen Hasheminia [73]	Mandibular molars	CBCT	Canal transportation and centering ability
19	2018	Simone Staffoli [110]	Simulated blocks	DDIP & Adobe Photoshop	Centering ability
20	2018	E. A. Saberi [72]	Mandibular molars	CBCT	Canal transportation
21	2018	Guohua Yuan [71]	Mandibular molars	MCT	Canal transportation
22	2018	Pedro Marks Duarte [86]	Maxillary molars	MCT	Canal transportation and centering ability
23	2018	Felipe Gonçalves Belladonna [70]	Mandibular molars	MCT	Canal transportation
24	2017	Giulia Ferrara [89]	Mandibular and maxillary molars	DDIR & Adobe Photoshop	Canal transportation
25	2017	Amin A. H. Alemam [109]	Simulated resin blocks	DDIP & Image-Pro Plus	Canal transportation
26	2017	Maurizio D'Amario [69]	Mandibular molars	DDIR & AutoCAD	Canal transportation
27	2017	Taha Özyürek [108]	Simulated resin blocks	DDIP & AutoCAD	Canal transportation
28	2017	Caroline Zanesco [85]	Maxillary molars	MCT and DDIR	Canal transportation and centering ratio
29	2017	Pier Matteo Venino [97]	Max./Mand. molars, premolars and canine	MCT	Canal transportation and centering ratio
30	2017	Lu Shi [107]	Simulated resin blocks	DDIP & Adobe Photoshop	Centering ability
31	2016	Ana Grasiela da Silva Limoeiro [68]	Mandibular molars	MCT	Canal transportation and centering ability
32	2016	Zhaohui Liu [93]	Premolars	MCT	Canal transportation
33	2016	Farzana Paleker [67]	Mandibular molars	MCT	Canal transportation and centering ability
34	2016	Ranya Faraj Elemam [34]	Simulated resin blocks	DDIP & AutoCAD	Canal transportation
35	2016	Filipa Neto [106]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
36	2015	Ove A. Peters [28]	Mandibular molars	MCT	Canal transportation
37	2015	Jason Gagliardi [66]	Mandibular molars	MCT	Canal transportation and centering ability
38	2015	Emmanuel João Nogueira Leal Silva [105]	Simulated resin blocks	DDIP and Fiji	Canal transportation

No.	Year	Author/Reference	Type of Samples	Methods	Parameters
39	2015	Abdulrahman Mohammed Saleh [104]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
40	2015	Damiano Pasqualini [84]	Mandibular molars	MCT	Canal transportation and centering ability
41	2015	Guilherme Moreira de Carvalho [65]	Mandibular molars	CBCT	Canal transportation and centering ability
42	2014	K. K. Al-Manei [125]	Mandibular molars	DDIP & AutoCAD	Canal transportation
43	2014	Amr M. Elnaghy [64]	Mandibular molars	CBCT	Canal transportation and centering ability
44	2014	Matthew Thompson [103]	Simulated resin blocks	DDIP & Adobe Photoshop	Centering ability
45	2014	Dan Zhao [63]	Mandibular molars	MCT	Canal transportation
46	2014	Young-Hye Hwang [83]	Maxillary molars	MCT	Canal transportation
47	2014	Nazarimoghadam K[24]	Simulated resin blocks	DDIP & AutoCAD	Canal transportation
48	2013	Abeer M. Marzouk [61]	Mandibular molars	CBCT	Canal transportation
49	2013	Mina Zarei [60]	Mandibular molars	DDIP & Adobe Photoshop	Canal transportation and centering ability
50	2012	Jeffrey R Burroughs [50]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
51	2012	Brandon Yamamura [51]	Mandibular molars	MCT	Canal transportation and centering ability
52	2012	Cumhur Aydin [102]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
53	2012	Fernando Duran-Sindreu [121]	Mandibular molars	DDIR & AutoCAD	Canal transportation
54	2012	Ahmed Abdel Rahman Hashem [23]	Mandibular molars	CBCT	Canal transportation and centering ability
55	2012	Marc García [15]	Mandibular molars	DDIR and AutoCAD	Canal transportation
56	2012	Stern S [123]	Mandibular molars	MCT	Canal transportation and centering ratio
57	2011	Guobin Yang [59]	Mandibular molars	MCT	Canal transportation and centering ability
58	2011	Hani F. Ounsi [122]	Simulated resin blocks	DDIP & AutoCAD	Canal transportation
59	2011	Laila Gonzales Freire [58]	Mandibular molars	MCT	canal transportation and centering ability

No.	Year	Author/Reference	Type of Samples	Methods	Parameters
60	2011	Vittorio Franco [99]	Simulated resin blocks	DDIP & Adobe Photoshop	Canal transportation
61	2010	Frank C. Setzer [57]	Mandibular molars	DDIR & AutoCAD	Canal transportation
62	2010	Bekir Karabucak [55]	Mandibular molars	DDIR & AutoCAD	Canal transportation
63	2010	Rui Gonçalves Madureira [98]	Simulated resin blocks	DDIR & Adobe Photoshop	Canal transportation
64	2010	Richard Gergi [54]	Mandibular molars	CBCT	Canal transportation and centering ratio
65	2010	Mian K. Iqbal [12]	Mandibular molars	DDIR & AutoCAD	Canal transportation

Figure 4 indicates that 48 studies (74%) used extracted teeth while 17 studies (26%) used simulated blocks.

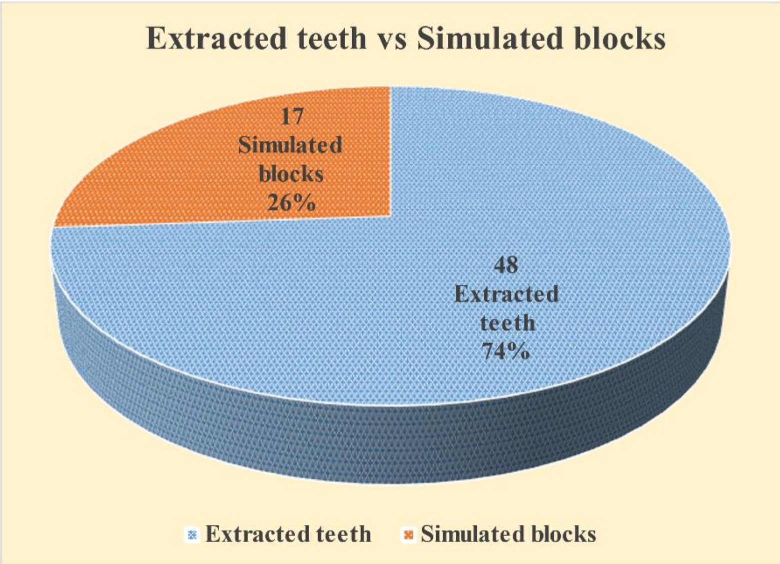


Figure 4: Extracted teeth versus simulated blocks

Figure 5 shows that 38 studies (58.5%) of the reviewed studies used Micro-Computed Tomography and Cone-Beam Computed Tomography (MCT+CBCT) to evaluate the shaping ability of rotary endodontic files while 26 Studies (40%) used Double Digital Images Radiographs and Photographs (DDIR+DDIP), with only one study (1.5%) that used both (DDIR) and MCT.

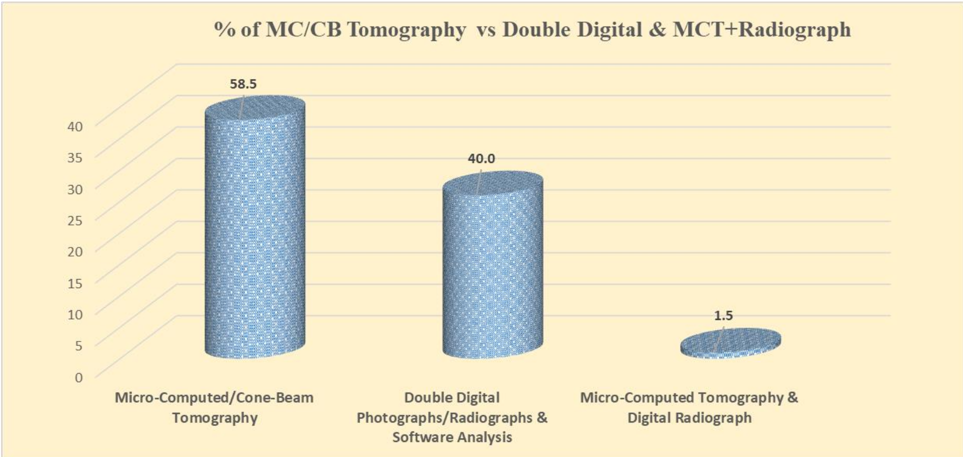


Figure 5: MC/CB Tomography vs Double Digital Images & MCT+DDIR

Reviewing all the selected study articles in detail resulted in the ranking of the methods used to assess shaping ability in terms of their frequency of use as shown in figure 6.

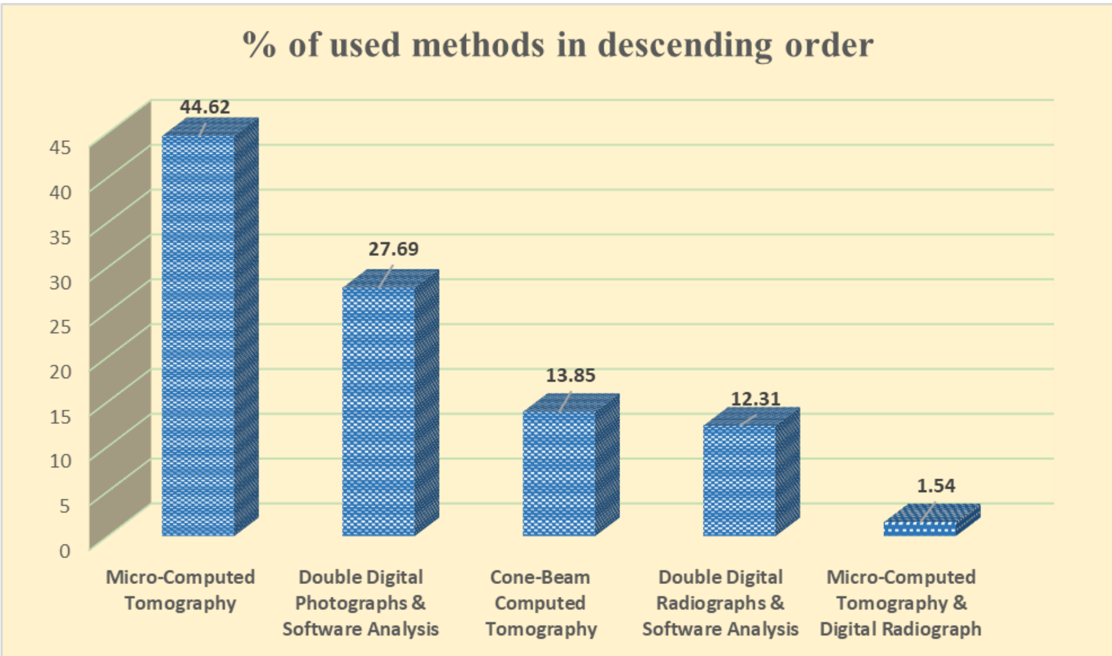


Figure 6: Percentage of used methods in descending order

The distribution of studies according to the types of samples, the methods used, and the evaluated parameters is shown in Table 2.

Table 2: Distribution of studies per types of samples, methods, and parameters

Parameters	**Canal transportation**	**Canal transportation & centering ability**	**Canal transportation & centering ratio**	**Centering ability**	**Total**
Type of Samples/Methods					
Mandibular and maxillary molars	1				1
DDIR & Adobe Photoshop	1				1
Mandibular molars	15	17	3	1	36
CBCT	2	4	1		7
DDIP & Adobe Photoshop		1			1
DDIP & AutoCAD	1				1
DDIR & AutoCAD	6				6
MCT	6	12	2	1	21
Mandibular premolars	1	1			2
CBCT		1			1
MCT	1				1
Max./Mand. molars, premolars and canine			1		1
MCT			1		1
Maxillary molars	1	2	2		5
MCT	1	2	1		4
MCT and DDIR			1		1
Maxillary premolars			1		1
MCT			1		1
Premolars	1				1
MCT	1				1
Simulated blocks	13			4	17
DDIP & Adobe Photoshop	6			4	10
DDIP & AutoCAD	4				4
DDIP and Fiji	1				1

Parameters	**Canal transportation**	**Canal transportation & centering ability**	**Canal transportation & centering ratio**	**Centering ability**	**Total**
Type of Samples/Methods					
DDIP & Image-Pro Plus	1				1
DDIR & Adobe Photoshop	1				1
Single rooted		1			1
CBCT		1			1
Total	32	21	7	5	65

Table 2 reveals that mandibular molars and simulated blocks types of samples constitute about 82% of the selected studies. For mandibular molars, more than 94% of the studies used Micro-Computed Tomography (MCT), Cone-Beam Computed Tomography (CBCT), and the Double Digital Image Radiographs (DDIR) with the AutoCAD software. For simulated blocks, about 77% of the studies used the Double Digital Image Photographs (DDIP) with either the Adobe Photoshop or the AutoCAD software.

Table 3 shows the distribution of selected studies per types of samples and parameters.

Table 3: Distribution of studies per types of samples and parameters.

		Parameters				**Total**
#	**Type of Samples**	**Canal transportation**	**Canal transportation and centering ability**	**Canal transportation and centering ratio**	**Centering ability**	
1	Mandibular and maxillary molars	1				1
2	Mandibular molars	15	17	3	1	36
3	Mandibular premolars	1	1			2
4	Max./Mand. molars, premolars and canine			1		1
5	Maxillary molars	1	2	2		5
6	Maxillary premolars			1		1
7	Premolars	1				1
8	Simulated blocks	13			4	17
9	Single rooted		1			1
	Total	32	21	7	5	65

Table 3 reveals that the most parameter evaluated was canal transportation followed by canal transportation and centering ability, while the least parameter was the centering ability followed by the centering ratio. It also shows that mandibular molar was the most selected type of samples followed by simulated blocks. For mandibular molar, about 92% of the studies evaluated canal transportation and/or centering ability, while for simulated blocks, all studies evaluated either canal transportation or centering ability.

Table 4 shows the distribution of selected studies over methods and parameters.

Table 4: Distribution of studies per methods and parameters

#	Methods	Parameters				Total
		Canal transportation	**Canal transportation and centering ability**	**Canal transportation and centering ratio**	**Centering ability**	
1	CBCT	2	6	1		9
2	DDIP & Adobe Photoshop	6	1		4	11
3	DDIP & AutoCAD	5				5
4	DDIP & Fiji	1				1
5	DDIP & Image-Pro Plus	1				1
6	DDIR & Adobe Photoshop	2				2
7	DDIR & AutoCAD	6				6
8	MCT	9	14	5	1	29
9	MCT and DDIR			1		1
	Total	32	21	7	5	65

Table 4 reveals that the most method used was MCT followed by DDIP with the Adobe Photoshop software. This is also illustrated in more detail in the bar chart in Figure 6, which shows the frequency of use of methods in descending order after grouping the Double Digital Images for Photographs and Radiographs (DDIR+DDIP). Table 4 also reveals that almost half of the studies evaluated only the canal transportation parameter for most of the methods with the exception of the MCT, CBCT, and the Double Digital Images Photographs (DDIP) with the Adobe Photoshop software.

2.3 Assessment Process

The understanding of endodontic therapy concepts leads to great advance in instruments, which is the reason why many studies commenced to assess the performance and quality of these instruments to give recommendations for research guidance and clinical practices. In this part, literature that evaluated shaping ability of rotary endodontic files in the last 10 years are reviewed, sample selected by investigators are considered, steps taken for evaluation process are explained, and the evaluation methods involved are also described.

2.3.1 Types of Samples

Most studies on post-operative root canal shape or changes in root canal morphology have been performed in extracted teeth (Figure 4). Molar teeth was the most selected type, in which the highest percentage were found on mandibular molars (12, 15, 23, 28, 51, 54-82). Few experiments were performed on Maxillary molar (83-88) and only one study was performed on both maxillary and mandibular (89).

Researchers were interested in evaluating the quality of shaping ability of endodontic files in molar tooth, since it is the most commonly treated within the general dental practice (81, 90, 91). The mesial root was the preferred root for this type of experiment, usually because they are curved, with the greatest curvature in the mesio buccal canal. This anatomical feature of the curved mesio buccal canals often induces a greater challenge (82, 92) and generates a greater canal transportation by instrumentation than most other root canals (63).

Our review showed two studies investigated maxillary premolars with isthmus in which a study was also aiming to assess the cleaning abilities of the evaluated endodontic files (93). The other was concerned about the anatomical challenges connected to isthmus presence (94), as this anatomical feature would increases the difficulty in the canal instrumentation procedure. Additionally, in this review; two studies used mandibular premolar canals (95, 96) for the anatomical challenge related to feature of the long oval single canals found on them (95) and only one study presented mixed anterior and posterior (97) to enlarge the sample size.

Studies that used simulated canals in resin blocks were few (34, 50, 98-112), they were chosen as they were reliable, valid and credited model to test canal preparation techniques and instrument ability (103, 106). One study used simulated blocks in shape of molar (110), this artificial molar tooth models is made of a material that is closely equal to natural dentin so that each step of the treatment is comparable to real clinical practice. The studies used resin blocks confirmed that, those blocks can give better standardization and are able to reduce the variability that exists in the human root canal anatomy (50, 98, 100, 104-106), providing strictly controlled laboratory conditions (102). They also allow a direct comparison of the shapes obtained with different movements (99) and with different instruments (50, 104). However, those simulated canals in resin blocks model may neither match the various anatomical configurations in actual tooth structure nor match the clinical setup; the patient factor, for this clinical outcome might not be considered (217).

Ahmad et al. (113) compared the differences in the cutting proficiency of ultrasonic tool on curved canals in both simulated acrylic resin blocks and natural extracted teeth. They discovered that there were no qualitative or quantitative differences or any alterations in the way that material is removed along the canal's wall. Khalilak et al. (114) assessed apical canal deviation in extracted teeth compared to the simulated resin blocks (219) and found that the simulated resin blocks and natural teeth displayed similar apical deviation (114). Both research studies confirmed that their conclusions cannot be transferred to a clinical sitting (113, 114). Nevertheless, other studies, which presented their experiments on simulated resin blocks, showed that their accomplished results could be applied to natural human teeth with critical precautions (33, 104, 115-117).

Using rotary endodontic instruments in simulated resin blocks could produce heat generation. This is considered a major drawback of using this experiment on resin model, which leads to soften the resin material (118), and in return could interfere with the advancement of the instrument along the simulated canal (99). Later investigation explained that resin blocks showed such deformity only in cross section, which does not appear when natural root canals were tested (82).

2.3.2 Assessment Steps

Literature revealed that analyzing postoperative root canal shape is essential to evaluate the taper, flow of the prepared root canal, maintenance of the original canal shape, root canal transportation and cantering ability (119). Literature addressed the process of evaluating the transportation and centering ability of various instrumentation techniques and instruments with several experimental models and procedures (120).

Literature regularly reports a three-phase process for shaping ability evaluation:

- Images of the canals are taken before (pre-image or un-instrumented) and after (post-image or instrumented).
- The pre- images and post-images are superimposed or reconstructed.
- Measurements are taken for the difference between the pre- images and post-images using a mathematical equation.

From all studies obtained in the literature, these steps were reviewed and explained as follow:

2.3.2.1 Step 1: Scanning and Imaging

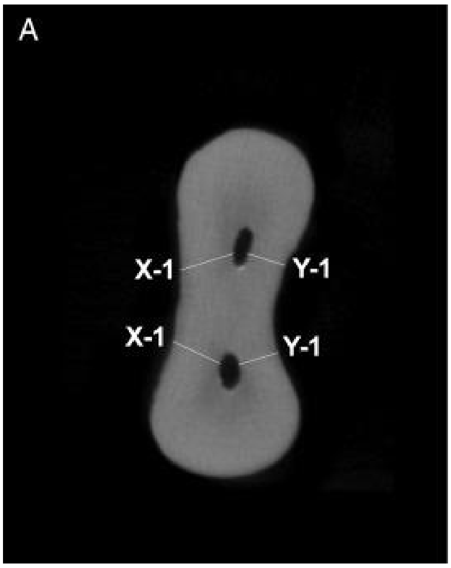
Different modalities were used to obtain the pre and post images by photographing or scanning the sample. They were acquired either in 2-dimensions (2D) or 3 dimensions (3D). The two dimensions included:

- Digital camera (24, 60, 98, 100, 102-106, 108-111)
- Macroscopic magnifier (34)
- Digital microscope (50, 112)
- Dental operating microscope (107)
- Radiograph (12, 15, 55, 57, 69, 85, 89, 98, 121)

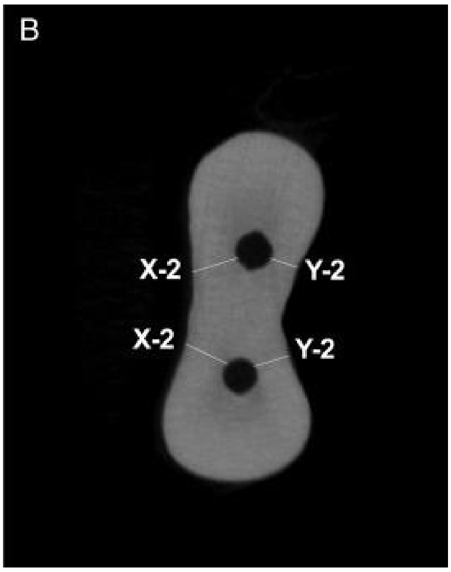
The 3-dimensions (3D) included:

- Computed Tomography (CT) (28, 54, 58, 59, 63, 66, 68, 70, 71, 74, 75, 77-88, 94, 96, 97, 100, 122, 123)
- CBCT device (64, 65, 72, 73, 76, 88, 95, 124)
- Spiral CT (51, 54)
- I-CAT (23, 61)

Images acquisitions happened in a cross-sectional view in many experimental studies(23, 28, 51, 58, 60, 61, 63, 65, 79-82, 94, 95, 125). Figure 7 represents MCT cross section of preoperative (A) and postoperative canals (B) in mandibular molar, while few studies preferred a perpendicular plan (47, 99). Figure 8 represents a perpendicular view for final layered canal images for three simulated blocks with different instrument preparation the (A) SAF, (B) Typhoon, and (C) Vortex groups.



(A) Preoperative root canal



(*B*) After preparation

Figure 7. Cross sectional view: Adapted from Pivoto-João et al., 2020 (79)

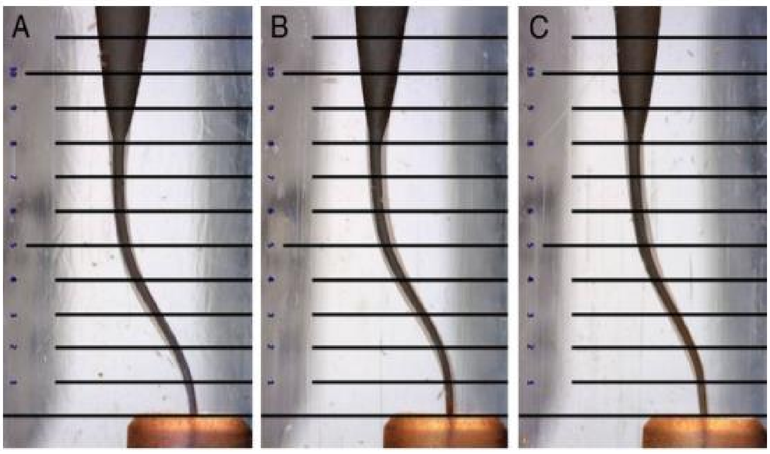


Figure 8: Perpendicular view: Adapted from Burroughs et al., 2012 (50)

The presence of curvature impacts on the type of views selection. Images captured in 2D cannot capture curvatures when they are found in different plan, this made 3Ds tools to overweight the 2D ones.

Despite various tools used to take photos of the sample, the captured photos or radiographs should be transferred to a digital imaging format. Sample should be photographed before and after instrumentation, operator should make sure the sample was taken in the same positions, sample has to be mounted in a support before and after the photographs taken (99, 102). This is to standardize the light conditions before and after preparation. Few studies mentioned embedding the tooth in a putty base or custom-made box with care so as not to obscure the canals and, they also used a gig to allow reproducible image acquisition (60, 110, 111, 124). This technique also called Bramante technique or, custom-made silicon device (105). The acrylic jig containing the root positioned at the center of the sensor so as to align perfectly with a square-shaped guide previously designed on the sensor, thus allowing the jig to be accurately repositioned during the experimental procedure (69). This technique is relatively simple and economical (64). Other procedure used were a platform or container to embedded tooth in acrylic resin (89, 97), or making simple landmarks or labelled reference points to easy repositioning the sample each time the photos are taken (24, 50, 103, 110).

2.3.2.2 Step 2: Superimposition /Reconstructing of Pre/Post Images

Different software programs facilitate the process of overlaying post-operative images with the preoperative one. Figure 9 illustrates the superimposition step where the pre instrumented canals in white while the post instrumented are in black.

Figure 9: images superimposed: Adapted from Shi L et al., 2017 (107)

Images would then be saved as one picture to be either kept or exported to another software for measurements. The most common software programs used for the superimposing are:

- Adobe Photoshop (15, 36, 50, 57, 60, 68, 69, 85, 89, 99, 102-104, 106, 107, 110-112, 121).
- AutoCAD (12, 24, 34, 50, 55, 57, 71, 98-100, 108, 125)
- Other software programs were used such as:
  - Image-Pro Plus software (109)
  - Pages (Apple Inc, Cupertino, CA)(108)
  - PaintShop Pro9 software (34)
  - Fiji (Fiji is Just ImageJ)(81, 105)
  - OnDemand 3D software (Cybermed Inc, Irvine, CA) (64).

For 3D reconstructing, the following software programs were used:

- 3-dimensional (3D) registration application of the data Viewer v.1.5.1 (Bruker MCT) (68, 70, 74, 76, 77, 79, 80, 82, 86, 93, 94)
- 3D Dental software (Cybermed, Seoul, Korea)(124),
- VGSudioMax visualization (Volume Graphics GmbH, Heidelberg, Germany) (28, 71, 75, 87)
- Image Fusion module MedINRIA, Paris, France) (93)
- Micro View software (GE Pre-clinical Imaging) (123)

2.3.2.3 Step 3: Measurements

A. Transportation measurements using

A.1. Software systems

A.1.1. The distance between two central axes or tips of two instruments of the pre and post canals considered a transportation amount (15, 57, 85, 103, 106, 121).

Most studies used AutoCAD (15, 26, 34, 57, 69, 100, 106, 108, 121, 125).

A.1.2. The amount of untouched area considered the transportation value (50, 74, 96, 102), two studies specified this measurement done through ImageJ/Fiji version 1.48c (National Institutes of Health, Bethesda, MD) (74, 96).

A.1.3. Difference between the canal configuration before and after instrumentation using UTHSCSA Image Tool version 3.00 for Windows; University of Texas Health Science Centre in San Antonio, TX) (99).

A.1.4. The difference in amount of resin removed through Image-J analysis software (89, 104) or without software subtracting the difference in the width between the two acrylic canals or dentinal thicknesses of the instrumented root canal from those of the instrumented canal (34, 89, 106, 108, 125).

The distance between the canal wall before and after instrumentation resulted of 0 to indicate no canal transportation occurred (102).

A.1.5. Bergmans et al method (39) was applied to measuring transportation in which central axis point was located within each pre-instrumentation canal on each scan. Using this axis as a reference point, polar coordinates were mapped at 8 points on the pre-instrumentation canal wall in 360°. The 8 points were mapped at 45° increments in a clockwise rotation: mesial (M), MB, buccal (B), distobuccal (DB), distal (D), distolingual (DL), lingual (L), and ML.

The coordinates mapped within the pre-instrumentation canal images should superimpose over the post instrumentation canal images, and after that, the distance between the post-instrumented canal walls and the pre-instrumented canal walls measured in 8 directions and the large distances occurred were the evident of canal transportation (67) as shown in figure 10.

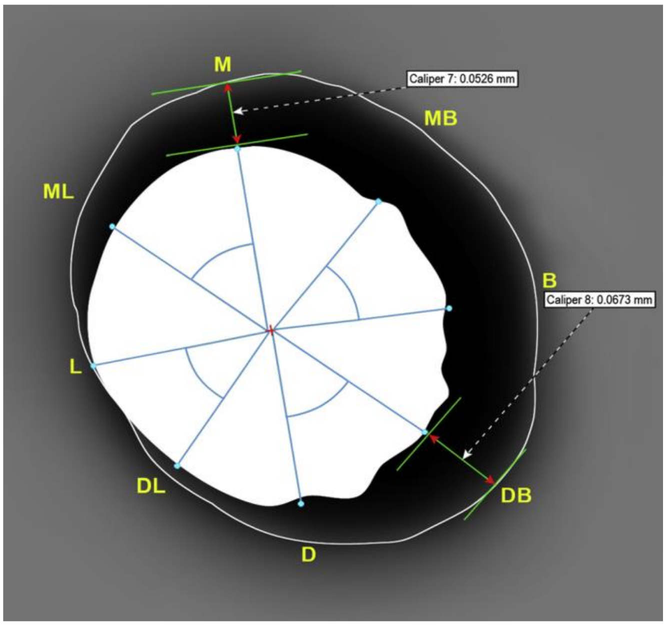


Figure 10: Bergmans et al méthode Adapted from Paleker F et al., 2016 (67)

A.2. Equation Methods

A.2.1. Gambill et al. method (126) implemented by most of the reviewed studies (23, 51, 54, 55, 58, 60, 61, 64, 65, 68, 70, 72-75, 77, 78, 81, 83, 85-88, 93-95, 97, 123, 124), is described as follow:

$([a_1 - a_2]/[b_1 - b_2])$, where:

- a_1 is the shortest distance from the mesial edge of the root to the mesial edge of the un instrumented canal,
- b_1 is the shortest distance from the distal edge of the root to the distal edge of the un-instrumented canal,
- a_2 is the shortest distance from the mesial edge of the root to the mesial edge of the instrumented canal, and
- b_2 is the shortest distance from the distal edge of the root to the distal edge of the instrumented canal. If the obtained result yielded the value of "0", this means that no canal transportation has occurred otherwise this would mean that transportation has occurred in the canal. As shown in figure 11.

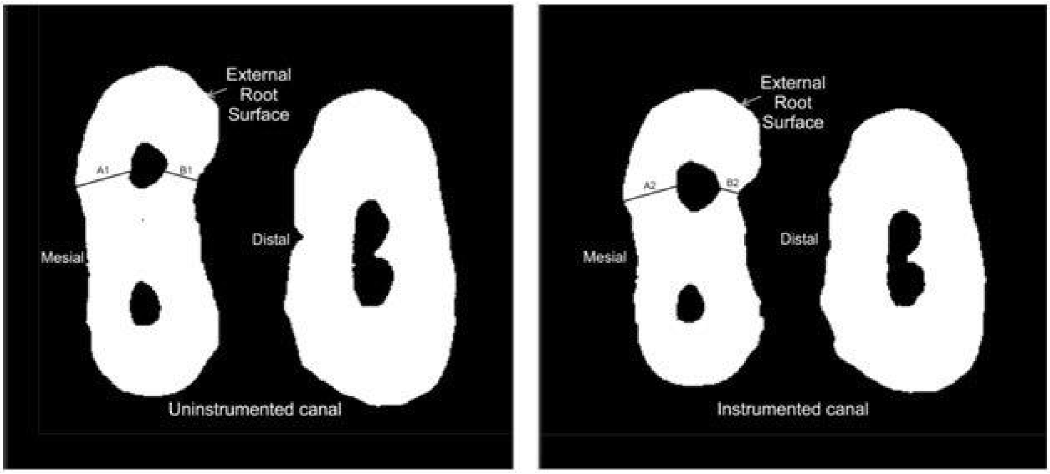


Figure 11: Gambill et al method: Adapted from Agarwal RS et al., 2015 (127)

A.2.2. Different formula were additionally mentioned in the literature to evaluate the transportation as follows (105):

$$\sqrt[2]{(x_b - x_i) + (y_b - y_i)}$$

where x_b and y_b are the coordinates for the non-instrumented canal and x_i and y_i are the coordinates for the instrumented canal. The resulted amount were then converted to millimeters considered as amount of canal transportation (105).

A.2.3. J. Lambers formula: Most of the studies that utilized the MCT, mentioned a special software associated with the CT for transportation measurement by assessing the changes in the centers of gravity. (28, 59, 63, 66, 71, 76, 80, 82, 84).

This analyzed in 3D-dimensional through the x-, y- and z-plane values. For this purpose, the center of gravity for each cross section of the apical third was calculated, and the connection of these centers along the z-axis was called the centroid. Apical transportation, which is referred as (D) in abbreviation of deviation was determined by comparing the centers of gravity of the pre- and post-preparation canals based on formula created by J. Lambers (128) as shown in figure 12.

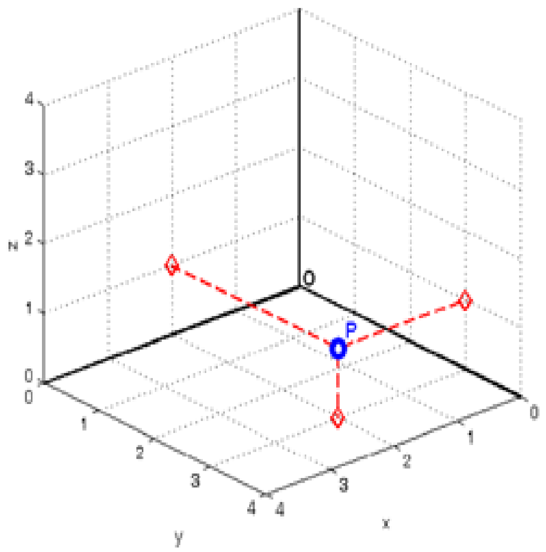


Figure 12: J. Lambers formula Adapted from Lambers et al., 2009 (128)

This figure, illustrates three points, point (2, 3, 1) in x y z space, denoted by the letter P. The three points, point (2, 3, 1) in x y z space, denoted by the letter P. The origin is denoted by the letter O. The projections of P onto the coordinate planes are indicated by the diamonds. The dashed lines are line segments perpendicular to the coordinate planes that connect P to its projections.

The formula described as follows:

$$D^2 = (x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2$$

B. Canal Centering ability Measurement

The centering ability was calculated by any of the following:

B.1. Dividing the resin quantity removed at the inner and outer walls of the canals by the resin quantity removed on the opposite wall; a lower value is considered the numerator of the ratio. If the ratio is equal or closer to "1", it is considered a better centering ability (102).

B.2. Gambill et al formula (126), which is similarly used to asses transportation (54, 58, 60, 65, 68, 73, 75, 78-80, 86, 88, 95), A result equals to 1 indicates perfect centering (54, 58, 65, 68, 86).

B.3. Canal gravity center (84) or Calhoun and Montgomery formula (67): $(X_1\text{-}X_2)/Y$ (129) (figure 13), where:

X_1 represents the maximum extent of canal deviation in one path.

X_2 is the movement in the opposite path.

Y is the diameter of the post-instrumented canal preparation.

These measurements were determined by the superimposition of the pre-instrumentation canal over the post-instrumentation canal. If the result ratios is closest to 0, it would indicate a superior centering ability (67, 125).

Figure 13 shows how Calhoun and Montgomery formula is calculated where:

(a) represents a cross-section of the tooth, the shaded area represents the pre-instrumentation canal shape, and the clear area represents the post-instrumentation canal shape,

(b) represents an enlargement of the box in (a), X_1 represents the maximum extent of canal movement in one direction, and X_2 is the movement in the opposite direction. Y is the diameter of the final canal preparation (130).

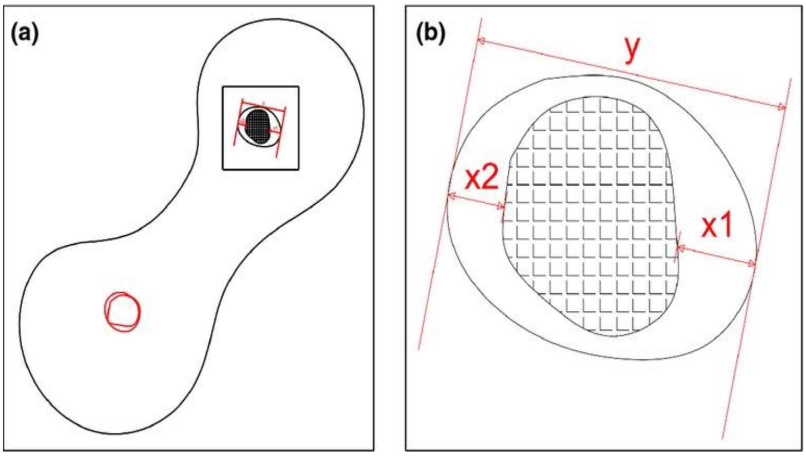


Figure 13: Calhoun and Montgomery formula Adapted from Calhoun G et al., 1988 (129)

C. Centering Ratio

The calculation of the centering ratio was carried out using different formulas. Some studies used Calhoun and Montgomery formula. This calculation was done using a computer software (ImageJ; NIH, Bethesda, MD) (107, 110, 112) or Image-Pro Plus software (109) as used in figure 13. Other studies (23, 51, 54, 64, 74, 77, 81, 85, 87, 94, 97, 123) utilized Gambil equation $(M_1-M_2)/(D_1-D_2)$ (126). Obtained value of 1:1 for the centering ratio indicated a perfect centering (figure 11).

2.3.3 Main Methods

Three main methods were cited in our reviewed literature to evaluate the performance of root canal instrumentation. These are: Double Digital Images, MCT, and CBCT (125).

I. Double Digital Images

Double Digital Images or Standardized Images technique has traditionally been one of the most used methods in endodontic research studies and was widely mentioned in this review (12, 15, 24, 34, 50, 55, 57, 58, 60, 69, 85, 89, 98, 100, 102-112, 121, 125).

This technique allows a direct analysis of post-instrumentation changes in root canal system and evaluates the tendency of instruments to maintain the original canal anatomy under standardized conditions in a simple approach (24, 126). Assessment of anatomic parameters like transportation, centering ability and centering ratio were easily achieved when this technique is selected (126). In addition, residual dentin and cutting efficiency of different instruments could also be evaluated (131-133).

Double Digital Radiographs/ Photographs Images (DDIR/DDIP) method was named double because of the double times exposure; one before and one after instrumentation. It is also called standardized because the technique has to maintain the same images' exposure position each time (134). It is relatively simple to perform, starting by digitizing the radiographs or photographs so that the operators would have the advantage of controlling contrast and brightness (135), then superimposing post and pre-instrumentation images using a computer software to evaluate the degree of canal transportation or other parameters.

When Double Digital Images method uses muffle system, it is called Bramante technique or a modification of the muffle block technique (44), where plaster block placed around a resin or indexed experimental tooth. (44). The block can be custom machined and sectioned in various planes to allow exact repositioning of the complete block or sectioned parts of the tooth in same position (136). In our review, one study applying Bramante technique (125) due to its low cost and simplicity, adequacy and considering it a very sufficient for the assessment of quality of root canal preparation (125).

Photographs and radiographs, cannot be observed in cross section view (137). All images received from this method are two-dimensional views. Deolivera etal (76) defined the 2-dimensions as area and perimeter, while the 3-dimensions as volume, surface area, and structure model index. In clinical radiograph, the two-dimension images are the clinical (mesiodistal), and the proximal (buccolingual), which did not display the real transportation because teeth do not always show their maximum curvatures in the mesiodistal or buccolingual planes (138, 139). Accordingly different adjustments were suggested to overcome this by implementing some modification. A recommendation to take another angulated radiograph, commonly perpendicular to the first one to provide understanding on the third dimension was proposed, however this still drops short of generating 3D data for quantitative analysis (122). Another suggestion was to inspect the tooth and locate the position of maximum curvature and enable setting it perpendicular to the X-ray beam (140). This modification was first suggested by Maggiore (140) allowing an exact evaluation of angle and radius of the curvature (132), however, still not indicated in cases of root canals with double curvatures because maximum curvatures in these canals normally occur in multiple planes (132).

Comparing DDIR to MCT, in evaluating canal transportation, showed similar statistical result. Although this outcome lacked the clinical relevance, radiograph is still a reliable and precise tool (85).

Double Digital Images Radiograph (DDIR) illustrates a nondestructive approach, demonstrating a slow exposure to radiation (137), easy to use, and has low-cost compared to the MCT, and very preferable to the investigators (12). All Images were taking in 2 perpendicular directions providing 2D estimates of 3D structures. This does not give an adequate and complete description of an object, leading to reduced accuracy in quantitative studies (100). Interpretation of radiographs and images remains always subjective (141) and lacks the ability to reveal volumetric information of the 3D view (100) making CT a superior (12).

II. MCT (Micro-Computed Tomography)

The MCT was the most selected method within this review (28, 51, 59, 63, 66-68, 70, 71, 74-88, 93, 94, 96, 97, 100, 123). Authors specified the reason to this selection as the tool advantages, mainly the ability to obtain 3D assessment of the root canal preparation (51, 66, 75, 88, 94, 96). One study used this method to anatomically match the sample to generate a calibrations by having a reliable baseline and ensures comparability of the groups by standardization (66). However, Stern et al chosen this method for their accurate images owing to their higher spatial resolution than conventional clinical scanners (123) and for their ability to overcome previous techniques limitations (51).

MCT was described as a state of-the-art method in examining the internal anatomy of teeth (126, 142). MCT can investigate the root canal geometry based on wide range of parameters including apical transportation, centering ratio, volume changes, cross-sectional shape, taper, and anatomical structure of root canal before and after instrumentation (7, 54, 143). Its three dimensional ability worked by collecting the two-dimensional projections of X-rays through a specimen, which are then used to reconstruct a three-dimensional image (144). It has been showed that initial scan that used to compare after shaping procedure was enough to test the volume change of the canal (145).

Other advantages of MCT method include its ability to detect anatomical complexities as accessory canals (146), C-shaped canals and isthmuses (147, 148). MCT has emerged as a powerful tool for ex vivo evaluation of root canal morphology due to its accuracy, noninvasive procedure (54), 3D performance at both apical level and point of maximum curvature (84).

The images provided through this method, are induced at a resolution of 11.84 mm, proving to be an excellent method for the precise evaluation of the apical millimeters of instrumented root canals (58). All transferred errors encountered by using radiographic or photographic are avoided (149). This ability to imaging a very small structure made using MCT within this context is very demanding due to its higher magnification and significantly higher resolution compared with the conventional tomography (145). MCT has higher resolution due to the lower voxel size. This importance of the resolution and quality of the image in scientific researches overweigh the time required for the analysis (145).

Previous literature that used MCT analysis were hindered either by insufficient resolution(126) or projection errors (150). Modern machines now offering better resolutions, more accurate measurement software with the capabilities of matching multi-dimensional data from specimens before and after preparation (151). For these reasons, the current generation of MCT is considered a superior method to evaluate the quality of root canal preparation techniques (152). In spite of its high cost in requiring a well-trained operator and long scanning and reconstruction time (145), MCT is becoming a substantial educational tool for pre-clinical teaching in endodontics (153).

III. CBCT (Cone-Beam Computed Tomography)

CBCT is an extra-oral imaging method able to produces 3-dimensional scans of the orofacial skeleton (154). This technique has been selected by few studies in our review (23, 54, 61, 64, 65, 72, 73, 76, 95, 124) along with its advanced type like spiral (54) and ICAT (23, 61). One study used the CBCT only for sample selection process (76). Authors declared that CBCT enabled collecting homogeneous and balanced experimental groups to analyze 2D and 3D values of the sample to precisely interpret endodontic instruments behavior during root canal preparation.

The rationale behind CBCT selection as assessment method, having noninvasive tool characteristic (23, 124), an accurate reproducible of 3-dimensional evaluation (23, 54, 64, 76, 95, 154), is that it can detect alterations in canal curvature, dentin thickness and root canal volume accurately(23, 54, 95, 124, 126, 155, 156).

BCT could overcome the limitations of conventional radiography (157) such as; compression of a three dimensional object into a two dimensional image, image distortion, anatomic superimposition (125). This is the main advantages of the CBCT (158), in addition to the fast data acquisition of CBCT when compared with MCT (73, 159). It is used in clinical endodontic practice and more frequently in endodontic researches to evaluate the root canal morphology, fractures, and changes in prepared root canals (160) volume change, surface area, 3D root canal axis, thickness, surface convexity, structure model index (82).

CBCT produces pure clear images with ability to record all the anatomic details of the teeth (82), however, it has a less resolution compared with MCT, which may cause problems when enhancing data during imaging for research purposes (161).

The method name is due to the X-ray beam shape and the area detector captures a cylinder-shaped volume of data in one gain (162). This made CBCT very convenient both clinically and in research lab (73), whilst MCT is better recommended for laboratory researches only (145). The main shortcomings of using CBCT method are the high cost of the equipment and the time spent in both scanning and reconstruction procedures (49, 73, 75, 93, 108, 111). CBCT scanning requires complex devices, and is more expensive than CT, periapical and panoramic radiography (163). Moreover its voxel size is large as root canal transportation measurement is affected by voxel size (164). Voxel size in MCT ranged from 16.7 mm73 to 39 mm compare with CBCT, which is larger (165), and could reached up to 400 μm (166). The larger voxel size in CBCT imaging led to a partial volume effect, making it impossible to perform accurate measurements (167).

2.3.4 Summary

This detailed discussion of the reviewed studies aimed to enhance understanding of the most reliable method to evaluate shaping ability of endodontic files considering the selected parameters, enabling the researchers to have a standard for testing the shaping ability for NiTi rotary instruments on a strong evidence base. This would further serve as a reference to the clinical practitioners for their daily practice.

Measurement of apical transportations can be particularly challenging because of the fact that there is no gold standard method for their assessment as all methods chosen by researchers have limitations (122). Additionally, apical transportation itself is difficult to measure because no standard exists for this measurement (12, 121). Lastly, it is almost difficult to commence comparison between studies that assessed root canal transportation and centering ability due to lack of standardized evaluation methods among the reviewed studies. Studies on the canal shaping affected by instrumentation need to be homogenous with respect to multiple factors such as canal shape and size, sample model nature, proper superimposition of before and after instrumentation images, the selected method and the study design to objectively evaluate and compare the tools used for evaluation to achieve the optimal recommendation.

Double Digital Images (DDIR+DDIP) technique is a simple method offering two-dimensional photograph to the sample, while MCT and CBCT present a three-dimensional image. Both CT and CBCT are preferred due to their ability to capture images in three-dimension with accurate measurements, providing an opportunity for various slices of the same images. They also have a high efficiency in detecting anatomical complexities in root canal system. They are both superior methods in evaluating and assessment canal preparation quality and could help in sample selections; however, they have a larger radiation exposure, longer time and complex procedure as compared with the Double Digital methods.

3 CONCLUSIONS

This work conducted searches and analyses on the canal transportation and centering ability evaluation parameters. More than 600 studies were identified and screened resulting in sixty-five studies being selected and analyzed. Some conclusions and recommendations are:

1. Evaluating the shaping ability of the root canal files becomes essential with the gradual introduction of new instruments to the market.

2. MCT is an outstanding method in evaluating transportation and centering ability.

3. Future studies should be based on the use of 3D evaluation techniques and more homogeneous samples so that the result would give a better understanding of the instrument performance to the internal anatomy of the root canal system.

4. A possible extension to this work is that future reviews should be carried out on an individual parameter for more accurate results and a systematic review would be advised for obtaining a better and valid evidence base recommendation.

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