



SATHYABAMA INSTITUTE OF SCIENCE & TECHNOLOGY

(Deemed to be University)

Jeppiar Nagar, Chennai



COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY

By

Dr. S. ARAVINTHAN

Dissertation submitted to

**Sathyabama Institute of Science & Technology
(Deemed to be University) Chennai, Tamil Nadu.**

In partial fulfillment of the requirements for the degree of

Master of Dental Surgery

In the Speciality of

CONSERVATIVE DENTISTRY AND ENDODONTICS

Under the guidance of

Prof. Dr. R. KURINJI AMALAVATHY, M.D.S

Head of the Department

Department of Conservative Dentistry and Endodontics

Sathyabama Dental College and Hospital

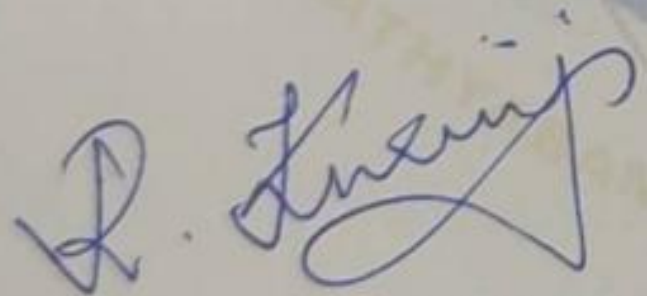
Jeppiar Nagar, Chennai-600119, Tamil Nadu.

2018 – 2021

CERTIFICATE BY THE GUIDE

This is to certify that this dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY** is the bonafide record of work done by **Dr. S. ARAVINTHAN**, under our guidance during his postgraduate study period between 2018-2021.

A Dissertation submitted to the **Sathyabama Institute of Science & Technology (Deemed to be University)** Chennai, Tamil Nadu, in partial fulfillment of the requirements for the degree of **Master of Dental Surgery in the Speciality of Conservative Dentistry and Endodontics**.



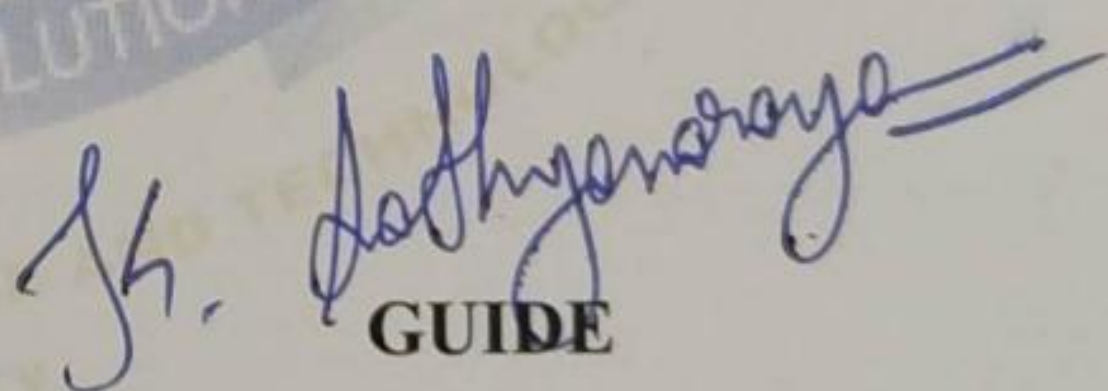
HOD

Dr. R. KURINJI AMALAVATHY M.D.S

Professor,

Department of Conservative Dentistry and
Endodontics

Sathyabama Dental College &
Hospital, Chennai.



GUIDE

Dr. K. SATHYANARAYANAN M.D.S

Reader,

Department of Conservative Dentistry
and Endodontics

Sathyabama Dental College &
Hospital, Chennai.

Date: 30/3/2021

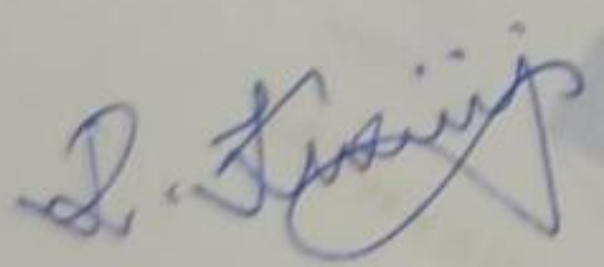
Place: Chennai

**ENDORSED BY THE HEAD OF THE INSTITUTION
AND HEAD OF THE DEPARTMENT**

This is to certify that the dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS- A MICRO CT STUDY** is the bonafide record of work done by **Dr. S. ARAVINTHAN**, under the guidance of **Dr. R. KURINJI AMALAVATHY, M.D.S** Professor and Head, Department of Conservative Dentistry and Endodontics, Sathyabama Dental College & Hospital, Chennai, Tamil Nadu.

Head of the Department

DEAN


Dr. R. KURINJI AMALAVATHY M.D.S


Dr. B. Thayumanavan, M.D.S

Professor and Head of the Department.

Dean

Department of Conservative Dentistry and
Endodontics

Sathyabama Dental College &
Hospital, Chennai.

Sathyabama Dental College &
Hospital, Chennai.

Date: 30/3/21

Place: Chennai



DECLARATION BY THE CANDIDATE

I hereby declare that **Sathyabama Institute of Science & Technology**, Chennai, shall have the rights to preserve, use and disseminate this dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY** as print or electronic format for academic/ research purposes.




Signature of the candidate

Date: 30/3/2021

Place: Chennai



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)



Accredited with "A" grade by NAAC

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119, Tamil Nadu, India.

Phone : 044 - 2450 3150 / 3151 / 3152 / 3154 / 3155 Fax : 044 - 2450 2344

Website : www.sathyabama.ac.in

EC/NEW/INST/2020/1397

26th March 2021

Ref: 173/IRB-IBSEC/SIST Dated 16th March 2021

Dr. A. Wilson Aruni, PhD, FAMPV
Pro Vice chancellor,
Chair Person, Institutional
Biosafety & Ethical Committee
(IBEC), SIST

Dr. B. Thayumanavan, MDS
Dean, Sathyabama Dental College
Secretary & Convener
Institutional Review Board &
Institutional Biosafety & Ethical
Committee (IBEC), SIST

To,
Dr.S.Aravinthan,
III MDS
Department of Conservative Dentistry
Sathyabama Dental College & Hospital
Chennai -119

This is to inform you that the Institutional Bio-Safety & Ethical Committee has approved your study proposal entitled "**Comparative evaluation of Root canal transportation, amount of root canal dentin removal and centering ability after instrumentation in mesial roots of mandibular molars using three Ni-Ti rotary file systems – A Micro CT study**", based on the presentation of the proposal made and recommendations of the Institutional Bio-Safety & Ethical Committee/IRB held on 2nd March 2021.

The validity of the Ethical clearance is for one year and you are expected to submit six-month progress and the final report of the study to IHBSEC/IRB

Dr. Thayumanavan
Secretary & Convener
IBEC, SIST

Dr. A. Wilson Aruni
Deputy Chair Person
IBEC, SIST



SATHYABAMA INSTITUTE OF SCIENCE & TECHNOLOGY

(Deemed to be University)

Jeppiar Nagar, Chennai



COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY

By
Dr. S. ARAVINTHAN

Dissertation submitted to
Sathyabama Institute of Science & Technology
(Deemed to be University) Chennai, Tamil Nadu.

In partial fulfillment of the requirements for the degree of

Master of Dental Surgery

In the Speciality of

CONSERVATIVE DENTISTRY AND ENDODONTICS

Under the guidance of

Prof. Dr. R. KURINJI AMALAVATHY, M.D.S

Head of the Department

Department of Conservative Dentistry and Endodontics

Sathyabama Dental College and Hospital

Jeppiar Nagar, Chennai-600119, Tamil Nadu.

2018 – 2021

CERTIFICATE BY THE GUIDE

This is to certify that this dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY** is the bonafide record of work done by **Dr. S. ARAVINTHAN**, under our guidance during his postgraduate study period between 2018-2021.

A Dissertation submitted to the **Sathyabama Institute of Science & Technology (Deemed to be University)** Chennai, Tamil Nadu, in partial fulfillment of the requirements for the degree of **Master of Dental Surgery in the Speciality of Conservative Dentistry and Endodontics**.

GUIDE

Dr. R. KURINJI AMALAVATHY M.D.S

Professor and Head of the Department.

Department of Conservative Dentistry and
Endodontics

Sathyabama Dental College &
Hospital, Chennai.

Co- guide

Dr. K. SATHYANARAYANAN M.D.S

READER

Co-Guide

Department of Conservative Dentistry
and Endodontics

Sathyabama Dental College &
Hospital, Chennai.

Date:

Place: Chennai

**ENDORSED BY THE HEAD OF THE INSTITUTION
AND HEAD OF THE DEPARTMENT**

This is to certify that the dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS- A MICRO CT STUDY** is the bonafide record of work done by **Dr. S. ARAVINTHAN**, under the guidance of **Dr. R. KURINJI AMALAVATHY, M.D.S Professor and Head**, Department of Conservative Dentistry and Endodontics, Sathyabama Dental College & Hospital, Chennai, Tamil Nadu.

Head of the Department

DEAN

Dr. R. KURINJI AMALAVATHY M.D.S

Dr. B. Thayumanavan, M.D.S

Professor and Head of the Department.

Dean

Department of Conservative Dentistry and
Endodontics
Sathyabama Dental College &
Hospital, Chennai.

Sathyabama Dental College &
Hospital, Chennai.

Date:

Place: Chennai

DECLARATION BY THE CANDIDATE

I hereby declare that **Sathyabama Institute of Science & Technology**, Chennai, shall have the rights to preserve, use and disseminate this dissertation titled **COMPARATIVE EVALUATION OF ROOT CANAL TRANSPORTATION, AMOUNT OF DENTIN REMOVAL AND CENTERING ABILITY AFTER INSTRUMENTATION IN MESIAL ROOTS OF MANDIBULAR MOLARS USING THREE Ni-Ti ROTARY FILE SYSTEMS - A MICRO CT STUDY** as print or electronic format for academic/ research purposes.



Signature of the candidate

Date:

Place: Chennai



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with "A" grade by NAAC

Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119, Tamil Nadu, India.



Phone : 044 - 2450 3150 / 3151 / 3152 / 3154 / 3155 Fax : 044 - 2450 2344

Website : www.sathyabama.ac.in

EC/NEW/INST/2020/1397

26th March 2021

Ref: 173/IRB-IBSEC/SIST Dated 16th March 2021

Dr. A. Wilson Aruni, PhD, FAMPV
Pro Vice chancellor,
Chair Person, Institutional
Biosafety & Ethical Committee
(IBEC), SIST

Dr. B. Thayumanavan, MDS
Dean, Sathyabama Dental College
Secretary & Convener
Institutional Review Board &
Institutional Biosafety & Ethical
Committee (IBEC), SIST

To,
Dr.S.Aravinthan,
III MDS
Department of Conservative Dentistry
Sathyabama Dental College & Hospital
Chennai -119

This is to inform you that the Institutional Bio-Safety & Ethical Committee has approved your study proposal entitled "**Comparative evaluation of Root canal transportation, amount of root canal dentin removal and centering ability after instrumentation in mesial roots of mandibular molars using three Ni-Ti rotary file systems – A Micro CT study**", based on the presentation of the proposal made and recommendations of the Institutional Bio-Safety & Ethical Committee/IRB held on 2nd March 2021.

The validity of the Ethical clearance is for one year and you are expected to submit six-month progress and the final report of the study to IBSEC/IRB

Dr. Thayumanavan
Secretary & Convener
IBEC, SIST

Dr. A. Wilson Aruni
Deputy Chair Person
IBEC, SIST

DECLARATION OF PLAGIARISM CHECK

From,

Dr. S.ARAVINTHAN

III-year Post Graduate Student,

Department of Conservative Dentistry and Endodontics,

Sathyabama Dental College and Hospital,

Chennai - 600119.

To,

The Head of the Department,

Department of Conservative Dentistry and Endodontics,

Sathyabama Dental College and Hospital,

Chennai.

SUB: Declaration of plagiarism check of my dissertation to be submitted to the “Sathyabama Institute of Science and Technology”- 2021.

I hereby declare that I have checked my dissertation for plagiarism using Grammarly Software (reference no: 32273359) - plagiarism checker software on 13-03-2021. The unique content was 90% and the plagiarized content was 10%. The plagiarized content corresponds to definitions and terminologies that have to be quoted and duly cited.

Yours sincerely,

Dr. S.ARAVINTHAN

PLAGIARISM REPORT

Introduction	2%
Review of Literature	5%
Materials and Methods	2%
Results and Discussion	1%
Summary	0%
Conclusion	100 % original

ACKNOWLEDGEMENT

*It is a genuine pleasure to express my deep sense of thanks and gratitude to my respected Professor, **Dr. R. KURINJI AMALAVATHY**, M.D.S, Head of the Department, Department of Conservative Dentistry & Endodontics, Sathyabama Dental College and Hospital, Chennai. Her timely advice, meticulous scrutiny, scholarly advice and scientific approach have helped me to a very great extent to accomplish this task. I heartfully thank her for all the good she has brought to my Post Graduate education.*

*I owe a deep sense of gratitude to my respected teacher and Guide, **Dr .K. SATHYANARAYANAN**, M.D.S, Reader and Co-guide, Department of Conservative Dentistry & Endodontics, Sathyabama Dental College and Hospital, Chennai, for the patient guidance, suggestions, immense support, and constant encouragement to strive for perfection.*

*I would like to express my thanks to **Dr. B. THAYUMANAVAN**, Dean Sathyabama Dental College and Hospital for giving me the freedom to utilize college facilities.*

*I would also like to express my sincere and heartfelt gratitude to **Dr. Megavarnan and Dr. Hrudi Sundar Sahoo** for the valuable suggestions and guidance.*

*My Sincere And Respectful Thanks To **Dr. Murali Sivakumar**, M.D.S Reader, Department Of Conservative Dentistry &Endodontics, **Dr. Sushmita** M.D.S, Reader, Sathyabama Dental College And Hospital , Chennai, For Their Support And Guidance. My Sincere Thanks To **Dr. Purushotham, Dr. Hari Krishna Reddy, Dr. Pavani, Dr. Arun, Dr.Hasini** For Their Guidance Throughout The Course.*

*I would also like to thank **Dr. Pratheepa. R** PHD, Research scholar, SASTRA deemed to be University for her great work in reconstruction of micro-CT images and analysis for my study.*

*I would also like to thank **Dr. S. Porchelvan**, Professor of biostatistics, Saveetha Medical College, Saveetha Institute of Medical and Technical Sciences, Chennai, for helping me with statistical analysis for my study.*

*I would like to acknowledge the support and encouragement of my colleagues **Dr. N. Akshaya, Dr.Dhanireddy.V. Padmaja**. I would like to express my*

*gratitude to **Dr. R. Adisree** for helping me through the thesis study and my juniors **Dr. R. Kalpana, Dr. R. Deepika, Dr. R. Brindha, Dr. Jayakrishanan, Dr. Angel** for their valuable support. I would like to express my love and gratitude to my parents, **Mr. R. Sankar & Mrs. S. Usharani**, My sister **Mrs. Sowmiya. S** and my uncle **Mr. Santhosh kumar. S** for their everlasting support and love.*

*I thank **GOD ALMIGHTY** for being there for me at every step of the way and guiding me in the successful completion of this dissertation. Lastly, I offer my regards to all of those who supported mein any respect during the completion of the project.*

CONTENTS

S.NO	TITLE	PAGE NO.
1.	INTRODUCTION	1
2.	AIM AND OBJECTIVES	9
3.	REVIEW OF LITERATURE	11
4.	MATERIALS AND METHODOLOGY	42
5.	STATISTICAL ANALYSIS	57
6.	RESULTS	58
7.	DISCUSSION	71
8.	SUMMARY	82
9.	CONCLUSION	85
10.	REFERENCES	86

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
1.	The mean and standard deviation of absolute values (Amount of transportation) in millimetre for canal transportation in mesiobuccal root canals for all three tested groups at 3mm, 6mm, and 9mm levels	62
2.	The mean and standard deviation of absolute values (Amount of transportation) in millimetre for canal transportation in mesiolingual root canals for all three groups at 3mm, 6mm, and 9mm levels	63
3.	The mean and standard deviation of original values in millimetres for direction of canal transportation and its frequency of deviation in percentage for mesiobuccal root canals at 3mm, 6mm and 9mm levels.	64
4.	The mean and standard deviation of original values (Direction of transportation) in millimetre for canal transportation in mesiolingual root canals for all three tested groups at 3mm, 6mm and 9mm levels	65
5.	The mean and standard deviation for centering ratio in mesiobuccal and mesiolingual root canals for the tested groups at 3mm, 6mm and 9mm level.	66
6.	The mean and standard deviation of root canal width to root width ratio before and after instrumentation for all tested groups at 3mm, 6mm and 9mm level.	66
7.	The mean and standard deviation of percentage increase in root canal in relation to root width ratio for all tested groups at 3mm, 6mm and 9mm level.	67

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1	Armamentarium with batch number	43
2	Freshly extracted teeth samples	46
3	Samples stored in 0.1% thymol solution	46
4	Stereomicroscope	47
5	Examination under stereomicroscope	47
6	Excluded samples (Red arrow indicate samples with cracks and fracture) after stereomicroscope evaluation	47
7	Mesial part of root after decoronation	48
8	Digital radiographic examination of samples in Bucco-Lingual direction (Red ring indicates excluded samples after radiographic examination)	48
9	Digital radiographic examination of samples in Mesio-Distal direction (Red ring indicates excluded samples after radiographic examination)	48
10	Samples mounted on custom made attachment	49
11	Bruker micro-CT machine	50
12	Samples placed in micro-CT machine for scanning.	50
13	Access cavity preparation	51
14	Represents the sequence of instruments used for TruNatomy group instrumentation.	52
15	Represents the sequence of instruments used for DC Taper 2H group instrumentation	53
16	Represents the sequence of instruments used for 2 Shape group instrumentation	53
17	Micro CT images a) Pre instrumentation b) post instrumentation c) Superimposed images (Green: pre-operative canal; Red: Post-operative canal) green and red lines represents the measuring lines from shortest margin of root to shortest margin of	56

	canal before and after instrumentation respectively.	
18	Micro CT images a) Pre instrumentation b) Post instrumentation for canal/root width ratio	56
19	Micro CT images for trunatomy group	68
20	Micro CT images for DC Taper group	69
21	Micro CT images for 2 Shape group	70

INTRODUCTION

The endodontic triad for successful root canal therapy depends on proper access cavity preparation, thorough debridement of pulp cavity by cleaning and shaping of the root canals, followed by the obturation of the root canal system.⁽¹⁾ Chemo mechanical preparation of the root canal system has been considered as a critical step in root canal therapy, aiming to remove necrotic tissue, microorganisms, and dentin debris from the root canal system.⁽¹⁾ Microbial biofilms in the infected root canal are the primary cause for apical periodontitis. One of the important contributions of mechanical instrumentation is the reduction of microbial load by disruption of biofilm from the root canal.⁽²⁾ Instrumentation mechanically removes the adhered biofilms in the root canal and also creates sufficient space to allow the irrigants to reach the apical third of the root canal system. Several studies have reported the reduction of bacterial load up to two folds after instrumentation and irrigation using physiological saline.⁽³⁾ Enlarging the root canal to adequate sizes removes heavily infected dentin-containing biofilms. It exposes the bacteria to irrigants and intracanal medicaments upto the apical part of the root canal and into dentinal tubules to a specific limit. Hence, instrumentation of the root canal is always prerequisite for all cleaning methods. Improper instrumentation of root canal could lead to persistent apical pathology, resulting in failure of root canal therapy.⁽⁴⁻⁷⁾

Historically endodontic files were manufactured from carbon steel had poor corrosion resistance and were prone to rust. In the early 1900s Kerr, the manufacturing company designed and manufactured the endodontic instruments that were made from stainless steel blanks to improve the efficacy of root canal preparation and to eliminate the disadvantage of carbon steel files. ⁽⁸⁾ Stainless steel files possess an inherent stiffness, which increases with an increase in the instruments' size. Because of its stiffness, the operators had difficulty in preparing curved root canals, especially while using filing motion where the restoring forces attempt to return the instruments to their original shape. ⁽⁹⁾ The advent of NiTi rotary instruments which use 360° rotating low-speed motors have changed the view of root canal instrumentation. *Walia et al. in 1988* were the first to report the application of Nickel Titanium (NiTi) in endodontics. The files are manufactured from nitinol orthodontic wire that composed of 55% nickel and 45% titanium by weight. It had two to three times greater flexibility during bending and torsion when compared to stainless steel files of similar sizes. ⁽¹⁰⁾ Studies have proven that NiTi files to be more flexible than stainless steel files, leading to better preservation of root canal curvature while minimizing procedural errors. ^(11–13) These instruments enabled the practitioners to prepare the challenging root canal complexities to a greater size without producing iatrogenic errors compared to hand stainless steel files. ^(14–16)

The first generation of NiTi rotary files (Eg. ProFile series; Dentsply Tulsa and Maillefer) had passive cutting radial lands with fixed tapers of 4% and 6% over the entire length of their active blades. A large sequence of files were required to accomplish the objectives of root canal preparation which became the drawback of first-generation NiTi rotary files. By the end of 1990s, the second generation of NiTi rotary files came into the market, which had active cutting edges without radial lands and required fewer instruments to fully prepare the root canal due to the presence of variable tapers in a single file. Examples of second-generation NiTi rotary files include ProTaper Universal (Dentsply Tulsa), Mtwo (VDW), K3 (Sybron endo). These files had a variable helical angle between the cutting blades and a variable pitch aimed to reduce the screw-in effect. ⁽¹⁷⁾ The cross-section of these instruments provided greater flexibility compared to first-generation files. However, these files had spring back potential due to their shape memory therefore were less centered in the root canal and reduced torsional resistance led to fracture during instrumentation of curved canals. ^(18–20)

The schilder's principles of instrumentation of root canals should produce continuously tapering funnel-shaped canals following the original path of root canal anatomy, resulting in narrow apical diameter. ⁽²¹⁾ However, these principles were challenging to adhere when instrumenting curved canals, especially

in mesial roots of maxillary and mandibular molars which can lead to a greater likelihood of procedural errors such as root canal transportation, ledge formation, strip perforations, and instrument separation which negatively influences the outcome of root canal therapy by affecting the apical seal. ^(22,23)

Root canal centering ability is defined as an instrument's ability to remain centered in the root canal during instrumentation. Canal transportation is the sustained deviation from the root canal's original axis, creating damage to the apical foramen, leading to loss of apical stop during obturation. ⁽²⁴⁾ Heat treatment is one of the fundamental approaches towards adjusting the transition temperatures of NiTi alloys. It consists of heating a material to a given temperature and cooling it under controlled conditions, after a set period, to obtain specific properties such as superelasticity and shape memory. These two properties are influenced by temperature, heating time, and cooling rate. The martensite phase is readily elastically deformable and can be induced by temperature (cooling) or stress. ⁽²²⁾ Phase transition temperatures depend on the alloy's chemical composition, heat treatment method, and the parameters of cold operation. At room temperature, NiTi endodontic files have shown that the alloy is fully in the austenitic phase exhibiting super elastic property. In recent years, several new thermomechanical processing and manufacturing technologies have been developed to optimize NiTi alloys' microstructure. ⁽⁸⁾ The manufacturers have

begun to focus on utilizing temperature changes in NiTi instruments, which reduces cyclic fatigue and improves safety while working in curved canals. This led to the evolution of third-generation NiTi rotary files. The examples of third-generation (Heat treated) rotary NiTi files are (Eg: HyFlex CM (HyFlex; Coltene Whaledent, Cuyahoga Falls, OH), K3XF (SybronEndo, Orange, CA), ProFile GT Series X (GTX; Dentsply Tulsa Dental Specialties, Tulsa, OK), ProFile Vortex (Vortex) and Vortex Blue (Dentsply Tulsa), etc...

Thermomechanical alteration and surface treatment of NiTi alloy maintain its crystallographic structure, greatly improves their flexibility and cutting efficiency while still maintaining them centered in the root canal. This allows for a biological preparation without removing excessive dentin from the root canal wall. Inadvertent removal of root canal dentin jeopardizes the remaining dentinal thickness and decreases fracture resistance eventually predisposing a root canal-treated tooth to vertical root fracture. Recent studies showed the performance of heat-treated files in the curved canals to be more efficient. ⁽²⁵⁻²⁸⁾

Around the same time, *Yared* experimented on different kinematics for NiTi files to reduce the number of rotations of file during instrumentation to reduce cyclic fatigue. Files were experimented to move in repetitive up-and-down or back-and-forth

motion called reciprocating motion led to the raise of fourth-generation NiTi files. ⁽²⁹⁾Examples of few files in this generation are Wave One and Wave One Gold (Dentsply Tulsa Dental Specialties and Dentsply Maillefer, Ballaigues, Switzerland), Reciproc and Reciproc Gold (VDW, München, Bayern Germany), etc... Many studies have shown that files using reciprocating motion have increased cyclic resistance, reduced torsional stress thereby reducing the incidents of instrument separation; and also require fewer instruments and lesser time for root canal preparation. ^(16,23)The fifth-generation shaping files have been designed so that the center of mass and the center of rotation are offset, producing a mechanical wave of motion that travels along the file's length, minimizing the engagement between the file and the root canal wall. Reduced engagement to the dentin resulted in a limited screw-in effect and undesirable taper lock inside the curved canals. The offset design increased the cross-sectional space leading to enhancement in cutting efficiency. It also provided space for debris removal without extruding out of periradicular space or clogging into the root canal space. ⁽³⁰⁾ Examples of few files in this generation are ProTaper Next (Dentsply Tulsa Dental Specialties and Dentsply Maillefer, Ballaigues, Switzerland), Revo – S (micro mega) etc.

The concept of preserving peri-cervical dentin came into play in recent years, which made a paradigm shift in root canal

instrumentation. Clark and Khademi in 2010 proposed that the peri-cervical dentin i.e., the dentin roughly 4mm above and 6mm below the crestal bone should be preserved to improve the long-term clinical survival of the root canal treated teeth. ⁽³¹⁾

Many files have been introduced into the market based on the concept of preservation of peri-cervical dentin. Of which, TruNatomy instruments (TRN) (Dentsply Sirona, Pennsylvania, United States) has been developed as a novel type of heat-treated NiTi instrument with a superior design. The TRN shaping instruments are provided in three different sizes, which are small (size 20/.04 taper), prime (size 26/.04 taper), and medium (size 36/.03 taper). The manufacturer has claimed that the three shaping instruments of TRN are produced from a slim NiTi wire design of 0.8mm diameter, which provides more space for the debris removal with a variable that has an off-centered parallelogram cross-section design that aids in preserving peri cervical dentin and tooth integrity. ⁽³²⁾

The newly renamed DC Taper is SS White's anatomically designed endodontic file line claim to provide excellent safety, strength, and flexibility. "DC" stands for “dentin conservation” and more accurately reflects one of the key benefits of using these files. DC Taper rotary files have a parabolic cross-section design, and it is made of control memory wire (CM wire). ⁽³³⁾ 2Shape File System

(TS; MicroMega, Besancon, France) is a new generation file system produced with proprietary heat treatment (T-wire), aiming to enhance both the flexibility and cyclic fatigue resistance by 40%. It consists of two files: a TS1 (25/.04) and TS2 (25/.06). This system represents the latest generation of files with a triple helix cross-section, having two leading cutting edges, and one secondary cutting edge, which makes it a perfect compromise between cutting efficiency and debris removal. ⁽³⁴⁾

To our knowledge, there were no studies in the literature evaluating and comparing the shaping ability of TruNatomy, De Taper, and 2Shape files.

AIM AND OBJECTIVES

AIM:

The aim of the present study was to evaluate and compare the canal transportation, centering ability and the amount of root canal dentin removal by three different Ni-Ti rotary files in moderately curved mesial roots of extracted human mandibular molars using micro-computed tomography.

OBJECTIVE:

The objective of this study was to compare three NiTi rotary file systems on

- (i) Canal transportation measured from the superimposed pre-operative and post-operative scanned images of micro-CT at 3mm, 6mm and 9mm levels.
- (ii) Canal centering ability measured from the superimposed pre-operative and post-operative scanned images of micro-CT at 3mm, 6mm and 9mm levels.
- (iii) Amount of dentin removed calculated by measuring the entire root width to canal width from the preoperative and postoperative images of micro-CT at 3mm, 6mm and 9mm levels.⁽³⁵⁾

HYPOTHESIS:

The null hypothesis tested was that there would be no difference in canal transportation, canal centering ability, and the amount of root canal dentin removal among the three NiTi rotary file systems being studied, in mesial roots of moderately curved human mandibular molars.

Alternative hypothesis was that there would be a difference in canal transportation, canal centering ability, and the amount of root canal dentin removal among the three NiTi rotary file systems being studied, in mesial roots of moderately curved human mandibular molars.

REVIEW OF LITERATURE

Christina Razcha et al. in 2020 ⁽²⁷⁾ compared the apical transportation and centering ability of 4 different root canal preparation systems such as Hyflex CM (HCM), Hyflex EDM (HEDM), One Curve (OC), Wave One Gold (WOG) produced with thermal treatments in mesial canals of mandibular molars and evaluated using Microcomputed tomography (Micro-CT) in 3mm, 5mm & 7mm levels from the apex. Results showed that HCM and HEDM maintained the original canal shape. HCM caused less canal transportation than WOG at the 3-mm level in both the buccal and lingual canals. Also, HCM resulted in less canal transportation than WOG and OC at the 7-mm level regarding lingual canals. No statistically significant difference was recorded between the groups when the mean centering ratios were compared. They concluded that all 4 test groups prepared the root canal safely with negligible errors. They found that HCM performed better than WOG and OC in preparing moderately curved root canals.

Funda Yilmaz et al. in 2020 ⁽²⁸⁾ compared the root canal dentin removal and apical canal transportation of 3 different Ni-Ti files such as ProTaper Next (PTN), One Shape (OS) & Edge File X3 (EF X3) in mesiobuccal canals of maxillary first molars using Micro-CT. Results showed that the percentage of dentin removed on the coronal portion and the amount removed for the whole canal length

were statistically similar between groups ($P < .05$). The average amount of apical transportation for the PTN, OS, and EF X3 was 0.197, 0.263, and 0.218 mm, respectively. Statistically, there were no significant differences between the 3 rotary instruments for apical transportation. They concluded that the amount of dentin removed for the coronal portion and whole canal length was similar for all files and no apical transportation of root canal with 3 NiTi files systems studied.

Tufenkci et al. in 2020 ⁽³⁶⁾ performed microg-CT analysis evaluating the shaping ability of one curve (OC), one shape (OS) and ProTaper Next (PTN) files in 3-dimensionally printed lower molars with constant mesiobuccal canal curvature of about 45°. Results showed that all systems showed an increase in canal volume and surface area with no significant difference among OS and OC files. Whereas PTN showed significantly increased canal volume compared to the other two. This was attributed to design of rotary files used in this study. OS and OC have similar triangular cross sections whereas PTN system has rectangular cross section with off centered mass and regressive taper which can make higher contact with the root canal wall resulting in more dentin removal compared to OS and OC. They concluded that the OC file system showed significantly less transportation at apical 3rd than other tested file systems. This may be due to the alloy made of C- wire having

control memory wire property. They confirmed all the three tested file groups are safe to use in severely curved mandibular molars.

Htun et al. in 2020 ⁽³⁷⁾ evaluated the shaping and cleaning ability of unique stainless steel rotary file system (Gentlefile; MedicNRG, Kibbutz Afikim, Israel) compared with 2 nickel-titanium rotary instruments Hyflex EDM; HEDM (Coltene/Whaledent, Switzerland) and ProTaper Next; PTN, (Dentsply Sirona, Ballaigues, Switzerland) using micro-CT imaging in mandibular premolars with curvature ranging from 15° to 25°. The results showed that Gentlefile showed less transportation of root canal in middle third level than HEDM and PTN systems, superior smear layer removal and less debris accumulation than other file system. This was attributed to ultra-flexibility, high rotation speed and abrading motion of Gentlefile system. The greater canal transportation of PTN file at middle 3rd due to increased stiffness and higher vertical force generation compared to Gentlefile system.

Abdullah Mahmoud Riyahi et al. in 2020 ⁽³⁸⁾ evaluated the cyclic fatigue resistance of TruNatomy, Twisted file and ProTaper next Ni-Ti rotary file systems in artificially created stainless steel canals with 60° curvature and 5mm radius. The results showed that TruNatomy files had a significantly higher number of cycles to fracture compared to other file systems. They concluded that thermal treatment, cross-sectional design and thickness of NiTi wire

used in TruNatomy file have resulted in superior cyclic fatigue resistance than other rotary file systems compared in this study.

Amr M. Elnaghy et al. in 2020 ⁽³⁹⁾ evaluated the cyclic fatigue resistance of newly developed TruNatomy file system (TRN) in single and double (S-shaped) curvature canals with Hyflex CM (HCM), Vortex Blue (VB) and RaCe (RC) instruments. The instruments were tested in artificial canals with double curvature (coronal curve; 60° curvature, 5 mm radius and apical curve; 70° curvature and 2 mm radius) and single curvature (60° curvature, 5 mm radius). The results showed that TRN and HCM revealed a higher number of cycles to failure compared with the other instruments for both tested sizes in single and double curvature canals. Whereas TRN and HCM showed no statistically significant difference among them and they concluded that the probability of higher survival rate to failure in the curved canal was higher in TRN and HCM files compared to other two file systems tested in this study.

Peet J. van der Vyver & Ove A Peters et al. in 2020 ⁽⁴⁰⁾ reported a series of cases using a newly developed files system called TruNatomy. It explained the clinical application and benefits of this new file system in minimally invasive endodontics. The authors claimed that this file system could prepare the root canal with maximum preservation of pericervical dentin and offers the

clinician more simplicity, safety, improved cutting efficiency and mechanical properties compared to previous generations of rotating instruments.

Gianluca Plotino et al. in 2020 ⁽⁴¹⁾ did a systematic review on the influence of negotiation, Glide Path and Pre flaring procedures on the shaping of the root canal. They concluded that glide path preparation reduces the risk of debris extrusion, has no influence on the incidence of dentinal crack formation, and improves the preservation of the original canal anatomy. Creating a glide path may have no impact on Reciproc files in reaching the full working length. Pre flaring increases the accuracy of working length determination. Further randomized clinical trials are required to evaluate a glide path's effect and pre flaring on root canal treatment outcome.

Shalini Singh et al. in 2019 ⁽⁴²⁾ compared the volume of dentin removal, canal transportation and centering ability of three Ni-Ti file systems such as 2 Shape (2S), Wave One Gold (WOG) & ProTaper Gold (PTG) in the mesiobuccal canal of mandibular 1st molar and evaluated using cone beam computed tomography (CBCT). Results showed no significant differences between the 2S and WOG in terms of the total volume of removed dentin, apical transportation, and centering ratio. In contrast, ProTaper showed a greater significant difference when compared to 2S and WOG. They

concluded that both 2S and WOG maintained the original shape of root canal anatomy and less dentin removal than the ProTaper gold file. The results are attributed to the files' metallurgy and use of lesser number of files compared to multiple file systems.

Van der Vyver et al. in 2019⁽⁴³⁾ evaluated the shaping ability of NiTi instruments manufactured from M wire such as ProTaper Next (PTN), nickel titanium wire namely One Shape (OS) and gold wire such as Wave One Gold (WOG) using different glide path files such as K file (KF), One G (OG) and ProGlider (PG) in mesiobuccal roots of maxillary molars analysed using micro-CT at 2mm, 5mm and 9mm levels. The results showed that centering ratios for all groups are similar. Apical canal transportation was significantly high for KF/OS group and KF/PTN group. At 5mm level canal transportation was significantly higher in KF/PTN group than other tested groups except KF/OS and OG/OS were statistically similar. WOG combined with PG showed better shaping ability than other groups due to its working motion, metallurgy and cross-sectional design. They concluded that PTN and OS instruments used in combination with KF showed significantly higher canal transportation and PTN instruments removed higher volume of dentin regardless of glide path preparation technique used.

Nieves Perez et al. in 2019⁽⁴⁴⁾ evaluated the shaping ability of TRU Shape (TRU) and XP endo shaper (XPS) in moderately curved root

canals of maxillary premolars analysed using micro-CT. The results showed no statistical difference among the files. They concluded that TRU and XPS produced less canal transportation and lesser change in canal volume and less untouched surfaces on canals in moderately curved upper premolars. This was probably due to reason that both the files were made from blue NiTi alloy exhibiting higher flexibility. But, none of the systems were able to touch all parts of root canal wall.

Albuquerque et al. in 2019 ⁽²⁶⁾ compared the root canal transportation, centering ability and dentin removal after instrumentation in mesial canals of lower molar using various rotary and reciprocating systems such as ProTaper Next (PTN), Vortex blue (VTX), Wave One Gold (WOG) and ProDesign logic (LOG). Micro-CT images was used to analyze the pre and post instrumentation of tested groups. The results showed no statistical difference among tested groups in canal transportation at 6mm and 9mm from the apex, whereas at 3mm, LOG showed a smaller mesial deviation than PTN. In terms of centering ability, LOG showed the best centering ability at 3mm and least at 9mm. LOG files showed less dentin removal apical 3rd compared to other systems. They concluded that different results had been obtained among tested groups in different parameters at each third.

Aydin et al. in 2019 ⁽⁴⁵⁾ compared the transportation and centering abilities of the ProGlider (PG), Wave One Gold Glider (WOGG) and R-Pilot (RP) file systems and the changes in the structure model index (SMI), surface area, and root canal volume after creating the glide path in the mesial canals of mandibular first molar with moderate curvature using the micro-CT method. Mesio Buccal and mesiolingual canals of mandibular first molars were instrumented using VDW gold Reciproc files after glide path preparation with respective experimental files. Results showed that WOGG and RP file systems showed better-centering abilities at all thirds compared with the PG file system. No significant difference was found in the apical third between the groups in terms of degree of canal transportation. The changes in the root canal volume and surface area in the WOGG and RP groups were significantly lower than in the PG group. This may be attributed to the smaller taper of WOGG and RP files. The authors concluded that The WOGG and RP file systems caused similar levels of change in the root canal systems based on all parameters. Moreover, it was determined that the PG file system caused a significantly higher volume and surface area increase than the WOGG and RP file systems. This was due to the file motion used and authors found that reciprocation motion produced more centered canal preparation compared to rotary motion.

Oliveira et al in 2019 ⁽⁴⁶⁾ evaluated the changes in canal geometry and transportation of severely curved mesial roots of mandibular molars prepared by four heat treated NiTi file systems such as Pro-Taper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland), Reciproc (RC; VDW GmbH, Munich, Germany), Reciproc Blue (RCB, VDW GmbH), and TRUShape (TRU; Dentsply Tulsa Dental Specialties, Tulsa, OK) systems using micro-CT. The results showed that all file systems showed a significant increase in root canal surface post instrumentation. No significant difference was found in canal transportation, volume and surface area increase in RC and RCB systems compared to PTN and TRU files. In coronal third RC and RCB showed greater increase in mean than PTN and TRU. The authors concluded that instruments with greater taper may produce higher morphologic changes. However, regardless of instrument sequence, taper, design and kinematics, heat treated files did not show any difference in dimensional change and canal transportation in the apical area.

Amr M. Elnaghy et al. in 2018 ⁽⁴⁷⁾ compared the cyclic fatigue resistance of different Ni-Ti file systems such as 2 Shape (TS), One Curve (OC), Vortex Blue (VB), ProFile Vortex (PV), and RaCe (RC) instruments in artificial canals with a single curvature (60° curvature, 5 mm radius) and double curvature (coronal curve, 60° curvature, 5 mm radius; and apical curve, 70° curvature and 2 mm radius). The results showed that the VB instrument had a

significantly higher number of cycles for failure (NCF) than the other instruments in double (S-shaped) and single curvature canals. There was no significant difference between OC and TS in the NCF in single, apical, and coronal double curvature canals. They concluded that the fatigue resistance of VB was greater than that of other instruments. OC and TS instruments displayed superior cyclic fatigue resistance than PV and RC instruments.

Gianluca Plotino et al. in 2018 ⁽⁴⁸⁾ evaluated the cyclic fatigue resistance of Hyflex EDM (HEDM), Wave One Gold (WOG), Reciproc Blue (RB), and 2Shape (TS) NiTi systems having different metallurgic properties. The instruments were tested in artificial canals which were made of stainless steel with an inner diameter of 1.5 mm, 45° and 90° angles of curvatures and a radius of curvature of 5 mm and the number of cycles to fracture (NCF) and time to fracture (TTF) were evaluated. Results showed that the TTF of all the instruments tested in the artificial canal with 45° curvature, RB had statistically the highest cyclic fatigue resistance followed by HEDM and TS. In the artificial canal with 90° curvature, RB showed a significantly higher cyclic fatigue resistance than the other tested files. When the NCF values were considered, HEDM reported a significantly higher cyclic fatigue resistance than TS in both canal curvatures analyzed. They concluded that Reciproc Blue files showed higher cyclic fatigue resistance than other tested files.

Drukteinis et al. in 2018 ⁽²⁵⁾ evaluated and compared the dentin removal, canal volume and percentage of uninstrumented canal surface of 3 different rotary systems such as ProTaper Next (PTN), Bio Race (BR) and Genius (GN) in mesial roots of mandibular first molar analysed using micro-CT imaging. The results showed no significant difference among tested groups in all parameters. They concluded that BR, PTN & GN NiTi file systems were equally effective with no evidence of change in the root canal shaping.

Zuolo et al in 2018 ⁽⁴⁹⁾ compared the shaping ability of four NiTi file systems such as Bio Race, Reciproc, Self-Adjusting File (SAF) and TRUShape in oval canals of mandibular central incisors using micro-CT. Results showed that SAF has least percentage of untouched canals compared to Bio Race and Reciproc. The Reciproc system removed significantly more dentine (4.18%) compared to the Bio Race (2.21%) and SAF (2.56%) systems. TRUShape showed intermediate results for both untouched surfaces and dentine removal with no significant difference between BioRace and Reciproc. The authors concluded that none of the shaping systems produced optimal shaping in oval root canal. SAF touched most part of root canal but removed less dentin. This was attributed to the hollow NiTi lattice of SAF which adapts three dimensionally to root canal by itself allowing greater surface of walls to be touched and transline motion helps to remove lesser dentin. They also concluded

that Reciproc removed more dentine due to its kinematics and larger taper and design.

Park et al. in 2018 ⁽⁵⁰⁾ compared the root canal volume change and canal transportation of Vortex Blue (VB), ProTaper Next (PTN) and ProTaper Universal (PTU) NiTi files using micro-CT in human molar with curvature ranges from 20°- 45°. Results showed that VB files produced inward canal transportation than the other two tested systems and PTU showed higher transportation than PTN. This was mainly attributed to skipping of coronal flaring step in the study. No significant difference was found in canal volume change among three tested systems. They concluded that VB files produced better shaping ability in severely curved canals without changing the root canal anatomy.

Duarte et al. in 2018 ⁽⁵¹⁾ evaluated the centering ability, canal transportation and cyclic fatigue resistance of Twisted file (TF) adaptive and Navigator EVO file systems in two different motions (adaptive and continuous rotation) in mesiobuccal canals of maxillary molar using micro-CT. Results showed no significant difference found at 3mm and 9mm in both file systems in terms of evaluated parameters. The TF continuous motion produced higher canal transportation towards the furcal region at 6mm than the navigator adaptive and continuous motion. Higher cyclic fatigue resistance found in continuous motion than adaptive motion

regardless of the file system used. The authors concluded that both systems produced similar shaping ability with an increase in the life span of files found in continuous motion than adaptive. Good centering ability and little canal transportation occurred when mesiobuccal root canals from maxillary molars were prepared up to size 35.04 instruments.

Berechet et al. in 2018 ⁽⁵²⁾ evaluated the changes in root canal morphology after instrumenting with ProTaper Next (PTN) and One Shape file (OS) in mandibular molars analyzed using Micro-CT. Results showed that there is no difference in volume and surface area increase of the root canals. The authors concluded that both instruments maintained the original anatomy path by maintaining continuous, safe and tapered preparation.

Belladonna et al in 2018 ⁽⁵³⁾ assessed the canal transportation, percentage of dentin removed and untouched canal walls in mesial roots of mandibular molars prepared by blue thermal treated file (Reciproc Blue; RCB) compared with M wire file (Reciproc; RC) using micro-CT. Results showed that no significant different among the two files in all analyzed parameters. They concluded that root canals prepared with conventional M wire and Reciproc Blue file produced similar shaping outcome.

Guimaraes et al. in 2017 ⁽⁶⁵⁾ compared the shaping properties of TRUShape and Reciproc instruments in oval-shaped canals of mandibular premolars. The results showed that TRUShape revealed less unprepared areas than Reciproc. However, this is not statistically significant at the apical 3rd of the root canal. They concluded that none of the instruments could completely prepare oval-shaped root canals.

Brasil et al. in 2017 ⁽⁵⁵⁾ compared the canal transportation, unprepared areas and dentin removal after instrumentation with ProTaper next (PTN) and BT RaCe (BTR) in mesial canals of mandibular molar evaluated using micro-CT imaging. They found no statistical difference between both the systems in all evaluated parameters. The unprepared areas for full canal length (10mm) and apical segment (5mm) were 33% and 14% for BT-RaCe and 31% & 14% for PTN respectively. The authors concluded that none of the tested instruments prepared the canal width exceeding 40% which increases the risk of root fracture because of excessive dentin removal, and no differences were found among the unprepared surfaces between the two instrumentation systems.

Pinheiro et al. in 2017 ⁽⁵⁶⁾ evaluated the shaping ability of 5 thermally treated NiTi file systems such as Hyflex CM (HCM), ProDesign Logic (PDL), ProTaper gold (PTG), Hyflex EDM (HEDM) and ProDesign S (PDS) in mesial roots of mandibular

molars. The results showed no significant difference among rotary systems in canal transportation. In cervical transportation HCM and PDL showed less deviation than other systems. They concluded that all of the tested NiTi file systems produced similar shaping ability.

Almeida Rodrigues et al. in 2017 ⁽⁵⁷⁾ done a review on the relationship of recently introduced Ni-Ti files with different movement kinematics and shaping ability, apical extrusion of debris and dentin defects in root canal preparations. A total of 45 papers were included for analysis describing the effects of reciprocating, continuous and adaptive movements on the Wave One Gold, Reciproc, Hyflex CM and Twisted File Adaptive systems. The results showed that due to the wide range of testing conditions and methodologies that have been used to compare the systems, the results appear to be inconsistent in determining the best approach

Kyaw Moe et al in 2017 ⁽⁵⁸⁾ evaluated the shaping ability of two NiTi files with off centered mass such as ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) and Revo-S (RS; Micro-Mega, Besancon, France) compared with NiTi file having conventional centered mass ProTaper Universal (PTU; Dentsply Maillefer) in mandibular molars using micro-CT. The results showed that PTU system had less centered preparation in apical 1mm than PTN and RS groups. They concluded that regardless of alloy type, cross section and taper variation, files with off centered

rotation showed better centered preparation and lesser transportation compared to files with conventional mass of rotation.

Alovisi et al in 2016 ⁽⁵⁹⁾ evaluated the ability of different files for glide path ProGlider (PG) PathFiles (PF) and K-files (KF) with shaping outcome of ProTaper Next (PTN) file in curved root canals of maxillary molar using micro-CT. Results showed that increase in the canal diameter ratio after glide path preparation at apical level with significant difference in maintenance of canal anatomy by PF and PG files as compared to K files. At coronal level PG showed maximum increase in canal diameter than K file. This may be attributed to its progressive taper. K file showed more canal transportation than PF and PG at apical level. They concluded that overall ProGlider instruments facilitated more centered root canal preparation after shaping PTN file than other two tested glide path files.

Yu Gu et al. in 2016 ⁽⁶⁰⁾ assessed the various heat-treated files such as Twisted Files (R-phase), Wave One (M-wire), Hyflex CM, or V Taper 2H (CM-wire) in an S-shaped resin canal, evaluated the canal volume change and canal transportation using micro-CT. the results showed that all the tested files produced canal transportation at the coronal portion whereas twisted files produced more transportation at the apical level compared to other files.

Limoeiro et al. in 2016 ⁽⁶¹⁾ evaluated the shaping ability of PTN and BioRace (BR) NiTi instruments in curved mandibular molars analyzed using Micro-CT. The results showed no significant difference between the two systems in terms of canal volume change, transportation and untouched canal surfaces. They concluded that both the systems prepared mesial canals of a mandibular molar with a negligible amount of procedural error and less transportation of root canals.

Saberi et al in 2016 ⁽⁶²⁾ compared the centring ability and transportation of ProTaper Next (PTN), ProTaper Universal (PTU), Race 123 and RevoS using micro-computed tomography in mesial roots of mandibular molars. Results showed that in the coronal and middle third of the root canals, the differences in centring between PTN and PTU/RevoS were significant. PTN showed more centered preparation than other file systems. This was attributed to the off centered rectangular cross section and variable taper of the file.

Silva et al in 2016 ⁽⁶³⁾ evaluated the canal transportation and centering ability of ProTaper Next (PTN) and Twisted File Adaptive (TFA) systems in moderately curved mesial roots of mandibular molars using micro-computed tomographic (micro-CT) imaging. Results showed that root canals prepared with both PTN and TFA had no significant difference in tested parameters at all levels. They

concluded that both systems produced similar root canal preparation at all evaluated levels.

Palekar et al. in 2016 ⁽⁶⁴⁾ evaluated the canal transportation and centering ability of K files, ProGlider (PG), and G Files (GF) after glide path enlargement in mesiobuccal and mesiolingual canals of the lower molar. The results showed that KF was less centered in the root canal at 1mm than PG. No significant difference was found among the NiTi glide path files. They concluded that PG and GF showed less canal transportation and produced more centered preparation than KF.

Dayananad Chole et al. in 2016 ⁽⁶⁵⁾ done a review on canal transportation of root canal during instrumentation. They stated that factors influencing the apical transportation of root canal are instrument cross-section, a taper of the file, Tip design and manufacturing alloy. They found that an increase in taper increases the chances of apical transportation. Ni-Ti files showed higher transportation compared to stainless steel files because of non-end cutting tips. Instruments with a positive rake angle showed higher chances of transportation compared to others. They concluded that irrespective of the instrument used canal transportation is seen in Ni-Ti files and stainless-steel files with various cross-sections, taper, tip design and alloys.

Van der vyer et al in 2016 ⁽⁶⁶⁾ compared the canal centering ability and transportation of three glide path files such as K flex files, ProGlider files and One G files in curved root canals of mesiobuccal roots of maxillary molars analysed using micro-CT found that One G and ProGlider files showed statistically significant mean of centering ratio compared to K flex files and changes in canal volume were significantly similar for three glide path files.

Ordinalo – Zapata et al. in 2015 ⁽⁶⁷⁾ evaluated the accuracy of the Clearing technique and CBCT in the assessment of root canal configuration and compared using Micro-CT as a reference standard. They concluded that assessing anatomical configuration in the mesial roots of mandibular molar neither CBCT nor Clearing technique is accurate than micro-CT.

Acar et al. in 2015 ⁽⁶⁸⁾ compared the accuracy of micro-CT and CBCT in detecting the accessory canals in primary molars. The results showed a statistical difference in the correlation of micro-CT images compared with a stereomicroscope, which was used as a gold standard tool to detect accessory canals in primary molars. No statistical difference was found between CBCT and stereomicroscope images. They concluded that although micro-CT is not suitable for clinical practice, it provides detailed information on root canal configuration compared to CBCT and stereomicroscope. However, Clinically, CBCT is a convenient tool for analysing the

root canal geometry but may not analyse primary teeth' internal anatomy.

Gagliardi et al in 2015 ⁽⁶⁹⁾ evaluated the shaping characteristics of ProTaper Gold (PTG; Dentsply Maillefer, Ballaigues, Switzerland, ProTaper Next (PTN, Dentsply Maillefer) and ProTaper Universal (PTU, Dentsply Maillefer) systems using micro-computed tomographic imaging in mesial roots of mandibular first molars. Results showed that PTN had higher percentage of static voxels than PTU and PTG groups. PTG and PTN groups showed less transportation, less dentin removal and higher centering ability than PTU system whereas, PTN had higher untouched canal surface than PTG and PTU group. This may be attributed to smaller dimension of file with offset motion of PTN system. The authors concluded that all file systems were able to instrument moderately curved mesial root canals of mandibular molars without clinically significant errors.

Pasqualini et al. in 2015 ⁽⁷⁰⁾ evaluated the shaping property of ProGlider with ProTaper next (PG/PTN) and ScoutRace/BioRace (SR/BR) nickel-titanium rotary system in mesiobuccal canal of maxillary first molar analyzed using micro-CT. Results showed that canal centering ability was superior in PG/PTN group in apical 3rd and at point of maximum curvature with no statistical difference in canal volume change, but PG/PTN slightly reduced the inner dentin

wall thickness with no significant difference. They concluded that neither of the systems produced a significant shaping error. PTN was more conservative in root canal anatomy compared to the BR file.

Gergi et al. in 2015 ⁽⁷¹⁾ compared and evaluated the shaping ability of several nickel titanium instrument systems with different motions: two reciprocating single-file systems (Reciproc and Wave One) and one continuous rotation/reciprocation full-sequence system [Twisted File (TF) Adaptive] using micro-computed tomography in mesial canals of the mandibular canal. Results showed that none of the instruments were able to prepare the root canal system thoroughly. Reciprocation and Adaptive Motions were found to cut dentine efficiently to full working length, with no procedural errors. The TF Adaptive system maintained the original canal anatomy with less canal transportation and better centering ability.

Ove A peters et al. in 2015 ⁽⁷²⁾ tested the effects of TRUShape (TRU) and conventional rotary file (Vortex; VX) in terms of dentin volume, smallest radicular wall thickness, treated canal surface, canal transportation and accumulated hard tissue debris. The results showed that both instruments promoted preparation with no overt procedural errors. Vortex removed significantly more dentin both at size #20 and #30. TRU removed less dentinal wall compared to VX

with TRU showing less canal transportation. The authors concluded that TRU was able to produce better shaping of root canal compared to VX with less canal transportation.

Pedulla et al in 2015 ⁽⁷³⁾ evaluated the shaping ability of curved root canals using Twisted File Adaptive (TFA) files (SybronEndo, Orange, CA) and Mtwo (Sweden & Martina, Padova, Italy) activated by continuous rotation or adaptive motion in severely curved mandibular molars having two separate mesial root canals. Results showed that TFA files showed less increase in volume and surface area than other group with no significant difference. TFA files showed less transportation and higher centering ability compared to Mtwo in both motions. They concluded that TFA performed significantly better in middle and coronal third of root canal than Mtwo and showed no significant difference in apical third between the devices regardless of kinematics used. The difference in results in middle and coronal third are attributed to heat treatment and adaptive motion of NiTi files.

Ha JH et al. in 2014 ⁽⁷⁴⁾ examined the effect of several standard geometric characteristics of rotary instruments on the 'screw-in' forces and stresses generated on root dentine using 3D finite element analysis (FEA). Four cross-sectional designs (triangular, slender-rectangular, rectangular and square) were evaluated. The results showed that a square cross-section instrument had the

highest 'screw-in' force and torsional stresses, followed by the rectangle, the triangle design, and the slender-rectangle design. The file with a closer pitch generated lower stresses than a file with a longer pitch. The greater the root canal curvature, the higher the 'screw-in' force and reaction torque generated. The authors concluded that Screw-in tendency is attributed to both canal curvature and instrument geometry. Hence, they advised to use brushing motion to prevent the instrument from being pulled into the canal.

Zhao et al. in 2014 ⁽⁷⁵⁾ described the canal shaping properties of 3 NiTi rotary files Protaper Next (PTN), Protaper Universal (PTU), and Wave One (WO) in human first mandibular teeth by using micro-CT. Results showed that the distal canal had a significantly higher number of untouched surfaces than the mesial canal. PTN system showed less transportation compared to PTU & WaveOne in apical 3rd of mesial canals. There was no significant difference in the transportation between the file systems in distal canal. They concluded that curved canals prepared using PTN files showed less transportation than other file systems and WaveOne showed faster instrumentation of root canal compared to PTU and PTN files.

Gergi et al. in 2014 ⁽⁷⁶⁾ evaluated and compared the canal transportation ability of Reciproc (RP), WaveOne Gold (WOG) and Twisted files Adaptive (TF) NiTi file systems in severely curved

mesial canals of a mandibular molars. TF showed less canal transportation with the statistical difference in apical third compared to the other two file systems. No statistical difference was found in canal transportation among WOG & Reciproc. The authors concluded that TF produced better shaping of the root canal than WOG and Reciproc.

Mohan Gundappa et al. in 2014 ⁽⁷⁷⁾ systematically reviewed the articles on canal centering ability of rotary cutting Ni-Ti instruments and subjected the results to meta-analysis found that maximum of studies has been conducted in mesiobuccal canal of mandibular first molar with curvature ranging from 15° - 60°. The difference among the rotary instruments on centering ability showed statistically no difference. CBCT was found to be the most effective method of evaluating canal centering ability. Because of a wide variety of factors that would influence the centering ability, the clinician should be selective in choosing the file system that best fits each tooth's individual needs.

Alves et al. in 2014 ⁽⁷⁸⁾ evaluated the shaping ability of single file reciprocating (Reciproc, WO) and multiple files including rotary file such as Hyflex CM (HCM) and adaptive file such as Twisted File (TF) in mesial canals of mandibular molars. Results found that the Reciproc group showed a greater increase in canal volume at apical 3rd compared to others. TF and HCM showed less canal

transportation than Reciproc and WO groups. They concluded that shaping procedures led to the enlarged 3-Dimensional parameters in the root canal. TF and HCM maintained the original canal anatomy than Reciproc and WaveOne group.

Mcraay et al. in 2014 ⁽⁷⁹⁾ evaluated canal transportation and canal centering ability of PTU and WO reciprocating file in the mesial roots of mandibular molars analyzed using Micro-CT. The results showed that WO showed better centering ability than PTU in 1mm, 3mm, 5mm. PTU showed less transportation than WO in 1mm and 3mm with no statistically different values. They concluded that both systems produced safer root canal preparation in mandibular molars.

Bürklein and Schafer in 2013 ⁽⁸⁰⁾ discussed the impact of canal transportation on treatment outcomes. They identified some factors responsible for canal transportation: (i) root canal anatomy – Severely curved root canals have a smaller diameter of radius results in transportation of root canal. (ii) Instrument technique - Independent of the instrumentation technique, straight-line access is required to reduce the canal transportation risk. Creating a glide path reduces the risk of canal transportation; Modern full-sequence rotary NiTi systems, reciprocating or full rotation single-file systems, and the SAF are best suited to prepare even severely curved canals with a negligible risk of canal transportation. They found that data available on the impact of canal transportation on

treatment outcomes are inconclusive. Unfortunately, only a little evidence is available to justify that the use of contemporary instruments has a significant impact on the outcome of root canal therapy.

Versiani et al. in 2013 ⁽⁸¹⁾ assessed the shaping ability of single file SAF, WaveOne (WO), Reciproc and multiple file systems (PTU) in oval canals of mandibular canines using Micro-CT. The results showed a significant increase in canal diameter postoperatively in all systems with untouched surfaces present mainly in the lingual part of canals. SAF showed less change in canal diameter and untouched surfaces, whereas WO and PTU presented the highest number of untouched canal but with no statistical difference. They concluded that all systems performed similarly in the shaping of oval canals.

Netto et al. in 2013 ⁽⁸²⁾ compared the two endodontic preparation systems (PTU and Endo EZE AET) in single rooted mandibular premolars using micro-CT. The results showed no significant difference in canal volume change between two systems, but a significantly higher amount of prepared surfaces by Endo EZE AET file system compared to PTU. They concluded that Endo EZE AET prepared more surfaces in the root canal with no difference in canal volume than PTU.

Zhao et al. in 2013 ⁽⁸³⁾ evaluated the preparation of mesiobuccal root canals in maxillary molar with Hyflex CM (HCM), Twisted files (TF) and K3 instruments using micro-CT imaging. Results found that TF showed increased dentin removal than HCM & K3. Less transportation of canal was found in TF than K3, whereas no significant difference was found between HCM & TF. No significant differences were found in terms of untreated canal surfaces. The authors concluded that HCM and TF demonstrated better shaping ability than K3 instruments in maxillary molars.

Stern et al. in 2012 ⁽⁸⁴⁾ assessed the canal volume change and instrumentation time among ProTaper files used in continuous and reciprocating motion compared to TF in continuous rotation in mandibular molars. The authors found that there is no statistical difference in canal volume change and centering ability. They concluded that more centered canal preparation was evident regardless of motion used in ProTaper and TF files.

Yamamura et al. in 2012 ⁽⁹⁾ compared the canal transportation ability and the centering ratio of EndoSequence and Vortex rotary files in separate mesiolingual and mesiobuccal canals of mandibular molar analyzed using micro-CT imaging. The results from this study revealed that both the systems showed no statistical difference in canal transportation and centering ability at 1mm, 3mm and 5mm, and EndoSequence rotary file (30/.04) showed statistical difference

in the transportation of root canal compared with Vortex files at 7mm. The authors concluded that this study does not support one rotary file system over another in canal transportation and centering ability.

Freire et al. in 2011 ⁽⁸⁵⁾ evaluated the canal centering ability and canal transportation of files manufactured using twisted (Twisted files; TF) and grinding (EndoSequence; ES) process after instrumentation in mesiobuccal canals and mesiolingual canals of lower molar respectively analyzed using micro-CT. Results showed a statistical difference in 3 and 4mm levels among tested groups with lesser transportation and higher centering ability produced by TF than ES instruments. They concluded that both the twisted and grinding process for manufacturing NiTi files produced similar values in tested parameters.

Paque et al. in 2011 ⁽⁸⁶⁾ assessed the shaping ability of Self Adjusting file (SAF) system in long oval root distal canals mandibular molars using micro-CT. Results showed that volumes and surface areas increased significantly by $4.84 \pm 1.73 \text{ mm}^3$ and $3.34 \pm 1.73 \text{ mm}^2$, respectively and no gross preparation errors were detected. Unprepared canal surface varied between individual canals, and the mean unprepared surface was $23.5\% \pm 8.9\%$. Canal transportation scores were higher in the coronal root canal third ($106 \pm 50 \text{ mm}$) than the apical third ($81 \pm 49 \text{ mm}$). They concluded

that the preparation of long oval-shaped root canals in mandibular molars with the SAF was effective and safe.

Loizides et al. in 2007 ⁽⁸⁷⁾ done a comparative study evaluating the effects of Endoflare, Hero-shaper, Hero-apical and Protaper Ni-Ti rotary instruments on root canal geometry on the mesial root of mandibular molar analyzed using micro-CT. Differences in canal roundness, cross-sectional area, the perimeter of each canal before and after instrumentation, and the extent of root canal transportation were calculated. Both preparation techniques prepared the canals rapidly with a sufficient round shape. They concluded that greater potential for improvement in shaping ability using hybrid instrumentation.

Peters OA et al. in 2001 ⁽⁸⁸⁾ evaluated the effects of root canal preparation using four NiTi file systems (i.e., NiTi K files, ProFile, Lightspeed, GT- Rotaries) on canal volume and surface area in extracted human maxillary molars using micro-CT. They also attempted to quantify canal transportation three dimensionally. Results showed that instrumentation of canals increased volume and surface area. Prepared canals were significantly more rounded, had greater diameters and were straighter than unprepared canals. However, all instrumentation techniques left 35% or more of the canals' surface area unchanged. They concluded that there were few differences between the four canal instrumentation techniques used.

By contrast, a strong impact of variations of canal anatomy was demonstrated.

Peter's OA et al. in 2000 ⁽⁸⁹⁾ evaluated the potential and accuracy of a three-dimensional, non-destructive technique for visualizing the root canal geometry utilizing high resolution computed tomography. They were able to calculate surface areas, volumes of each canal and canal diameter. They concluded that this is an innovative technique assessing the root canal geometry accurately and is non-destructive also serves as a tool for future experimental studies in endodontology.

Wu et al. in 2000 ⁽⁹⁰⁾ evaluated the effect of apical transportation on the apical seal on root filling in single and curved canals using NiTi file (Lightspeed) and Stainless-steel file (K file). They concluded that stainless steel instrumentation using step-back technique showed more apical transportation than the NiTi file. They also found that the occurrence of apical transportation is a negative factor in curved canals obturated using lateral condensation leads to more leakage. They reported that apical transportation over 0.4 mm could negatively affect the sealing ability of filling material.

Rhodes et al. in 1999 ⁽⁹¹⁾ examined the root canal after instrumentation using prototype micro-CT compared with video

images. They concluded that micro-CT is an accurate, non-invasive method of examining the tooth structure that can be applied quantitatively and qualitatively. Correlation between micro-CT and digital images were highly significant.

MATERIALS AND METHODOLOGY

ARMAMENTARIUM USED:

ROTARY FILES:

1. TruNatomy (TRN; Dentsply Sirona, USA) (LOT: 1636146).
2. V- Taper 2H (SS White, Lakewood, CA) (LOT: D69023222).
3. 2Shape (TS; Micro-Mega, Besancon, France) (LOT: 042817).

GLIDE PATH FILES:

1. TruNatomy glider (Dentsply Sirona, USA) (LOT: 1636144).
2. ONE G (Micro-Mega, Besancon, France). (LOT: 0428)
(Figure-1).

FILE OPERATING SYSTEM– X Smart Plus (Dentsply Sirona)
(REF: A 103200000000)

HAND FILES- #8 size and # 10 size K files (Mani, Japan).

Endobloc (Dentsply Sirona, USA) (LOT: 1406250).

BURS:

1. Endo Access bur (Dentsply Sirona, USA) (LOT 1641029).

IRRIGATING SOLUTIONS:

1. 3% Sodium Hypochlorite (NaOCl; VIP vensons, India) (B.NO: 09295).
2. 17% Ethylene diamine tetra acetic acid (Anabond, India) (B. No: DSS/038).

3. 0.9% Normal saline (NS) (REF: 83NE304016).

NEEDLES AND SYRINGES:

1. TruNatomy irrigation needles (Dentsply Sirona, USA) (20KM059).
2. 30 G side vented needles (Ultra dent, USA) (B. No: 842026USJ2).

Stereomicroscope (LEICA M205A).

Composite resin (GC Solare X) (LOT: 1436124).

Bruker micro-CT (Sky scan 1176, Kartuizersweg 3B, Belgium)

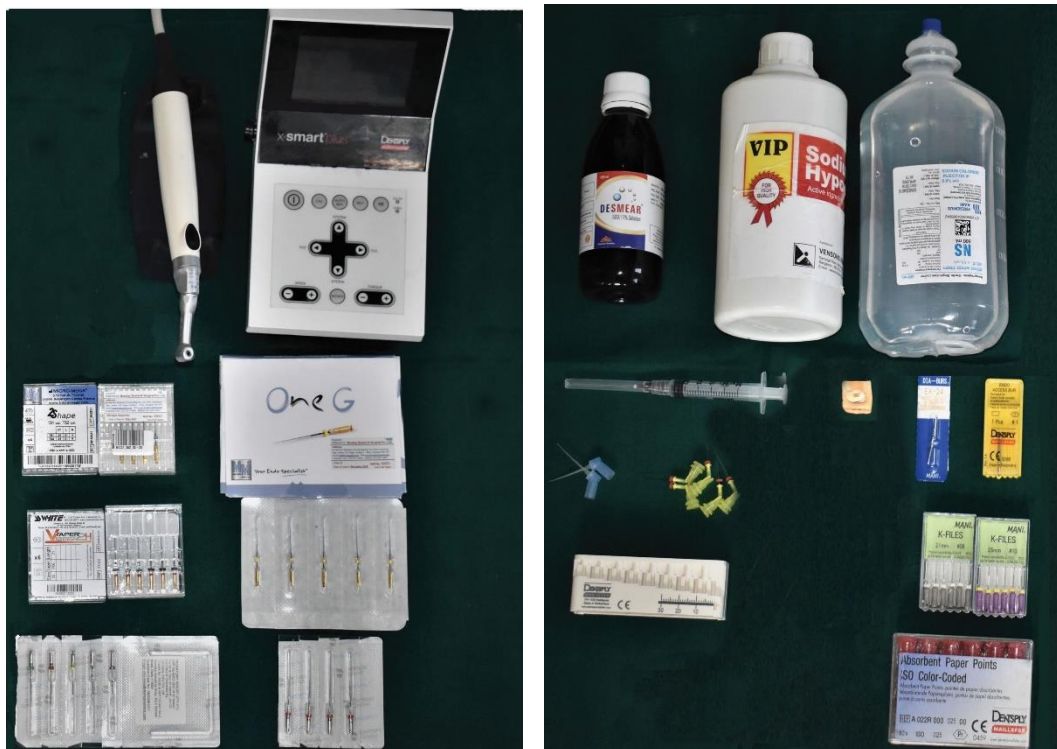
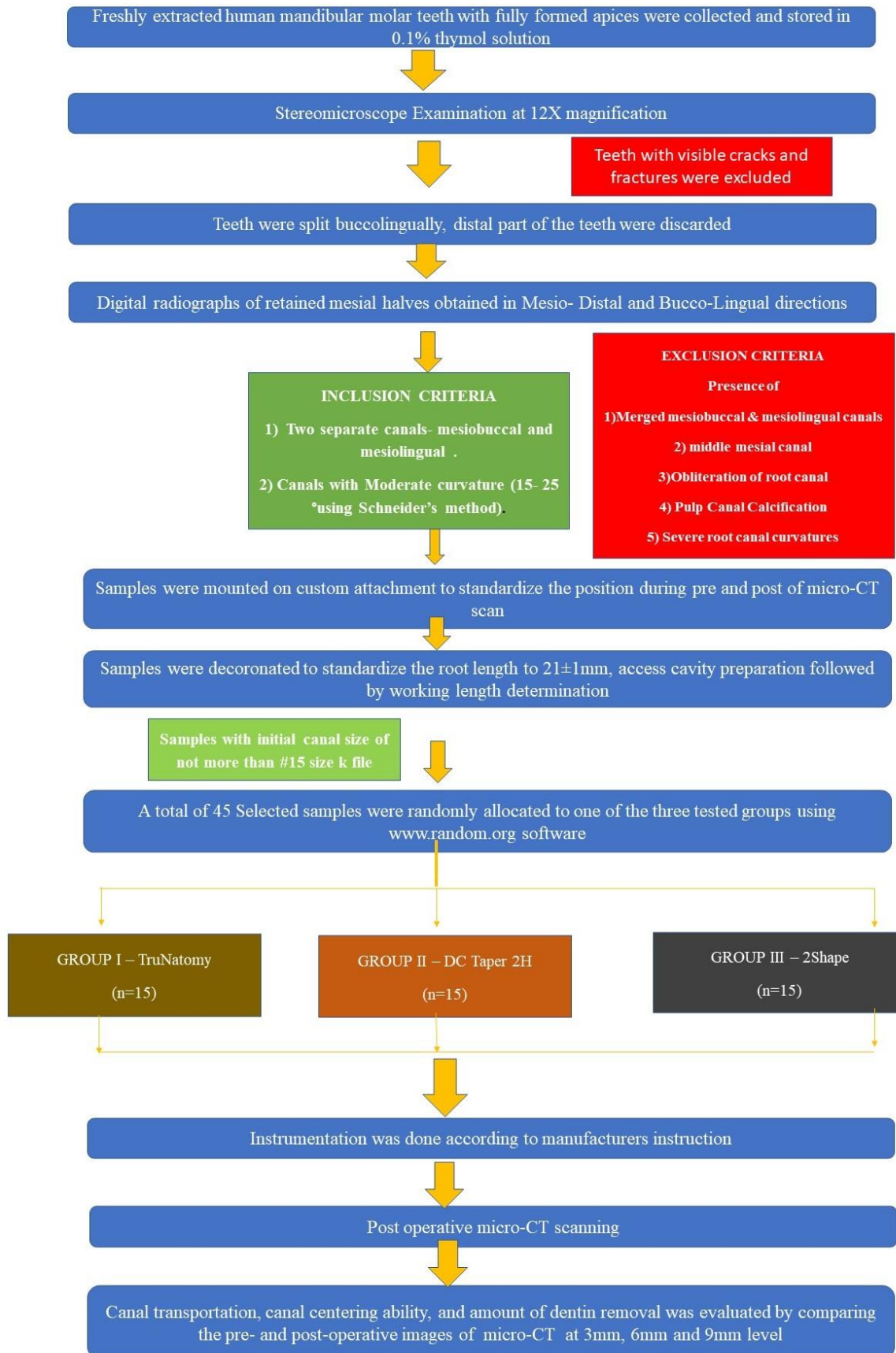


Figure 1: Armamentarium with batch number



FLOWCHART OF METHODOLOGY

METHODOLOGY

This study was approved by Institutional Review Board & Institutional Biosafety & Ethical committee (IBEC), SIST, IRB number: **173/IRB-IBSEC/SIST**.

SAMPLE SIZE CALCULATION:

The sample size was calculated based on a study ⁽⁹²⁾ with given effect size of 1.93 , an alpha-type error of 0.05 and a power beta of 0.90 into an a priori sample test from the f tests family (G*Power 3.1.9.3 for Macintosh; Heinrich Heine, Universität Dusseldorf, Dusseldorf, Germany). The results demonstrated the need for a minimum of 15 samples per group.

SAMPLE SELECTION:

Freshly extracted human mandibular molars with fully formed apices were collected (Figure 2). All teeth were stored in 0.1% thymol solution until further use to maintain dentin's viscoelastic property(Figure-3).⁽⁹³⁾ All teeth were examined under a stereomicroscope at 12x magnification to find cracks and fractures in root dentin (Figure -4&5). Teeth with cracks and fractures were excluded from this study (Figure-6a&6b). Teeth were sectioned in buccolingual direction using diamond disks and distal part of teeth were discarded (Figure 7). Digital radiographs of the retained mesial sections of the mandibular molars were obtained in mesiodistal and buccolingual direction to assess the root canal

curvature, root canal calcification and root canal configuration (Figure 8&9).⁽⁹⁴⁾ Teeth having separate mesiobuccal (MB) and mesiolingual (ML) canals with a moderate curvature ranging from 10° - 25° were included in this study. The curvatures of root canals were calculated using Schneider's method.⁽⁹⁵⁾ Teeth with merged mesial canals, middle mesial canal, root canal obliteration/ calcification and severely curved canals were excluded from this study. Teeth were decoronated using slow-speed diamond discs with water coolant approximately 2mm above the CEJ to standardize the root length to 21±1 mm.⁽⁹⁴⁾ Pre endodontic build up was done using composite resin (GC Solare X) in order to confine irrigants within canal.



Figure-2: Freshly extracted teeth samples



Figure- 3: Samples stored in 0.1% thymol solution

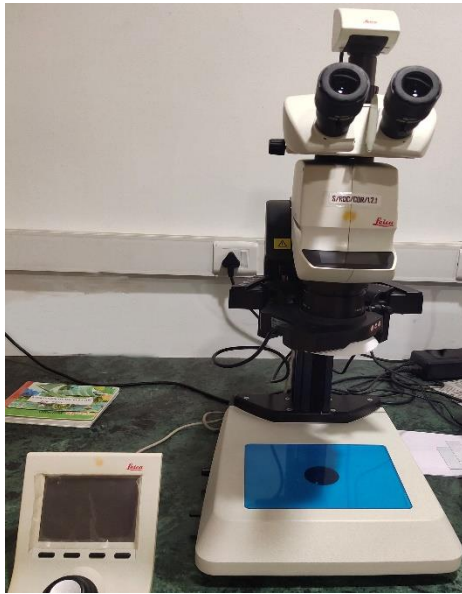


Figure-4: Stereomicroscope
(LEICA M205A)

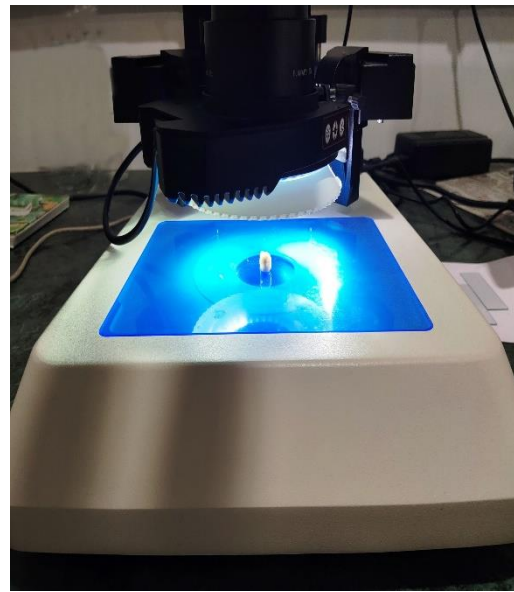


Figure 5: Examination under
stereomicroscope



Figure 6a & 6b: Excluded samples (Red arrow indicate samples with
cracks and fracture) after stereomicroscope evaluation



Figure 7: Mesial part of root after decoronation

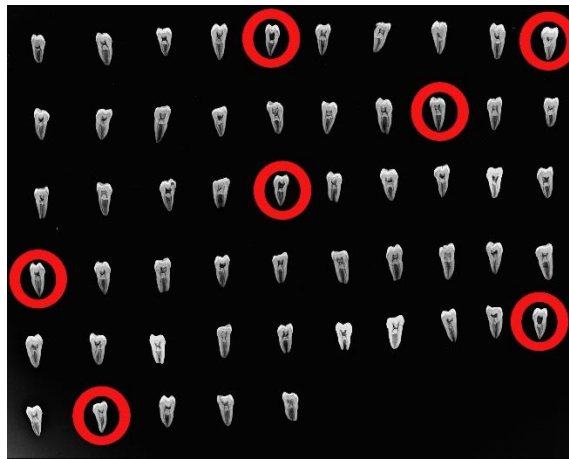


Figure 8: Digital radiographs of samples in Bucco-Lingual direction (Red ring indicates excluded samples)

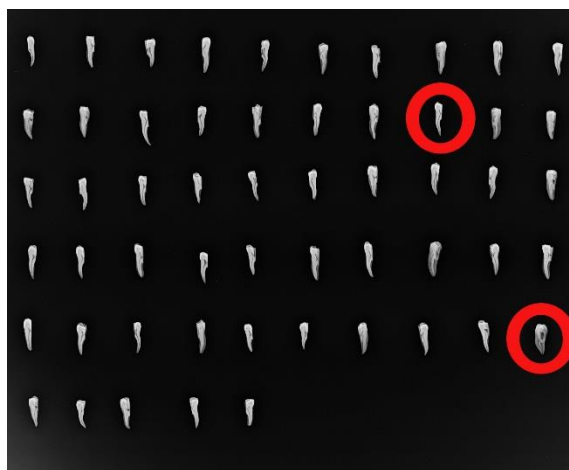


Figure 9: Digital radiographs of samples in Mesio-Distal direction (Red ring indicates excluded samples)

MICRO-CT SCANNING:

The selected teeth were embedded in putty molds using a custom made jig and polyvinyl siloxane material (Zhenmark, Dentsply Sirona) and were subject to micro-CT scanning before instrumentation at 100 kV, 110 mA, and 360° around the vertical axis with a rotation step of 0.5° using a 0.5-mm copper-aluminium filter, resulting in images with an 18- μ m voxel size. The cross-sectional images were reconstructed using specific algorithms and 3D models were generated (Figure10 -12).⁽⁹⁴⁾



Figure 10: Samples embedded in custom made attachment.



Figure 11: Bruker micro-CT machine (Sky scan 1176, Kartuizersweg 3B, Belgium)

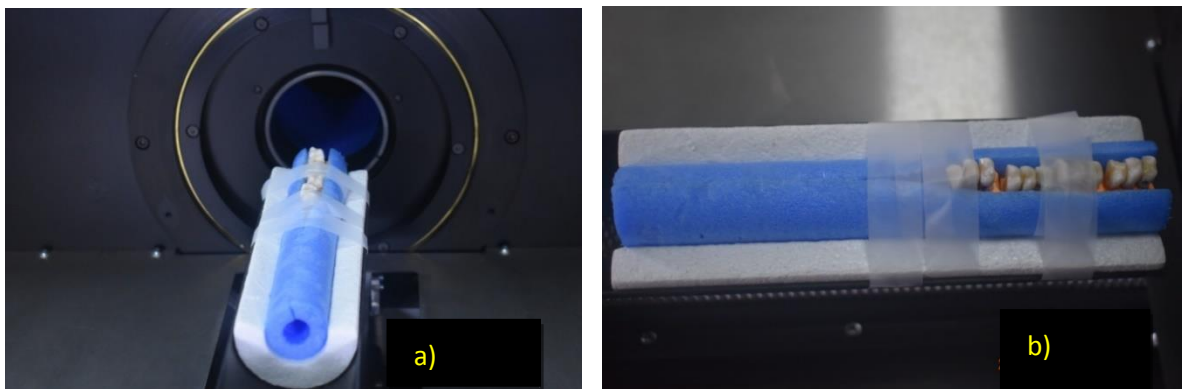


Figure 12a &12b: Samples placed in micro-CT machine for scanning.

ACCESS CAVITY PREPARATION:

Access cavity was prepared using Endo Access bur (Dentsply maillefer) driven by a high-speed airtor handpiece under water cooling (figure-13). The canals were then explored by advancing a size #10 K file (Mani, Japan) passively into the root canal until the

file's tip is just visible through the apex. The working length was determined by subtracting 0.5mm from that value. ⁽⁹⁴⁾ Teeth with initial apical size of not more than #15 k file were included from this study.



Figure 13: Access cavity preparation

ROOT CANAL INSTRUMENTATION:

Root canal instrumentation was performed by a single operator. An electric motor (X Smart Plus, Dentsply Sirona) was used to operate the files in continuous rotary movement in clockwise direction. All file systems prepared the root canal using crown down technique. A Glide path was established till working length using TruNatomy glider for Group 1 and using One G for Group 2 and 3. Irrigation was done after each file using 2.5 mL of 3% NaOCl was irrigated in each canal using 30G Navi tip needle for Group 2 and 3. TruNatomy irrigation needle was used for Group 1.

The master apical size was set to size #25 (Except in the TruNatomy file size #26). The rotary file of each system was used according to the manufacturer's instructions.

Group 1 - TruNatomy:

An endomotor set at a speed of 500rpm and torque of 1.5N cm with continuous rotary motion was used to operate the instruments of this system. The sequence of use of file are as follows (Figure 14).

Orifice modifier (20/.08)

TruNatomy glider (17/.02)

TruNatomy prime shaping files (26/.04).

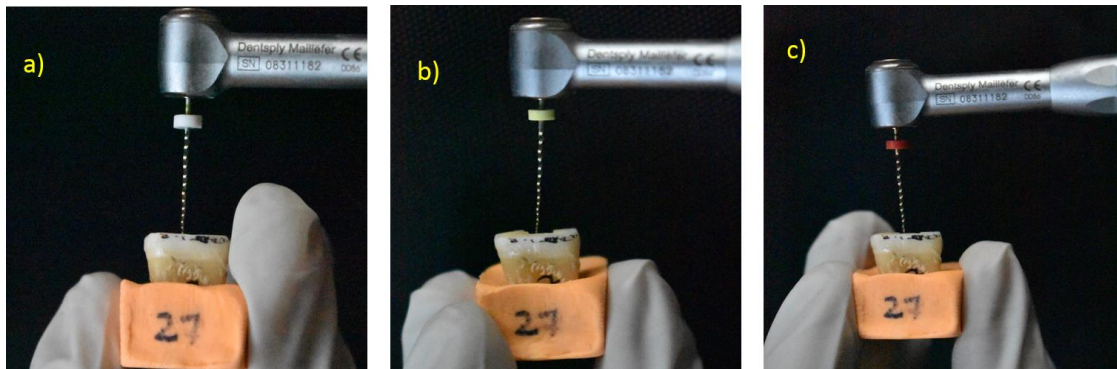


Figure 14: Represents the sequence of instruments used for TruNatomy group instrumentation. (a-TruGlider; b)&c)- TruNatomy shaping files)

Group 2 - DC TAPER 2H:

An endomotor set at a speed of 300 rpm and torque of 2N was used to operate the instruments of this system. The sequence of use of file are as follows (Figure – 15).

1. One G (#14/3% taper; micro mega)

2. DC Taper 2H file (25/6% taper)

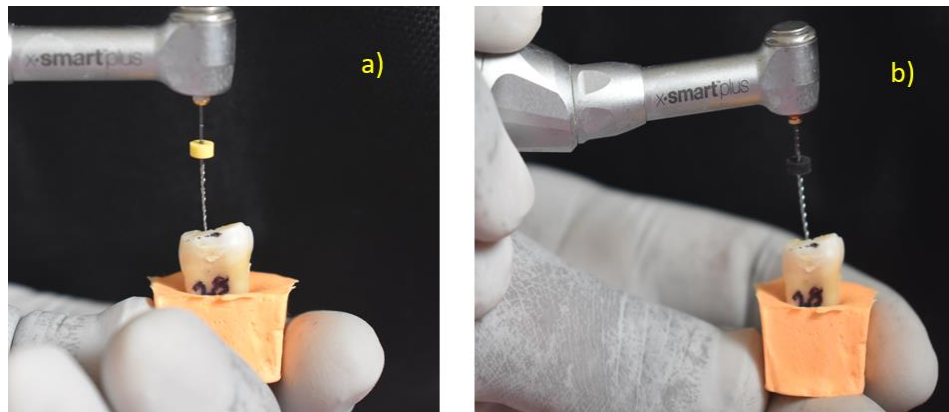


Figure 15: Represents the sequence of instruments used for DC Taper 2H group instrumentation. a) One G file ; b) DC Taper 2H file

Group 3 - 2 Shape (TS):

An endomotor set at a speed of 300rpm and a torque-speed of 2.5N cm are used to operate the instruments of this system. 2 shape available in two sizes 25/.04, 25/.06 tapers for the shaping of a root canal.

The sequence of use of file are as follows:

1. One G (14/.03%; Micro mega),
2. TS1 - 25/.04 taper
3. TS2 - 25/.06 taper file (Figure -.16)

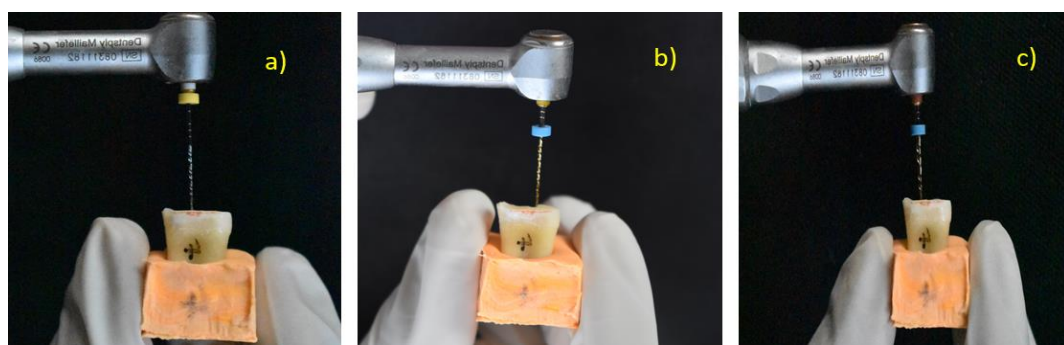


Figure 16: Represents the sequence of instruments used for 2 Shape group instrumentation
a) One G file; b) TS1; c) TS2 file

At the end of chemo mechanical preparation, all canals were irrigated with 2.5 mL of 17% EDTA for 1 minute and saline was used to flush the irrigants and as final rinse. Subsequently, the specimens were dried with absorbent paper points and were submitted to postoperative scans using the same parameters described in the initial scanning.

Evaluation Methodology:

CT An v.1.12 software (Bruker micro-CT) and Image J software v 1.44 were be used to measure and analyze pre-and-post instrumentation reconstructed images. Root canal diameter was evaluated at 3mm, 6mm & 9mm from the apical foramen to evaluate its change. ⁽⁹⁶⁾

1. Canal Transportation:

Root canal transportation was calculated in millimetres using the following equation as described by Gambill et al. ⁽⁹⁷⁾

$$\text{Amount of canal transportation} = (m1-m2) - (d1- d2)$$

Where, m1 and m2 represent the shortest distance from the mesial margin of the external root surface to the mesial margin of the uninstrumented and instrumented canal wall respectively; d1 and d2 represent the shortest distance from the distal margin of the external root surface to the distal margin of the uninstrumented and instrumented canal wall respectively. This was measured from the

superimposed micro- CT images of pre and post instrumentation (Figure- 17).

Based on this formula, a result of 0 equals no canal transportation, whereas values other than 0 represent amount of transportation and the sign represents direction. The tendency of transportation direction was assessed from the results obtained for each specimen; Positive value indicates canal transportation towards mesial curvature of root canal (outward). Negative value indicates the transportation towards distal side which means towards furcation side (inward).

2. Canal Centering Ratio:

$$\begin{aligned}\text{Centering ratio} &= (m1 - m2) / (d1-d2) \text{ if, } (m1-m2 < d1-d2) \\ &= (d1-d2) / (m1-m2) \text{ if, } (d1-d2 < m1-m2).\end{aligned}$$

According to this formula, a result of 1 indicates optimum centering. The closer the values are to '0' lesser the ability of instrument to remain centered in root canal during instrumentation.

3. Amount of root canal dentin removal:

Canal/ root width ratio was calculated from preoperative and postoperative images measuring in relation to the root diameter by measuring in mesiodistal direction at three levels (3mm, 6mm, 9mm) (Figure-18).⁽³⁵⁾

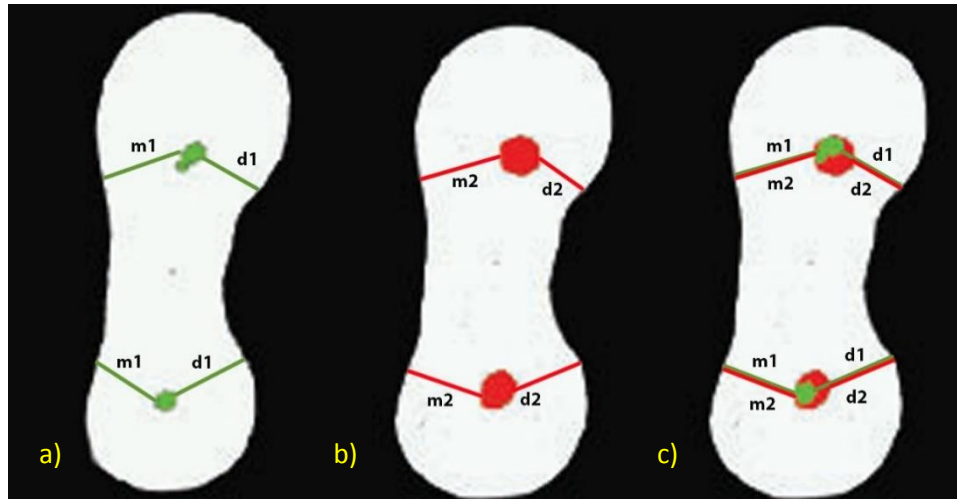


Figure 17: Micro CT images a) Pre instrumentation b) post instrumentation c) Superimposed images (Green: pre-operative canal; Red: Post-operative canal) green and red lines represents the measuring lines from shortest margin of root to shortest margin of canal before and after instrumentation respectively.

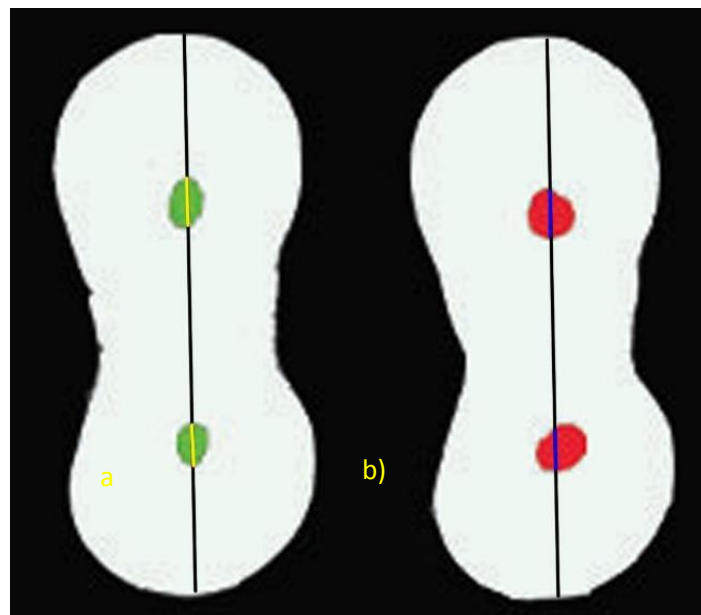


Figure 18: Micro CT images a) Pre instrumentation b) Post instrumentation a)pre instrumentation b) post instrumentation(black line indicates root width; yellow line indicates canal width pre instrumentation; blue line indicates canal width post instrumentation)

STATISTICAL ANALYSIS

Mean and standard deviations were obtained before and after root canal instrumentation for each group at 3mm, 6mm and 9mm. The Shapiro-Wilk test was used to evaluate the normal distribution of the data, and both parametric and nonparametric tests were used.

For Canal transportation, Centering ratio - One-way analysis of variance (ANOVA) was done to determine the difference in values among the groups at 3mm, 6mm and 9mm. In case of significant difference obtained between the groups by the ANOVA test, post hoc pair wise comparison was done to detect the difference in between the groups. Kruskal Wallis test was performed to obtain normality in data distribution. This test was used to assess the difference in mean values between the three tested groups.

For Amount of dentin removal - Intragroup and intergroup analysis were performed as follows. The paired t test was used for intragroup comparisons of canal/root width ratio before and after root canal instrumentation. One way ANOVA was used for intercomparisons of canal/root width ratio before and after root canal instrumentation and percentage increase in canal/root width ratio after instrumentation. Wilcoxon Signed Ranks Test was performed to assess the mean distribution within the tested groups.

Commercially available software (SPSS v17.0; SPSS Inc, Chicago, IL) was used for analysis at a 5% significance level.

RESULTS

Canal Transportation:

The mean original and absolute values of canal transportation in mesial roots of mandibular molar (mesiobuccal and mesiolingual canal) for three tested groups at 3mm, 6mm and 9mm level from the apex are listed in the Table: 1 -4

Amount of transportation: (Absolute values)

All the three tested groups showed some degree of transportation from the original canal in both mesiobuccal and mesiolingual root canal at 3mm, 6mm and 9mm level from the apex. The mean values of canal distribution for both mesial canals are tabulated in Table 1 and 2.

In mesiobuccal canal:

Among the three tested groups there was no statistically significant difference in amount of canal transportation at 3mm, 6mm level. At 9mm level the amount of transportation was significantly higher in Group III (TS; Micro mega) (0.38 ± 0.20) when compared to Group II (0.19 ± 0.32) (DC Taper 2H) ($p=0.01$) (Table 1) (figure-20, 21).

In mesiolingual canal:

Statistically significant difference in mean was found between Group I and Group II at 6mm level. Group I (0.25 ± 0.17) (figure19)

showed significantly higher canal transportation when compared to Group II (0.11 ± 0.11) ($p=0.02$) (Table 2). The other groups showed no statistically significant difference between them.

Overall result states that Group II showed lower mean values at all three levels in both mesial canals and showed significantly lesser transportation than Group III at cervical third (9mm) and Group I at mid root (6mm) level respectively. None of the groups showed canal transportation greater than 0.3mm except Group III at cervical level in both mesial canals.

Direction of transportation: (Original value)

The original mean values in millimetre and the deviation tendency in percentage were used to analyse the direction of transportation are listed in (Table 3-4).

In mesiobuccal canal:

- At 3mm level there was no statistically significant difference between the groups in the direction of transportation.
- At 6mm level Group II (-0.14 ± 0.15) showed significantly higher tendency to deviate towards the furcation with a frequency of 75% when compared to Group I (0.1 ± 0.19) ($p=0.03$) (figure-21b).
- At 9mm level there was no statistically significant difference between the groups in direction of transportation and all the

three groups showed an inward transportation tendency.

(Table -3)

In mesiolingual canal:

- At 3mm level there was no statistically significant difference between the groups in the direction of transportation.
- At 6mm level statistically significant difference was found between Group III and Group I. Group III (-0.19 ± 0.18) showed significantly higher tendency to deviate towards the furcation with the frequency of 70% when compared to Group I (0.02 ± 0.3) ($p=0.02$) (figure - 19b & 20b).
- At 9mm level, there was no statistically significant difference between the groups in direction of transportation and all the three groups showed an inward transportation tendency. (Table- 4)
- Overall results state that all the file systems showed some degree of transportation towards the furcation side. Deviation occurred more at the mid root level (6mm) in both mesiobuccal and mesiolingual canal. Group I showed a statistically lesser deviation tendency than Group II and Group III in mesiobuccal and mesiolingual canal respectively.

CANAL CENTERING RATIO:

The mean and standard deviation values of canal centering ratio in mesial canals of mandibular molar for all the three groups at 3mm, 6mm, and 9mm levels from the apex are listed in Table: 10-15.

No statistically significant difference was found between the groups at 3mm, 6mm and 9mm levels in both mesiobuccal and mesiolingual root canals ($P>0.05$) (Table – 5) Overall the file systems evaluated showed consistent centering ability with the centering ratio ranging between a minimum of 0.3 to a maximum of 0.9. Group I recorded a mean centering ratio ranging from 0.3 ± 0.2 to 0.94 ± 1.0 , Group II showed a mean centering ratio ranging from 0.5 ± 0.1 to 0.8 ± 0.4 , and Group III recorded a mean centering ratio from 0.5 ± 0.3 to 0.8 ± 0.7 .

AMOUNT OF ROOT CANAL DENTIN REMOVAL:

Root canal/root width ratio:

The root canal width in relation to root width was significantly increased by all the three file systems after preparation when compared to the original dimension at all levels $p>0.05$ (Table-6). Group III showed a statistically significant increase in the root canal to root width ratio compared to Group II at mid root level after preparation ($p=0.04$). The percentage increase in root canal width to root width in post preparation slices was significantly higher in group III at mid root level than Group I and II respectively ($p=0.04$) (Table 7).

CANAL TRANSPORTATION:

Table 1: The mean and standard deviation of absolute values (Amount of transportation) in millimetre for canal transportation in mesiobuccal root canals for all three tested groups at 3mm, 6mm, and 9mm levels

Absolute values (Amount of canal transportation) Mesiobuccal canal			95% confidence interval for mean	
Levels	Groups	Mean $\pm$ SD (mm)	Lower bound	Upper bound
9mm	I	0.28 $\pm$ 0.32	0.11	0.45
	II	0.19 $\pm$ 0.20	0.08	0.29
	III	0.38$\pm$0.20*	0.27	0.49
6mm	I	0.15 $\pm$ 0.14	0.07	0.23
	II	0.16 $\pm$ 0.13	0.08	0.23
	III	0.18 $\pm$ 0.12	0.11	0.24
3mm	I	0.12 $\pm$ 0.12	0.05	0.19
	II	0.05 $\pm$ 0.06	0.02	0.09
	III	0.11 $\pm$ 0.09	0.06	0.15

Kruskal Wallis and Post hoc Tukey were performed for intergroup comparison showing a significant difference between the groups with a p value of 0.014

* statistically significantly different from Group I

Table 2: The mean and standard deviation of absolute values (Amount of transportation) in millimetre for canal transportation in mesiolingual root canals for all three groups at 3mm, 6mm, and 9mm levels

Absolute values (Amount of transportation) Mesiolingual canal			95% confidence interval for mean	
Levels	Groups	Mean $\pm$ SD (mm)	Lower bound	Upper bound
9mm	I	0.32 $\pm$ 0.32	0.14	0.49
	II	0.24 $\pm$ 0.16	0.15	0.33
	III	0.36 $\pm$ 0.19	0.26	0.46
6mm	I	0.25$\pm$0.17*	0.16	0.35
	II	0.11 $\pm$ 0.11	0.05	0.17
	III	0.21 $\pm$ 0.16	0.12	0.30
3mm	I	0.22 $\pm$ 0.11	0.16	0.28
	II	0.15 $\pm$ 0.13	0.08	0.22
	III	0.16 $\pm$ 0.10	0.10	0.21

ANOVA, post hoc Tukey and Kruskal Wallis test were performed for intergroup comparison showing significant difference between the groups with p value of 0.02

* statistically significantly different from Group I

Table 3: The mean and standard deviation of original values in millimetres for direction of canal transportation and its frequency of deviation in percentage for mesiobuccal root canals at 3mm, 6mm and 9mm levels.

Original values (Direction of transportation) Mesiobuccal canal			95% confidence interval for mean		Deviation tendency (%)	
Levels	Groups	Mean±SD (mm)	Lower bound	Upper bound	Mesial	Distal
9mm	I	-0.13±0.41	-.355	0.08	25	75
	II	-0.13±0.24	-0.26	-.002	20	80
	III	-0.13±0.42	-0.35	0.10	45	55
6mm	I	0.10±0.20	-0.001	0.20	60	40
	II	-0.14±0.15*	-0.22	-0.05	25	75
	III	-0.00±0.22	-.10	0.13	50	50
3mm	I	-0.06±0.17	-0.15	0.02	40	60
	II	0.014±0.09	-0.03	.059	40	60
	III	-0.006±0.14	-.084	.071	50	50

ANOVA, post hoc Tukey and Kruskal Wallis test were performed for intergroup comparison showing significant difference between the groups with p value of 0.02

Table 4: The mean and standard deviation of original values (Direction of transportation) in millimetre for canal transportation in mesiolingual root canals for all three tested groups at 3mm, 6mm and 9mm levels

Original values (Direction of transportation) Mesiolingual canal			95% confidence interval for mean		Deviation tendency (%)	
Levels	Groups	Mean±SD (mm)	Lower bound	Upper bound	Mesial	Distal
9mm	I	-0.16±0.43	-0.39	0.06	25	75
	II	-0.21±0.20	-0.33	-0.10	20	80
	III	-0.25±0.33	-0.43	-0.07	45	55
6mm	I	0.02±0.31*	-0.14	0.20	60	40
	II	-0.05±0.15	-0.14	0.02	50	50
	III	-0.20±0.18	-0.23	-0.09	25	75
3mm	I	-0.002±0.25	-0.13	0.13	40	60
	II	0.15±0.13	0.08	0.22	40	60
	III	0.02±0.20	-0.09	0.12	50	50

ANOVA, post hoc Tukey and Kruskal Wallis test were performed for intergroup comparison showing significant difference between the groups with p value of 0.02

CENTERING RATIO

Table 5: The mean and standard deviation for centering ratio in mesiobuccal and mesiolingual root canals for the tested groups at 3mm, 6mm and 9mm level.

Centering	MESIOBUCCALCANAL			p	MESIOLINGUAL CANAL			p
ratio	Mean±SD			value	Mean±SD			value
Levels	3mm	6mm	9mm		3mm	6mm	9mm	
Group I	0.94±1.01	0.85±0.21	0.61±0.84	0.53	0.45±0.28	0.35±0.42	0.29±0.21	0.51
Group II	0.63±0.26	0.54±0.17	0.79±0.40	0.15	0.57±0.34	0.61±0.25	0.43±0.19	0.09
Group III	0.77±0.85	0.81±0.74	0.41±0.33	0.17	0.49±0.31	0.40±0.35	0.49±0.30	0.06

1. AMOUNT OF DENTIN REMOVAL - ROOT CANAL/ROOT WIDTH RATIO

Table 6: The mean and standard deviation of root canal width to root width ratio before and after instrumentation for all tested groups at 3mm, 6mm and 9mm level.

	PRE-OP canal/root width ratio			POST-OP canal/root width ratio		
	Mean±SD			Mean±SD		
Levels	9mm	6mm	3mm	9mm	6mm	3mm
Group I	0.10±0.02	0.07±0.02	0.07±0.02	0.12±0.05	0.09±0.02	0.09±0.03
Group II	0.09±0.02	0.06±0.02	0.06±0.02	0.11±0.03	0.08±0.01	0.09±0.01
Group III	0.09±0.02	0.07±0.03	0.07±0.02	0.13±0.04	0.11±0.03*	0.10±0.01
p value	0.77	0.26	0.13	0.45	0.04*	0.22

Table 7: The mean and standard deviation of percentage increase in root canal in relation to root width ratio for all tested groups at 3mm, 6mm and 9mm level.

		Mean ±SD	Confidence interval of 95%		p value
			Lower bound	Upper bound	
% prepared canal/ root - 9mm	Group I	8.4±2.6	7.0	9.8	.406
	Group II	8.1±1.8	7.2	9.1	
	Group III	9.8±1.8	8.9	10.8	
% prepared canal/ root - 6mm	Group I	8.7±1.5	7.9	9.5	.004
	Group II	8.2±1.0	7.7	8.8	
	Group III	10.6±2.9*	9.0	12.2	
% prepared canal/ root - 3mm	Group I	8.4±2.6	7.0	9.8	.057
	Group II	8.1±1.8	7.2	9.1	
	Group III	9.8±1.8	8.9	10.8	

p value showed statistically significant values at 6mm obtained from ANOVA, post hoc Tukey and Kruskal Wallis test.

* represents statistically significant difference from Group II.

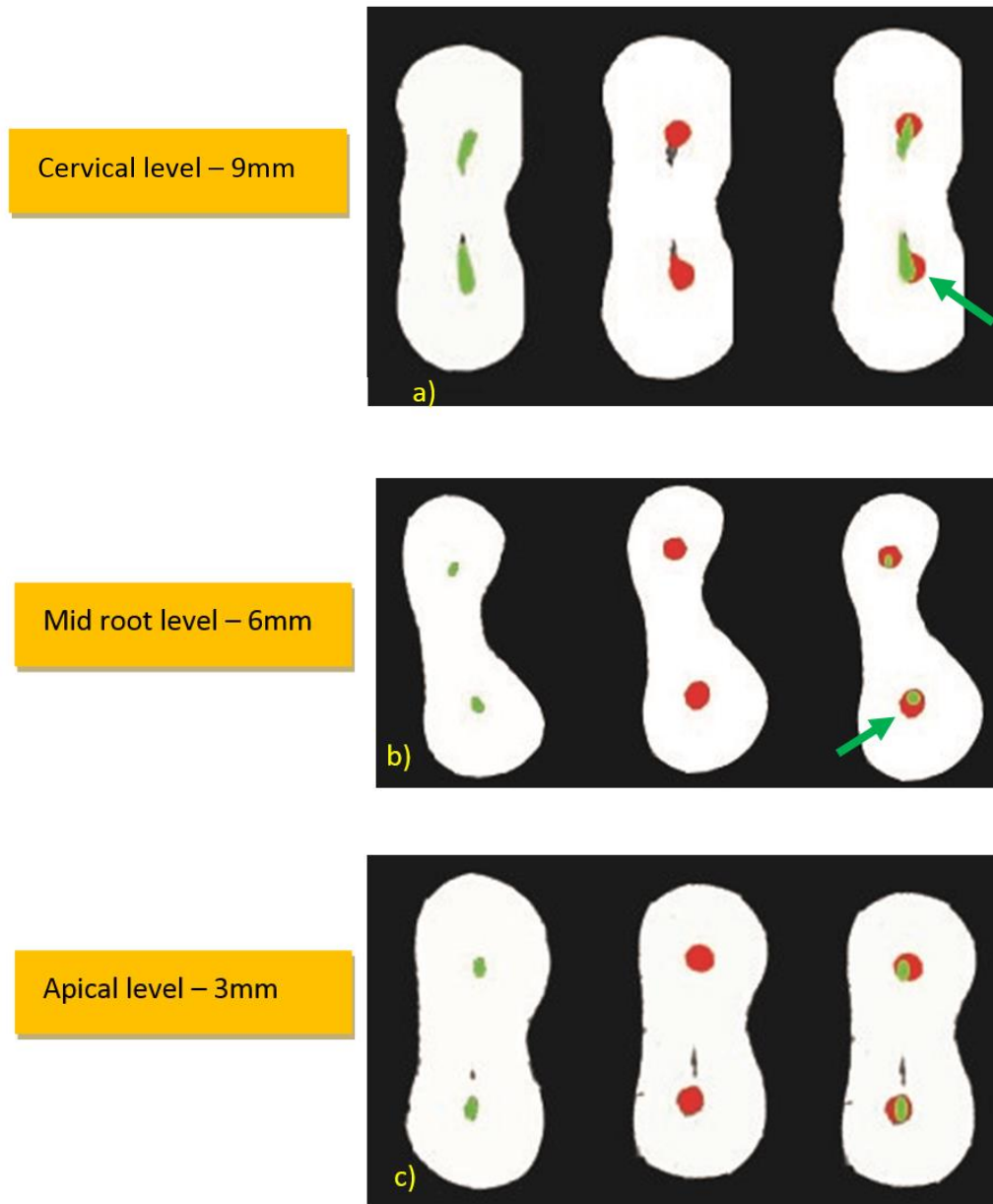
RESULTS IMAGES**GROUP 1 – TruNatomy (TRN; Dentsply Sirona)**

Figure 19: Representative samples are preoperative, postoperative and superimposed micro-CT images showing the effect of canal preparation with the Group I at the (a) coronal, (b) middle and (c) apical levels (green: preoperative canal, red: postoperative canal; Arrows- representing the canal transportation from the central axis of canal).

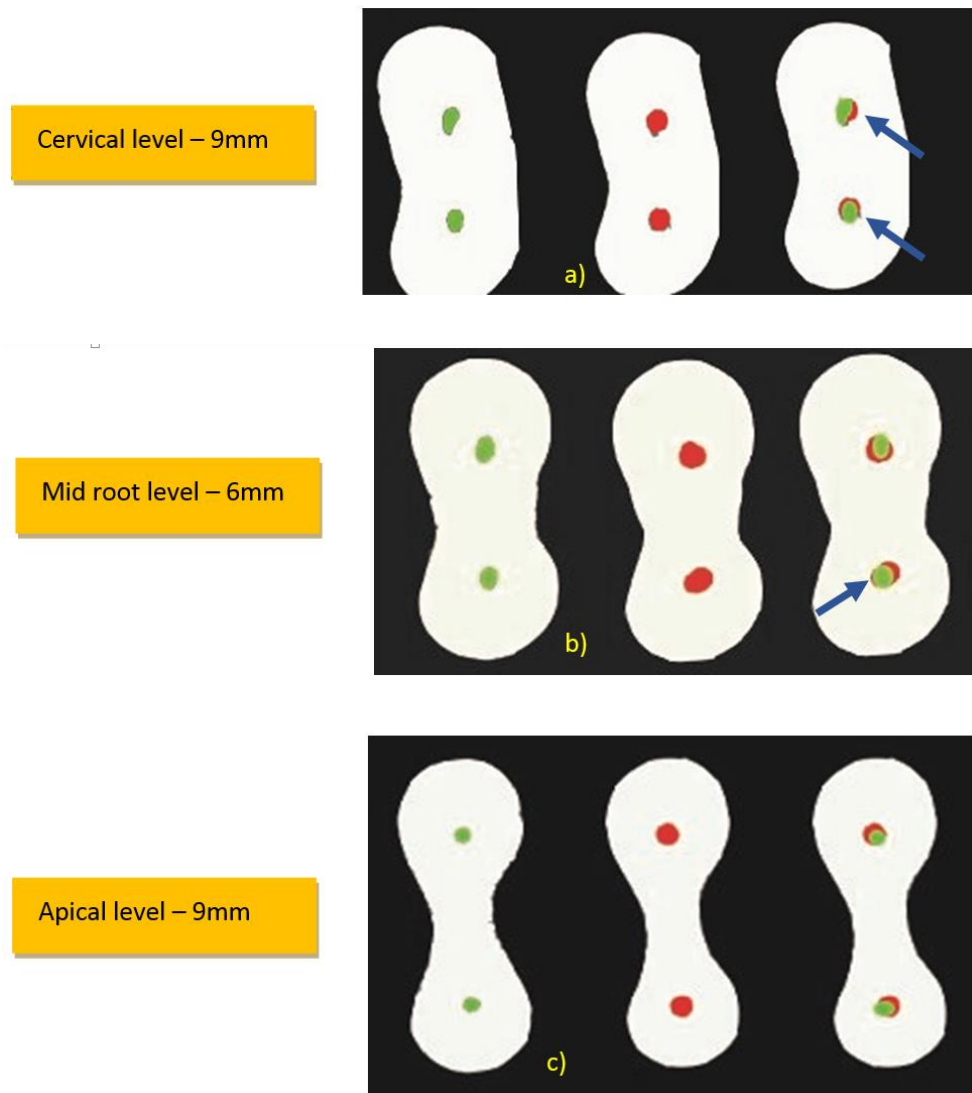
GROUP II – DC Taper 2H (SS White)

Figure 20: Representative samples are preoperative, postoperative and superimposed micro-CT images showing the effect of canal preparation with the Group II at the (a) coronal, (b) middle and (c) apical levels (green: preoperative canal, red: postoperative canal; Arrows- representing the canal transportation from the central axis of canal).

GROUP III: 2 Shape (TS; micro mega)

Figure 21: Representative samples are preoperative, postoperative and superimposed micro-CT images showing the effect of canal preparation with the Group III at the (a) coronal, (b) middle and (c) apical levels (green: preoperative canal, red: postoperative canal; Arrows- representing the canal transportation from the central axis of canal).

DISCUSSION

The primary role of mechanical instrumentation is to remove the inner layer of dentin and to disrupt the bacterial biofilms, while maintaining the original shape of the canal. ⁽⁹⁸⁾ Instrumentation of multirooted tooth poses a more significant challenge due to the complex anatomical structures such as curved root canals, lateral and accessory canals, fins, ramifications, isthmus and cul-de-sacs.⁽⁹⁹⁾ The common procedural errors encountered during instrumentation of curved root canals are, canal transportation, ledges, and straightening of the root canal. ⁽⁸⁾ Canal transportation is defined as “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.”⁽²⁴⁾ This can cause damage to apical foramen, elbow formation, ledging, Zipping and perforation.⁽⁸⁰⁾ More often than not excessive dentin removal from the inner root canal wall coronal to the curvature known as the “danger zone”, during instrumentation of a curved canal might result in strip perforation or weakening of root dentin.⁽¹⁰⁰⁾ Stainless steel files were traditionally used for cleaning and shaping procedures. They exhibited higher potential for procedural errors that led to excessive dentin removal reducing the long-term success of an endodontically treated tooth. ⁽¹⁰¹⁾ Therefore, in the present study stainless steel files were not used as a control group.

To overcome the above challenges NiTi instruments were introduced. Since the introduction of NiTi rotary systems by McSpadden and Wildey et al. in the 1990s, ⁽¹⁰²⁾ several studies have been conducted on their centering ability and canal transportation. These studies revealed the efficacy of NiTi rotary instruments in maintaining the original root canal anatomy, with minimal root canal aberrations; and ultimately facilitating the three-dimensional cleaning and shaping of the root canal system.^(103–106) Numerous improvements in kinematics, geometry and design of NiTi root canal instruments have been attempted over the past decades. ⁽¹⁰⁷⁾ Despite the advancements in endodontic instruments, instrumentation of the curved root canals are still an uphill task even for the most skilled and experienced clinicians.⁽¹⁰⁸⁾ Further innovations were made in the metallurgy of NiTi instruments that led to the manufacturing of heat-treated instruments. The heat treatment of NiTi files enhanced the flexibility and reduced incidence of instrument separation promising a more predictable biomechanical preparation of root canals with severe curvature. ⁽⁸⁾

A conservative preparation with sound remaining dentin thickness is of utmost importance.⁽¹⁰⁹⁾ Greater emphasis on preservation of the peri cervical dentin (PCD) has made a paradigm shift from the principles of traditional root canal preparation, including access cavity design and instrumentation technique to a more conservative approach. This zone of dentin, especially in

endodontically treated teeth is a critical substrate for stress distribution from coronal part onto the radicular surface thereby improving the survival rate without failure to occlusal loading. ⁽¹¹⁰⁾ Hence, assessment of the remaining dentin thickness after instrumentation becomes more significant.

TruNatomy (TRN) (Dentsply Sirona) instruments recently introduced into the market based on the concept of minimally invasive endodontics. TRN instruments are manufactured using a specially post thermal treated process which enhances the superelasticity of the file while dampening its shape memory as compared to M wire or conventional NiTi wire files. The advantage of having less shape memory is that, it can be precurved which aids in easy positioning of the file into the root canal. ^(40,111) Similarly, another file system namely DC Taper 2H (DC 2H; SS white) also based on the concept of dentin conservation is manufactured from Control Memory (CM) wire. Studies have proven that CM wire exhibit more resistance to cyclic and torsional fatigue when compared to conventional NiTi wire files. ^(112,113) 2 Shape (TS; Micro mega) made from T wire, claimed to be the latest technology in generations of file systems manufactured using proprietary heat treatment. This T wire metallurgy is said to enhance cutting efficiency and flexibility of file during instrumentation of curved root canals. The triple helix cross section of the file system enables more effective dentin removal, while respecting the canal curvature.

It has been reported that its smaller core diameter provides increased resistance to cyclic fatigue, resulting in reduced instrument separation during instrumentation. ^(114,115)

Several methods have been employed to evaluate canal transportation, centering ability and dentin removal of NiTi file systems, such as clearing technique with Indian ink injection, serial sectioning and microscopic evaluation, double digital radiographic evaluation, spiral Computed Tomography and Cone beam computed tomography (CBCT). Among these methods, CBCT is a well validated method for evaluating different aspects of root canal preparation. The most important feature of CBCT is that, it is non-destructive and allows quantitative analysis of sections three dimensionally but limited by its resolution range. ^(116–118) Rhodes et al was the first to suggest the use of micro-CT to study root canal geometry. ⁽⁹¹⁾ Ove A Peters was the first to successfully study the effect of instrumentation on root canal morphology using micro-CT. ⁽⁸⁹⁾ Since then, it became a popular tool among the researchers, because of its accuracy and non-invasive nature in assessing root canal morphology and its alterations such as change in volume, surface area, cross-sectional shape, taper, proportion, prepared surfaces and other 3D parameters providing detailed information in higher resolution. ^(92,93) Hence, it is currently considered the “gold standard” in evaluation of shaping ability of endodontic instruments. Therefore, the present study aimed to compare and

evaluate the shaping ability of the above-mentioned file systems using micro computed tomography in mesial roots of mandibular molar before and after instrumentation. Extracted human tooth closely simulates clinical condition compared to resin blocks. ⁽¹²¹⁾ But, they pose a challenge in variability of anatomy. Mandibular molars were selected in this study, because they are not only the most common teeth to undergo endodontic treatment, but also constantly present curvatures that increase the risk of procedural errors. ⁽¹²²⁾⁽¹²³⁾ Studies have proved that variations in the internal anatomy play a major role in ability of the instruments in preparation of root canal system. ⁽⁸¹⁾⁽¹²⁾ Mesial roots of mandibular molars most often present moderate curvature ranging from 10°-25°. ⁽⁸⁹⁾⁽¹²⁴⁾ Therefore, meticulous steps were undertaken in the current study to ensure standardization of molar teeth selected for evaluation. The teeth used in this study were balanced in terms of root canal curvature (10°-25°), root length (21±1mm), initial canal diameter (not more than #15 size k file) and root canal configuration (Vertucci type IV). A custom -made jig was prepared using polyvinylsiloxane material to ensure correct positioning of the samples during micro-CT scanning which enabled accurate comparison between pre- and post-operative image slices.

The three different NiTi rotary systems used in the study presented different features in cross section, alloy type and number of files used. All of them were recommended to use in continuous

rotary motion. To analyse the sole effect of the thermally treated NiTi instruments used in this study, no type of NiTi orifice shaper or gates gliden drills/stainless steel file was employed to perform cervical pre-enlargement except in TruNatomy (Group I) in which the use of TruNatomy orifice modifier was a part of the recommended sequence of instrumentation. Establishment of smooth glide path before the use of first shaping file is of utmost importance which enables the root canal instruments to follow the original root canal anatomy thereby reducing procedural errors especially during instrumentation of curved root canals. Therefore, glide path preparation has been considered as a starting point of all root canal instrumentations. ^(23,125,126) Many studies have proved that use of NiTi rotary glide path files reduced the occurrence of procedural errors than using manual K files. ^(64,66,127,128) In this study glide path preparation was carried out using TruGlider (Dentsply Sirona) for Group I as it was a part of the original kit. One G (Micro Mega) glide path file was used for DC Taper 2H and TS groups. Studies have shown more centred glidepath preparation with One G as compared to other glide path instruments. ^(41,59,64) There was no consensus in the literature about ideal diameter for apical preparation. All the systems used in this study presents a tailor-made sequence specific to the root canal dimension. Hence the apical preparation in the current study was standardized according to the manufacturer's instructions for the root canals with moderate curvature which was ISO tip size of 25 and 6% taper

for Group II and III; and size 26 and 4% taper for Group I. ⁽¹²⁹⁾ ⁽³⁷⁾
⁽³⁸⁾

Corroborating the results of the present study, the null hypothesis was partially rejected. There was a significant difference found between the file systems in canal transportation and root dentin removal at certain evaluated levels. Whereas, all the file systems showed comparable canal centering ability with no statistically significant difference between them.

All the evaluated file systems showed some amount of transportation from the original axis of the root canal. All groups showed highest mean values of transportation in the cervical third occurring more frequently towards furcation (inward) region. This finding was in agreement with other studies. ^(55,56,75) 2 Shape (Group II) showed highest mean values for canal transportation at all three evaluated levels among the three file systems in both the mesial canals. But, showed statistically significant higher amount (0.3 ± 0.2) of canal transportation than DC Taper 2H (0.28 ± 0.3) at cervical third of mesiobuccal canal ($p=0.01$). This may be attributed to 2 features, first the T-wire technology of the 2-shape system which has shown canal transportation comparable to files that were manufactured using M-wire technology (ProTaper Next) in previous study, ⁽¹³⁰⁾ which are known for their stiffness. ⁽¹³¹⁾ Secondly, the modified triangular cross section known for its aggressive

cutting.⁽³²⁾ TruNatomy (0.2 ± 0.1) showed significantly higher amount of canal transportation compared to DC Taper (0.11 ± 0.11) in the mid root level of mesiolingual canal ($p=0.02$), but it was important to note that the deviation occurred towards the safe zone. The higher outward canal transportation of TruNatomy files in the mid root level can be attributed to its short orifice modifier with 7.5mm of active cutting flutes and a taper of 8% making these files stiffer which might have resulted in a spring back effect at the mid root level. According to Wu et al ⁽⁹⁰⁾ apical transportation of more than 0.3mm negatively affected the seal. In the present study, all the file systems showed comparable amount of canal transportation at apical third ranging between 0.22 ± 0.11 mm to 0.05 ± 0.06 mm which was well within the permissible limit. However, 2 Shape system showed transportation of more than 0.3mm in cervical level but it is not clinically relevant.

When evaluating the direction of transportation, all the three NiTi rotary systems showed deviation more frequently in the inward direction and less often in outward direction. DC Taper (75%) and 2 Shape (75%) showed significantly higher tendency to deviate inward at mid root level of the mesiobuccal and mesiolingual canals respectively, in comparison to TruNatomy (40%) which showed a tendency of outward deviation. However, in the other two levels TruNatomy showed a tendency to deviate in the inward direction. These findings were in contrast with a previous study by *kabil et al*

comparing TruNatomy with four other file systems with different metallurgical properties, where TruNatomy consistently showed inward deviation at all the evaluated levels. ⁽¹³²⁾ Regarding centering ability, no statistically significant difference was found between the groups in both mesiolingual and mesiobuccal root canals at 3mm, 6mm and 9mm levels. All the file systems showed centering ratio ranging between 0.3-0.9mm, where 0.3mm represented the most off centered preparation while 0.9mm was the closest to the optimum centering ratio.

Mesial roots of mandibular molars are more prone to excessive removal of dentin in buccolingual direction than mesiodistal direction because of their curvature, risking root fracture. ⁽¹³³⁾ Several studies have reported that excessive dentin removal showed direct impact on fracture resistance of endodontically treated teeth. ^(134–136) A study done by *Wilcox et al* reported that 40% increase in canal width during instrumentation, increased the risk of root fracture during obturation or when subjected to masticatory loading. ⁽¹³⁷⁾ Therefore, in the present study percentage increase in root canal to root width ratio was calculated by comparing the width of root canal after instrumentation to the root width at each evaluated level. All the file systems showed a significant increase in root canal width in relation to root width after instrumentation ($p=0.04$). 2 shape system removed highest amount of dentin at all levels when compared to TruNatomy and DC

Taper 2H. And also, showed a statistically significant higher amount of dentin removal (10%) at mid root level, when compared to DC Taper (8%) and TruNatomy (8%) ($p=0.04$). However, none of the three tested systems removed dentin more than 40% at any of the evaluated levels.

Although not statistically significant from the overall results of the present study it is observed that, DC Taper showed least canal transportation and dentin removal with more centered preparation. This finding may be attributed to the parabolic cross-sectional design that provides the unique cutting efficiency while preserving the natural tooth structure and the Control Memory wire (CM wire) technology of DC Taper. Previous studies have shown that CM wire alloys exhibited lesser amount of transportation than R phase, M wire and other proprietary heat-treated wire such as C-wire. ^(27,131)

The present is not without limitations, being an invitro study all teeth samples were firmly held by hand which cannot be directly related to the orientation of the teeth in the clinical condition. This could have influenced the direction and angulation of placement of instrument into the root canal. Canal transportation was evaluated in the current study comparing the root wall dentin thickness in the thinnest region. Any amount of deviation that could have occurred in other regions were not accounted for. Analysis for root dentin

removal in the present study was evaluated using canal to root width ratio which is a 2-Dimensional measure that depicts dentin removal only in buccolingual direction. Further analysis of volumetric data and area of uninstrumented canal wall might present clearer insights to the magnitude and spatial distribution of dentin removed. Future studies are recommended to evaluate and compare these three tested NiTi rotary file systems in terms of debris removal, post-operative pain and fracture resistance to cyclic and torsional loading.

SUMMARY

This study was conducted to evaluate the canal transportation, centering ability and amount of dentin removal by three rotary NiTi file systems namely, TruNatomy (TRN; Dentsply Sirona, USA), DC-Taper 2H (SS White, Lakewood, CA) and 2Shape (TS; Micro-Mega, Besancon, France) in moderately curved mesial roots of human mandibular molar analysed using micro computed tomography. Freshly extracted human mandibular molars with fully formed apices were collected and stored in 0.1% of thymol solution until further use. Teeth with cracks, merged mesial canals, middle mesial canal, root canal obliteration / pulp calcifications and severely curved canals were excluded from this study. Teeth having separate mesiobuccal and mesiolingual root canals with curvature ranging from 10-25° were included in this study. Selected mesial roots were mounted on custom made jig and subjected to micro-CT scanning before instrumentation. After which, samples were decoronated, accessed and negotiated using #10 size K file. Teeth with initial apical size of not more than #15 K file (Mani, japan). were excluded in this study. Working length was determined by advancing the 10 K file into the root canal and final working length was determined 0.5mm short from the canal length. A total of 45 mesial roots of mandibular molars were used. Samples were randomly allocated to one of the three tested groups using random numbers generated from www.random.org. Group I (TruNatomy; TRN) (n=15), Group II (DC-Taper 2H) (n=15) and 2Shape (TS) (n=15). For root canal

instrumentation, all the three file systems followed manufacturer's instruction. 2.5 mL of 3% sodium hypochlorite was used as working solution, after instrumentation 2.5ml of 17% EDTA for 1 minute followed by a short burst of 3% sodium hypochlorite for 30 seconds in each canal was used for smear layer removal, and saline was used to flush out the irrigants and as final rinse. After instrumentation samples were reattached to custom molds for post-operative micro-CT scanning. Images were reconstructed using nRecon software version 2.0. CT An v. 1.18 software was used to analyse the change in canal geometry at 3mm, 6mm and 9mm level. Pre- and post-operative images were superimposed and canal transportation and centering ratio and Canal/root width ratio were calculated from the superimposed images using Image J software 1.52v at all evaluated levels. After statistical analysis, Results revealed that at mid root level, of mesiolingual canal TruNatomy showed statistically significant higher canal transportation than DC Taper ($p < 0.05$). No statistically significant difference was found between the tested groups at any of the other levels in mesiobuccal canal. 2 shape showed statistically significant higher canal transportation at cervical level of mesiobuccal canal when compared to DC Taper 2H ($p < 0.05$). For direction of transportation all the groups showed deviation more frequently towards inward direction and less often towards outward direction. No significant differences were found between the three tested groups at 3mm and 9mm in mesiobuccal and mesiolingual canals. Whereas, at 6mm level TruNatomy group

showed an outward deviation tendency in both mesiobuccal and mesiolingual canals which was statistically significant when compared to DC Taper in mesiobuccal canal and 2 Shape in mesiolingual canal respectively ($p < 0.05$). In terms of centering ratio, no statistically significant differences were found between tested groups at all evaluated levels in both mesial canals. In canal/root width ratio, all the systems showed an increase in canal width after instrumentation at all levels. 2 Shape showed significant increase in canal width when compared to TruNatomy at 6mm level ($p < 0.05$).

CONCLUSION

Within the limitation of the present study, it may be concluded that all the three NiTi rotary file systems were able to safely prepare the moderately curved mesial roots of mandibular molar with minimal errors.

DC Taper showed least amount of canal transportation and dentin removal with better centering ability in both mesial canals. TruNatomy has shown significant difference in canal transportation at mid root level of mesiolingual canal with least centering ability, but deviated towards outer dentin wall. 2 Shape showed highest mean values in canal transportation and canal/root width ratio at all evaluated levels with significantly more transportation in coronal third towards danger zone of mesiobuccal canal.

REFERENCES

1. Young G, Parashos P, Messer H. The principles of techniques for cleaning root canals. *Aust Dent J*. 2007 Mar;52:S52–63.
2. Sundqvist G, Figdor D, Persson S, Sjögren U. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative re-treatment. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology*. 1998 Jan 1;85(1):86–93.
3. Siqueira JF, Pérez AR, Marceliano-Alves MF, Provenzano JC, Silva SG, Pires FR, et al. What happens to unprepared root canal walls: a correlative analysis using micro-computed tomography and histology/scanning electron microscopy. *Int Endod J*. 2018 May;51(5):501–8.
4. Siqueira JF, Araújo MCP, Garcia PF, Fraga RC, Dantas CJS. Histological evaluation of the effectiveness of five instrumentation techniques for cleaning the apical third of root canals. *J Endod*. 1997 Aug;23(8):499–502.
5. Card S, Sigurdsson A, Orstavik D, Trope M. The Effectiveness of Increased Apical Enlargement in Reducing Intracanal Bacteria. *J Endod*. 2002 Nov;28(11):779–83.
6. Coldero LG, McHugh S, MacKenzie D, Saunders WP. Reduction in intracanal bacteria during root canal preparation with and without apical enlargement. *Int Endod J*. 2002 May;35(5):437–46.

7. 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 May;32(5):417–20.
8. Hulsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. *Endod Top*. 2005 Mar;10(1):30–76.
9. 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 Aug;38(8):1121–5.
10. Walia H, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. *J Endod*. 1988 Jan;14(7):346–51.
11. Sonntag D, Guntermann A, Kim SK, Stachniss V. Root canal shaping with manual stainless steel files and rotary Ni-Ti files performed by students: Preparation performed by students. *Int Endod J*. 2003 Apr;36(4):246–55.
12. Bergmans L, Cleynenbreugel JV, Wevers M, Lambrechts P. Mechanical root canal preparation with NiTi rotary instruments: Rationale, performance and safety. *Am J Dent*. 2001;14(5):10.
13. Cheung GSP, Liu CSY. A Retrospective Study of Endodontic Treatment Outcome between Nickel-Titanium Rotary and

- Stainless Steel Hand Filing Techniques. *J Endod.* 2009 Jul;35(7):938–43.
14. Esposito PT, Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. *J Endod.* 1995 Apr;21(4):173–6.
15. Glosson CR, Haller RH, Brent Dove S, del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. *J Endod.* 1995 Mar;21(3):146–51.
16. Bürklein S, Schäfer E. Critical evaluation of root canal transportation by instrumentation: Critical evaluation of root canal transportation by instrumentation. *Endod Top.* 2013 Sep;29(1):110–24.
17. Ruddle CJ. The ProTaper technique. *Endod Top.* 2005 Mar;10(1):187–90.
18. Arslan H, Yildiz ED, Gunduz HA, Sumbullu M, Bayrakdar IS, Karatas E, et al. Comparative study of ProTaper gold, reciproc, and ProTaper universal for root canal preparation in severely curved root canals. *J Conserv Dent JCD.* 2017 Aug;20(4):222–4.
19. Elnaghy AM, Elsaka SE. Shaping ability of ProTaper Gold and ProTaper Universal files by using cone-beam computed tomography. *Indian J Dent Res Off Publ Indian Soc Dent Res.* 2016 Feb;27(1):37–41.

20. Uygun AD, Kol E, Topcu MKC, Seckin F, Ersoy I, Tanriver M. Variations in cyclic fatigue resistance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. *Int Endod J*. 2016 May;49(5):494–9.
21. Schilder H. Filling Root Canals in Three Dimensions. *J Endod*. 2006 Apr 1;32(4):281–90.
22. Hulsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. *Endod Top*. 2005 Mar;10(1):30–76.
23. Patiño PV, Biedma BM, Liébana CR, Cantatore G, Bahillo JG. The Influence of a Manual Glide Path on the Separation Rate of NiTi Rotary Instruments. *J Endod*. 2005 Feb 1;31(2):114–6.
24. Glossary of Endodontic Terms - American Association of Endodontists [Internet]. [cited 2021 Jan 20]. Available from: <https://www.aae.org/specialty/clinical-resources/glossary-endodontic-terms/>
25. Drukteinis S, Peciuliene V, Dummer PMH, Hupp J. Shaping ability of BioRace, ProTaper NEXT and Genius nickel-titanium instruments in curved canals of mandibular molars: a MicroCT study. *Int Endod J*. 2019 Jan;52(1):86–93.
26. Albuquerque MS de, Nascimento AS, Braz R, Gialain IO, de Lima EA, Nery JA, et al. Canal Transportation, Centering Ability, and Dentin Removal after Instrumentation: A Micro-CT Evaluation. *J Contemp Dent Pract*. 2019 Jul;20(7):806–11.

27. Razcha C, Zacharopoulos A, Anestis D, Mikrogeorgis G, Zacharakis G, Lyroudia K. Micro-Computed Tomographic Evaluation of Canal Transportation and Centering Ability of 4 Heat-Treated Nickel-Titanium Systems. *J Endod.* 2020 May;46(5):675–81.
28. Yılmaz F, Eren İ, Eren H, Badi MA, Ocak M, Çelik HH. Evaluation of the Amount of Root Canal Dentin Removed and Apical Transportation Occurrence after Instrumentation with ProTaper Next, OneShape, and EdgeFile Rotary Systems. *J Endod.* 2020 May;46(5):662–7.
29. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. *Int Endod J.* 2008 Apr;41(4):339–44.
30. Ruddle DCJ, Machtou P, West JD. 5TH GENERATION TECHNOLOGY. *Adv Endod.* :8.
31. Clark D, Khademi J. Modern Molar Endodontic Access and Directed Dentin Conservation. *Dent Clin North Am.* 2010 Apr;54(2):249–73.
32. Van der Vyver PJ, Vorster M, Peters OA. Minimally invasive endodontics using a new single-file rotary system. *Int Dent–African ed.* 2019;9(4):6-20.
33. Shenoi P, Luniya D, Badole G, Makade C, Kubde R, Khode R. Comparative evaluation of shaping ability of V-Taper 2H, ProTaper Next, and HyFlex CM in curved canals using cone-

- beam computed tomography: An in vitro Study. Indian J Dent Res. 2017;28(2):181.
34. 60301807-C_Brochure-2Shape_EN_WEB.pdf.
35. Brasil SC, Marceliano-Alves MF, Marques ML, Grillo JP, Lacerda MFLS, Alves FRF, et al. Canal Transportation, Unprepared Areas, and Dentin Removal after Preparation with BT-RaCe and ProTaper Next Systems. J Endod. 2017 Oct;43(10):1683–7.
36. Tufenkci P, Orhan K, Celikten B, Bilecenoglu B, Gur G, Sevimay S. Micro-computed tomographic assessment of the shaping ability of the One Curve, One Shape, and ProTaper Next nickel-titanium rotary systems. Restor Dent Endod. 2020;45(3):e30.
37. Htun PH, Ebihara A, Maki K, Kimura S, Nishijo M, Okiji T. Cleaning and Shaping Ability of Gentlefile, HyFlex EDM, and ProTaper Next Instruments: A Combined Micro-computed Tomographic and Scanning Electron Microscopic Study. J Endod. 2020 Jul;46(7):973–9.
38. Riyahi AM, Bashiri A, Alshahrani K, Alshahrani S, Alamri HM, Al-Sudani D. Cyclic Fatigue Comparison of TruNatomy, Twisted File, and ProTaper Next Rotary Systems. Int J Dent. 2020 Feb 26;2020:1–4.
39. Elnaghy AM, Elsaka SE, Mandorah AO. In vitro comparison of cyclic fatigue resistance of TruNatomy in single and double

- curvature canals compared with different nickel-titanium rotary instruments. BMC Oral Health. 2020 Dec;20(1):38.
40. van-der-vyver.pdf [Internet]. [cited 2021 Jan 20]. Available from:
<http://www.moderndentistrymedia.com/moderndentistrymedia/wp-content/uploads/2019/08/van-der-vyver.pdf>
41. Plotino G, Nagendrababu V, Bukiet F, Grande NM, Veettil SK, De-Deus G, et al. Influence of Negotiation, Glide Path, and Preflaring Procedures on Root Canal Shaping—Terminology, Basic Concepts, and a Systematic Review. J Endod. 2020 Jun;46(6):707–29.
42. Singh S, Abdul MSM, Sharma U, Sainudeen S, Jain C, Kalliath JT. An in vitro Comparative Evaluation of Volume of Removed Dentin, Canal Transportation, and Centering Ratio of 2Shape, WaveOne Gold, and ProTaper Gold Files Using Cone-Beam Computed Tomography. :5.
43. van der Vyver PJ, Paleker F, Vorster M, de Wet FA. Root Canal Shaping Using Nickel Titanium, M-Wire, and Gold Wire: A Micro-computed Tomographic Comparative Study of One Shape, ProTaper Next, and WaveOne Gold Instruments in Maxillary First Molars. J Endod. 2019 Jan;45(1):62–7.
44. Perez Morales M de las N, González Sánchez JA, Olivieri Fernández JG, Laperre K, Abella Sans F, Jaramillo DE, et al. TRUShape Versus XP-endo Shaper: A Micro-computed Tomographic Assessment and Comparative Study of the

- Shaping Ability—An In Vitro Study. *J Endod.* 2020 Feb;46(2):271–6.
45. 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 Jun;45(6):791–6.
46. Filizola de Oliveira DJ, Leoni GB, da Silva Goulart R, Sousa-Neto MD de, Silva Sousa YTC, Silva RG. Changes in Geometry and Transportation of Root Canals with Severe Curvature Prepared by Different Heat-treated Nickel-titanium Instruments: A Micro-computed Tomographic Study. *J Endod.* 2019 Jun;45(6):768–73.
47. Elnaghy AM, Elsaka SE. Cyclic Fatigue Resistance of One Curve, 2Shape, ProFile Vortex, Vortex Blue, and RaCe Nickel-Titanium Rotary Instruments in Single and Double Curvature Canals. *J Endod.* 2018 Nov;44(11):1725–30.
48. Özyürek T, Gündoğar M, Uslu G, Yılmaz K, Staffoli S, Nm G, et al. Cyclic fatigue resistances of Hyflex EDM, WaveOne gold, Reciproc blue and 2shape NiTi rotary files in different artificial canals. *Odontology.* 2018 Oct;106(4):408–13.
49. Zuolo ML, Zaia AA, Belladonna FG, Silva EJNL, Souza EM, Versiani MA, et al. Micro-CT assessment of the shaping

- ability of four root canal instrumentation systems in oval-shaped canals. *Int Endod J*. 2018 May;51(5):564–71.
50. Park H-J, Seo M-S, Moon Y-M. Root canal volume change and transportation by Vortex Blue, ProTaper Next, and ProTaper Universal in curved root canals. *Restor Dent Endod*. 2018;43(1):e3.
51. Marks Duarte P, Barcellos da Silva P, Alcalde MP, Vivan RR, Rosa RA da, Duarte MAH, et al. Canal Transportation, Centering Ability, and Cyclic Fatigue Promoted by Twisted File Adaptive and Navigator EVO Instruments at Different Motions. *J Endod*. 2018 Sep;44(9):1425–9.
52. Berechet D, Rad IA, Berce CP, Bumbu BA, Vica V-M, Berechet M-C, et al. A micro-computed tomography study of morphological aspect of root canal instrumentation with ProTaper Next and One Shape New Generation in mandibular molars. :5.
53. Belladonna FG, Carvalho MS, Cavalcante DM, Fernandes JT, de Carvalho Maciel AC, Oliveira HE, et al. Micro-computed Tomography Shaping Ability Assessment of the New Blue Thermal Treated Reciproc Instrument. *J Endod*. 2018 Jul;44(7):1146–50.
54. Guimarães LS, Gomes CC, Marceliano-Alves MF, Cunha RS, Provenzano JC, Siqueira JF. Preparation of Oval-shaped Canals with TRUShape and Reciproc Systems: A Micro-

- Computed Tomography Study Using Contralateral Premolars. *J Endod.* 2017 Jun;43(6):1018–22.
55. Brasil SC, Marceliano-Alves MF, Marques ML, Grillo JP, Lacerda MFLS, Alves FRF, et al. Canal Transportation, Unprepared Areas, and Dentin Removal after Preparation with BT-RaCe and ProTaper Next Systems. *J Endod.* 2017 Oct;43(10):1683–7.
56. Pinheiro SR, Alcalde MP, Vivacqua-Gomes N, Bramante CM, Vivan RR, Duarte MAH, et al. Evaluation of apical transportation and centring ability of five thermally treated NiTi rotary systems. *Int Endod J.* 2018 Jun;51(6):705–13.
57. Pedrinha VF, Brandão JM da S, Pessoa OF, Rodrigues P de A. Influence of File Motion on Shaping, Apical Debris Extrusion and Dentinal Defects: A Critical Review. *Open Dent J.* 2018 Feb 28;12(1):189–201.
58. Kyaw Moe MM, Ha JH, Jin MU, Kim YK, Kim SK. Root Canal Shaping Effect of Instruments with Offset Mass of Rotation in the Mandibular First Molar: A Micro-computed Tomographic Study. *J Endod.* 2018 May;44(5):822–7.
59. Alovisei M, Cemenasco A, Mancini L, Paolino D, Scotti N, Bianchi CC, et al. Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. *Int Endod J.* 2017 Apr;50(4):387–97.

60. Gu Y, Kum K-Y, Perinpanayagam H, Kim C, Kum DJ, Lim S-M, et al. Various heat-treated nickel–titanium rotary instruments evaluated in S-shaped simulated resin canals. *J Dent Sci.* 2017 Mar;12(1):14–20.
61. da Silva Limoeiro AG, dos Santos AHB, De Martin AS, Kato AS, Fontana CE, Gavini G, et al. Micro-Computed Tomographic Evaluation of 2 Nickel-Titanium Instrument Systems in Shaping Root Canals. *J Endod.* 2016 Mar;42(3):496–9.
62. Saberi N, Patel S, Mannocci F. Comparison of centring ability and transportation between four nickel titanium instrumentation techniques by micro-computed tomography. *Int Endod J.* 2017 Jun;50(6):595–603.
63. Silva EJNL, Pacheco PT, Pires F, Belladonna FG, De-Deus G. Microcomputed tomographic evaluation of canal transportation and centring ability of ProTaper Next and Twisted File Adaptive systems. *Int Endod J.* 2017 Jul;50(7):694–9.
64. Paleker F, van der Vyver PJ. Comparison of Canal Transportation and Centering Ability of K-files, ProGlider File, and G-Files: A Micro-Computed Tomography Study of Curved Root Canals. *J Endod.* 2016 Jul;42(7):1105–9.
65. Chole DD, Burad DPA, Kundoor DS, Bakle DS, Devagirkar DA, Deshpande DR. Canal Transportation- A Threat in Endodontics: A Review. *IOSR J Dent Med Sci.* 2016 Jul;15(07):64–72.

66. van der Vyver PJ, Paleker F, Jonker CH. Comparison of preparation times of three different rotary glide path instrument systems. *South Afr Dent J*. 2015 May;70(4):144–7.
67. Ordinola-Zapata R, Bramante CM, Versiani MA, Moldauer BI, Topham G, Gutmann JL, et al. Comparative accuracy of the Clearing Technique, CBCT and Micro-CT methods in studying the mesial root canal configuration of mandibular first molars. *Int Endod J*. 2017 Jan;50(1):90–6.
68. Acar B, Kamburoğlu K, Tatar İ, Arıkan V, Çelik HH, Yüksel S, et al. Comparison of micro-computerized tomography and cone-beam computerized tomography in the detection of accessory canals in primary molars. :7.
69. Gagliardi J, Versiani MA, de Sousa-Neto MD, Plazas-Garzon A, Basrani B. Evaluation of the Shaping Characteristics of ProTaper Gold, ProTaper NEXT, and ProTaper Universal in Curved Canals. *J Endod*. 2015 Oct;41(10):1718–24.
70. Pasqualini D, Alovise M, Cemenasco A, Mancini L, Paolino DS, Bianchi CC, et al. Micro-Computed Tomography Evaluation of ProTaper Next and BioRace Shaping Outcomes in Maxillary First Molar Curved Canals. *J Endod*. 2015 Oct;41(10):1706–10.
71. Gergi R, Osta N, Bourbouze G, Zgheib C, Arbab-Chirani R, Naaman A. Effects of three nickel titanium instrument systems on root canal geometry assessed by micro-computed tomography. *Int Endod J*. 2015 Feb;48(2):162–70.

72. Peters OA, Arias A, Paqué F. A Micro-computed Tomographic Assessment of Root Canal Preparation with a Novel Instrument, TRUShape, in Mesial Roots of Mandibular Molars. *J Endod.* 2015 Sep;41(9):1545–50.
73. Pedullà E, Plotino G, Grande NM, Avarotti G, Gambarini G, Rapisarda E, et al. Shaping ability of two nickel–titanium instruments activated by continuous rotation or adaptive motion: a micro-computed tomography study. *Clin Oral Investig.* 2016 Nov;20(8):2227–33.
74. Ha JH, Cheung GSP, Versluis A, Lee CJ, Kwak SW, Kim HC. ‘Screw-in’ tendency of rotary nickel-titanium files due to design geometry. *Int Endod J.* 2015 Jul;48(7):666–72.
75. Zhao D, Shen Y, Peng B, Haapasalo M. Root Canal Preparation of Mandibular Molars with 3 Nickel-Titanium Rotary Instruments: A Micro-Computed Tomographic Study. *J Endod.* 2014 Nov;40(11):1860–4.
76. Gergi R, Arbab-Chirani R, Osta N, Naaman A. Micro-Computed Tomographic Evaluation of Canal Transportation Instrumented by Different Kinematics Rotary Nickel-Titanium Instruments. *J Endod.* 2014 Aug;40(8):1223–7.
77. Gundappa M, Khoriya S, Mohan R, Bansal R. Root canal centering ability of rotary cutting nickel titanium instruments: A meta-analysis. *J Conserv Dent.* 2014;17(6):504.
78. Marceliano-Alves MFV, Sousa-Neto MD, Fidel SR, Steier L, Robinson JP, Pécora JD, et al. Shaping ability of single-file

- reciprocating and heat-treated multifile rotary systems: a micro-CT study. *Int Endod J*. 2015 Dec;48(12):1129–36.
79. 2013 - A micro-computed tomography-based comparison of th.pdf.
80. Bürklein S, Schäfer E. Critical evaluation of root canal transportation by instrumentation: Critical evaluation of root canal transportation by instrumentation. *Endod Top*. 2013 Sep;29(1):110–24.
81. Versiani MA, Leoni GB, Steier L, De-Deus G, Tassani S, Pécora JD, et al. Micro-computed Tomography Study of Oval-shaped Canals Prepared with the Self-adjusting File, Reciproc, WaveOne, and ProTaper Universal Systems. *J Endod*. 2013 Aug;39(8):1060–6.
82. Moura-Netto C, Palo RM, Ribeiro CH. Micro-CT assessment of two different endodontic preparation systems. :5.
83. Zhao D, Shen Y, Peng B, Haapasalo M. Micro-Computed Tomography Evaluation of the Preparation of Mesio Buccal Root Canals in Maxillary First Molars with Hyflex CM, Twisted Files, and K3 Instruments. *J Endod*. 2013 Mar;39(3):385–8.
84. Stern S, Patel S, Foschi F, Sherriff M, Mannocci F. Changes in centring and shaping ability using three nickel-titanium instrumentation techniques analysed by micro-computed tomography (μ CT): Rotary versus reciprocating

- instrumentation, a μ CT analysis. *Int Endod J*. 2012 Jun;45(6):514–23.
85. Freire LG, Gavini G, Branco-Barletta F, Sanches-Cunha R, dos Santos M. Microscopic computerized tomographic evaluation of root canal transportation prepared with twisted or ground nickel-titanium rotary instruments. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontology*. 2011 Dec;112(6):e143–8.
86. Paqué 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 Apr;37(4):517–21.
87. Loizides AL, Kakavetsos VD, Tzanetakis GN, Kontakiotis EG, Eliades G. A Comparative Study of the Effects of Two Nickel–Titanium Preparation Techniques on Root Canal Geometry Assessed by Microcomputed Tomography. *J Endod*. 2007 Dec;33(12):1455–9.
88. Peters OA, Schönenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography: Canal preparation assessed by micro-CT. *Int Endod J*. 2001 Apr;34(3):221–30.
89. Peters OA, Laib A, Rügsegger P, Barbakow F. Three-dimensional Analysis of Root Canal Geometry by High-resolution Computed Tomography. *J Dent Res*. 2000 Jun;79(6):1405–9.

90. Wu M-K, 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(4):7.
91. Rhodes JS, Ford TRP, Lynch JA, Liepins PJ, Curtis RV. Micro-computed tomography: a new tool for experimental endodontology. *Int Endod J.* 1999 May;32(3):165–70.
92. 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 Dec;23(12):4255–62.
93. Secilmis A. Effects of storage solutions on mineral contents of dentin. :6.
94. Razcha C, Zacharopoulos A, Anestis D, Mikrogeorgis G, Zacharakis G, Lyroudia K. Micro-Computed Tomographic Evaluation of Canal Transportation and Centering Ability of 4 Heat-Treated Nickel-Titanium Systems. *J Endod.* 2020 May;46(5):675–81.
95. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol.* 1971 Aug;32(2):271–5.
96. Albuquerque MS de, Nascimento AS, Braz R, Gialain IO, de Lima EA, Nery JA, et al. Canal Transportation, Centering

- Ability, and Dentin Removal after Instrumentation: A Micro-CT Evaluation. *J Contemp Dent Pract*. 2019 Jul;20(7):806–11.
97. Gambill JM, Alder M. Comparison of Nickel-Titanium and Stainless Steel Hand-File Instrumentation Using Computed Tomography. *J Endod*. 1996;22(7):7.
98. Kataia M, Kataia E. Cutting efficiency of different cross sectional design protaperrotary instruments - in-vitro study. *J Innov Pharm Biol Sci*. 2016 Jan 1;3:116–22.
99. Gagliardi J, Versiani MA, de Sousa-Neto MD, Plazas-Garzon A, Basrani B. Evaluation of the Shaping Characteristics of ProTaper Gold, ProTaper NEXT, and ProTaper Universal in Curved Canals. *J Endod*. 2015 Oct;41(10):1718–24.
100. Abou-Rass M, Frank AL, Glick DH. The Anticurvature Filing Method to Prepare the Curved Root Canal. *J Am Dent Assoc*. 1980 Nov;101(5):792–4.
101. Schafer E, Diez C, Hoppe W, Tepel J. Roentgenographic Investigation of Frequency and Degree of Canal Curvatures in Human Permanent Teeth. *J Endod*. 2002 Mar;28(3):211–6.
102. Wildey WL, Senia ES. A new root canal instrument and instrumentation technique: a preliminary report. *Oral Surg Oral Med Oral Pathol*. 1989 Feb;67(2):198–207.
103. Htun PH, Ebihara A, Maki K, Kimura S, Nishijo M, Okiji T. Cleaning and Shaping Ability of Gentlefile, HyFlex EDM, and ProTaper Next Instruments: A Combined Micro-computed

- Tomographic and Scanning Electron Microscopic Study. *J Endod*. 2020 Jul;46(7):973–9.
104. Belladonna FG, Carvalho MS, Cavalcante DM, Fernandes JT, de Carvalho Maciel AC, Oliveira HE, et al. Micro-computed Tomography Shaping Ability Assessment of the New Blue Thermal Treated Reciproc Instrument. *J Endod*. 2018 Jul;44(7):1146–50.
105. Filizola de Oliveira DJ, Leoni GB, da Silva Goulart R, Sousa-Neto MD de, Silva Sousa YTC, Silva RG. Changes in Geometry and Transportation of Root Canals with Severe Curvature Prepared by Different Heat-treated Nickel-titanium Instruments: A Micro-computed Tomographic Study. *J Endod*. 2019 Jun;45(6):768–73.
106. Zuolo ML, Zaia AA, Belladonna FG, Silva EJNL, Souza EM, Versiani MA, et al. Micro-CT assessment of the shaping ability of four root canal instrumentation systems in oval-shaped canals. *Int Endod J*. 2018 May;51(5):564–71.
107. Gavini G, Santos M dos, Caldeira CL, Machado ME de L, Freire LG, Iglecias EF, et al. Nickel–titanium instruments in endodontics: a concise review of the state of the art. *Braz Oral Res* [Internet]. 2018 Oct 18 [cited 2021 Jan 3];32(suppl 1). Available from: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1806-83242018000500602&lng=en&tlng=en

108. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. *J Endod.* 1975 Aug;1(8):255–62.
109. Katz A, Wasenstein-Kohn S, Tamse A, Zuckerman O. Residual Dentin Thickness in Bifurcated Maxillary Premolars After Root Canal and Dowel Space Preparation. *J Endod.* 2006 Mar;32(3):202–5.
110. Clark D, Khademi J. Modern Molar Endodontic Access and Directed Dentin Conservation. *Dent Clin North Am.* 2010 Apr;54(2):249–73.
111. Elnaghy AM. In vitro comparison of cyclic fatigue resistance of TruNatomy in single and double curvature canals compared with different nickel-titanium rotary instruments. 2020;8.
112. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. *J Endod.* 2011 Jul;37(7):997–1001.
113. Chang SW, Shim KS, Kim YC, Jee KK, Zhu Q, Perinpanayagam H, et al. Cyclic fatigue resistance, torsional resistance, and metallurgical characteristics of V taper 2 and V taper 2H rotary NiTi files: Metallurgical characteristics of V taper and V taper 2H. *Scanning.* 2016 Nov;38(6):564–70.
114. Elnaghy AM, Elsaka SE. Cyclic Fatigue Resistance of One Curve, 2Shape, ProFile Vortex, Vortex Blue, and RaCe Nickel-Titanium Rotary Instruments in Single and Double Curvature Canals. *J Endod.* 2018 Nov;44(11):1725–30.

115. Özyürek T, Gündoğar M, Uslu G, Yılmaz K, Staffoli S, Nm G, et al. Cyclic fatigue resistances of Hyflex EDM, WaveOne gold, Reciproc blue and 2shape NiTi rotary files in different artificial canals. *Odontology*. 2018 Oct;106(4):408–13.
116. Berutti E, Fedon G. Thickness of cementum/dentin in mesial roots of mandibular first molars. *J Endod*. 1992 Nov;18(11):545–8.
117. Shenoi P, Luniya D, Badole G, Makade C, Kubde R, Khode R. Comparative evaluation of shaping ability of V-Taper 2H, ProTaper Next, and HyFlex CM in curved canals using cone-beam computed tomography: An in vitro Study. *Indian J Dent Res*. 2017;28(2):181.
118. Jainan A, Mahakunakorn N, Arayatrakulikit U, Sutthiprapaporn P, Noisombat R. Cone-beam computed tomography evaluation of curved root canals prepared using reciprocal rotary files and rotational rotary files. *J Conserv Dent JCD*. 2018 Feb;21(1):32–6.
119. Acar B, Kamburoğlu K, Tatar İ, Arıkan V, Çelik HH, Yüksel S, et al. Comparison of micro-computerized tomography and cone-beam computerized tomography in the detection of accessory canals in primary molars. :7.
120. Ordinola-Zapata R, Bramante CM, Versiani MA, Moldauer BI, Topham G, Gutmann JL, et al. Comparative accuracy of the Clearing Technique, CBCT and Micro-CT methods in studying

- the mesial root canal configuration of mandibular first molars. *Int Endod J*. 2017 Jan;50(1):90–6.
121. Shen Y, Cheung GSP. Methods and models to study nickel-titanium instruments: Methods and models to study nickel-titanium instruments. *Endod Top*. 2013 Sep;29(1):18–41.
122. Bjorndal L, Laustsen MH, Reit C. Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare. *Int Endod J*. 2006 Oct;39(10):785-90.
123. Wayman BE, Patten JA, Dazey SE. Relative frequency of teeth needing endodontic treatment in 3350 consecutive endodontic patients. *J Endod*. 1994 Aug;20(8):399–401.
124. Berutti E, Fedon G. Thickness of cementum/dentin in mesial roots of mandibular first molars. *J Endod*. 1992 Nov;18(11):545–8.
125. Berutti E, Negro AR, Lendini M, Pasqualini D. Influence of Manual Preflaring and Torque on the Failure Rate of ProTaper Rotary Instruments. *J Endod*. 2004 Apr 1;30(4):228–30.
126. Cassim I, Vyver P. The importance of glide path preparation in endodontics: a consideration of instruments and literature. *SADJ J South Afr Dent Assoc Tydskr Van Suid-Afr Tandheelkd Ver*. 2013 Aug 1;68:322, 324–7.
127. Gergi R, Rjeily J, Sader J, Naaman A. Comparison of Canal Transportation and Centering Ability of Twisted Files, Pathfile-ProTaper System, and Stainless Steel Hand K-Files by Using Computed Tomography. *J Endod*. 2010 May 1;36:904–7.

128. Pasqualini D, Bianchi CC, Paolino DS, Mancini L, Cemenasco A, Cantatore G, et al. Computed micro-tomographic evaluation of glide path with nickel-titanium rotary PathFile in maxillary first molars curved canals. *J Endod*. 2012 Mar;38(3):389–93.
129. *Protocole-2Shape-2.pdf*.
130. Staffoli S, Özyürek T, Hadad A, Lvovsky A, Solomonov M, Azizi H, et al. Comparison of shaping ability of ProTaper Next and 2Shape nickel–titanium files in simulated severe curved canals. *G Ital Endodonzia*. 2018 Nov 1;32(2):52–6.
131. Gu Y, Kum K-Y, Perinpanayagam H, Kim C, Kum DJ, Lim S-M, et al. Various heat-treated nickel–titanium rotary instruments evaluated in S-shaped simulated resin canals. *J Dent Sci*. 2017 Mar;12(1):14–20.
132. 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. *Journal of Endodontics*. 2021 Mar 1;47(3):477-84.
133. Lertchirakarn V, Palamara JEA, Messer HH. Patterns of vertical root fracture: factors affecting stress distribution in the root canal. *J Endod*. 2003 Aug;29(8):523–8.
134. Tang W, Wu Y, Smales RJ. Identifying and Reducing Risks for Potential Fractures in Endodontically Treated Teeth. *J Endod*. 2010 Apr;36(4):609–17.

135. Adorno CG, Yoshioka T, Jindan P, Kobayashi C, Suda H. The effect of endodontic procedures on apical crack initiation and propagation ex vivo. *Int Endod J.* 2013 Aug;46(8):763–8.
136. Mireku AS, Romberg E, Fouad AF, Arola D. Vertical fracture of root filled teeth restored with posts: the effects of patient age and dentine thickness. *Int Endod J.* 2010 Mar;43(3):218-25.
137. Wilcox LR, Roskelley C, Sutton T. The relationship of root canal enlargement to finger-spreader induced vertical root fracture. *J Endod.* 1997 Aug;23(8):533–4.