ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)

IJDSIR : Dental Publication Service

Available Online at: www.ijdsir.com

Volume – 5, Issue – 2, March - 2022, Page No. : 478 - 500

The effect of different rotary and single file system on the dentinal root crack formation - An in-vitro study

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Citation of this Article: Dr. Jisha Elizabeth, Dr. Ananthakrishna S., Dr. Pradeep P. R., Dr. Syam Prasad T, "The effect of different rotary and single file system on the dentinal root crack formation - An in-vitro study", IJDSIR- March - 2022, Vol. – 5, Issue - 2, P. No. 478 – 500.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Background and objectives: Aim of the study was to study the effect of different rotary and single file system on the dentinal root crack formation using stereomicroscope.

Materials and method: Hundred and five single rooted teeth, after decoronation and establishing the working length were biomechanically prepared and randomly divided into seven groups based on the instruments used for the canal preparation. The groups are

Group 1: - Control group (n=15)

Group 2: - Preparation with Hy Flex EDM (n=15)

Group 3: - Preparation with Wave One (n=15)

Group 4: - Preparation with One Shape (n=15)

Group 5: - Preparation with Hero shaper (n=15)

Group 6: - Preparation with Race (n=15)

Group 7: - Preparation with Pro Taper Universal (n=15). After each instrumentation technique, the specimens were irrigated with 3% sodium hypochlorite using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length. Canals were rinsed with distilled water after the completion of the procedure to avoid dehydration. The root samples were horizontally sectioned at 3, 6 and 9mm from the apex with a low-speed saw under water cooling. All the samples were then viewed under stereomicroscope for the detection of microcracks. The results obtained from the stereomicroscope were subjected to ONE WAY ANOVA test followed by Cohran's Q test.

Result: The crack formation at the apical 3mm, 6mm and 9mm of the root canal was highest in one shape file system (86.7 %,73.3% and 66.7% respectively) followed by Wave One system (66.7 %, 53.3% and 33.3% respectively) then Hy Flex EDM (46.7%, 40.0% and 33.3% respectively), Hero shaper file (26.7 %, 20.0% and 13.3% respectively), Pro Taper universal file (20.0%,13.3% and 6.7% respectively) and Race file (13.3%, 6.7% and 6.7% respectively). The control group showed no amount crack formation in the root dentinal walls.

Interpretation and conclusion: Within the limitations of the study, it could be concluded that among the single file system and rotary file system, the single file system induced more amount of dentinal microcracks than the rotary file system. And among the single file system, the continuous file system caused more amount of dentinal microcrack than the reciprocal file system.

Keywords: Hero shaper, Hy Flex EDM, One Shape, Pro Taper Universal, Race, Wave One

Introduction

The main objective of endodontic treatment is to retain the remaining tooth structure after the decay and the trauma for the functional and aesthetic purpose. For this purpose, a good biomechanical preparation is necessary.[1] The aim of biomechanical preparation includes elimination of bacteria, removal of debris and creating a canal form that will allow a proper seal. However additional preparations may lead to formation of craze lines or fractures in the root dentine as a result of these there may be formation of vertical root fractures (VRF) which is one of the major frustrating complications of root canal treatment.[2]

An aberrant root canal anatomy often results in inadequate debridement or asymmetric shaping leading to many adverse events such as generation of abnormal root surface strain, canal center transportation, ledge formation, perforation, and microcrack induction on the root surface with resulting root fractures.[1]

The NiTi rotary files have become more widely used root canal preparation in endodontics. With the use of these rotary files, the complication seen with the stainless-steel files (such as ledges, zips, perforations, canal transportation) are much less.[3]

Recently introduced Nickel-titanium (NiTi) endodontic files have increased flexibility and strength, but are vulnerable to cause cracks or fractures. The Hy Flex EDM and Wave One are two well-known single file instruments designed and marketed to shape the root canals using a single file technique. HEDM are made with well-known controlled memory (CM) and are manufactured using electrical discharge machining (EDM), noncontact thermal erosion process that partially melts and evaporates the wire by high-frequency spark discharges. During this procedure, the shape of a work piece is changed by building a potential between the NiTi metal and the tools. The sparks initiated in this process are melting and vaporizing the material of the work piece in its surface layer.

Wave One is manufactured using M-wire NiTi to enhance the flexibility and fatigue resistance of the instrument.[4] It is a single-use, single file system to shape the root canal system completely from start to finish. These instruments are designed to work with a reverse cutting action. They have a triangular cross section at the tip end and convex triangular cross section at the coronal end. They have an advantage of reduced instrument fatigue. [5]

One Shape systems are made of conventional austenite 55-NiTi alloy. These files function at a speed of 400 rpm and have a torque of 4Ncm.[6] They are used in full

continuous rotation. They provide better cutting and improved resistance to cyclic fatigue.[7]

Pro Taper universal rotary files made from conventional super elastic NiTi wire have a convex triangular cross-sectional design and various percentage tapers to enable an active cutting motion.[8] They have three shaping files and three finishing files. Compared to other Pro Taper system they have certain modifications like: new rounded tip with transition angle removed, improved S2 file in order to better smooth the transition, grooves have been added to F2/F3 files to make they more flexible, change of cross section of F3 blades from U-shaped flutes to triangular concave shape with a shallow U-shaped groove, reduced coronal taper to improve tactile sense to feel apical constriction.[9]

The Hero Shaper is a new system that supplements the existing Hero 642. They have triple helix cross-section but the helix pitch and the helix angle have been modified, while the handle has been shortened for improved access and are available in ISO sizes 20, 25 and 30.[10] These files also have modifications in the pitch of the blade, which varies depending on the taper. With these modifications these files have increased efficiency, flexibility and strength.[11]

Race instruments have a design with alternating cutting edges. They are manufactured from stainless steel as well as from Ni-Ti alloy. The surfaces of Race instruments are electrochemically treated for improvement of cutting efficacy.[12] They have a triangular cross section with distinct positive cutting angles. They also have an improved cyclic fatigue resistance in continuous rotation.[13]

Therefore, the purpose of the study was to assess the effect of different rotary and single file system on the dentinal root crack formation.

Materials and methods

Hundred and five single rooted teeth that were indicated for extraction due to orthodontic reasons and periodontal problems were collected for this study. Teeth were carefully cleaned and stored in 10% buffered formalin.

All the teeth were decoronated apical to the cementoenamel junction to standardize the canal length to 13 mm with a diamond disc under water coolant. The root samples were then viewed under stereomicroscope to access any pre-existing external defects or cracks.

Samples were randomly divided into seven groups (one control and six experimental) based on the instruments used for the canal preparation (n= 15 in each group)

Group 1: - Control group

Group 2: - Preparation with Hy Flex EDM

Group 3: - Preparation with Wave One

Group 4: - Preparation with One Shape

Group 5: - Preparation with Hero shaper

Group 6: - Preparation with Race

Group 7: - Preparation with Pro Taper Universal

Working length of all samples were established by subtracting 1mm from the length of a size 10 K-file inserted into the canal until the tip of the file become visible at the apical foramen.

Group 1: Control group (n =15)

- Roots in the control group were instrumented with stainless steel hand K-files.
- #15 K-file was used as an initial file. Roots were prepared to apical size #25 and prepared up to size # 50 using a step-back technique with 1-mm increments.
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.

Group 2: Preparation with Hy flex EDM (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- Hy flex EDM was used according to manufacturer's instructions at 500 rpm and 2.5 Ncm torque with torque-controlled endodontic motor till #25.06
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.

Group 3: Preparation with Wave One (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- Wave One is a single-file system with reciprocating motion made of M-Wire alloy to increase instrument flexibility.
- Wave One Primary file, which had a tip size of 0.25 mm and a 06 taper in the apical 3 mm, was selected.
- Instrument was used in reciprocating, slow in-and-out pecking motions.
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.

Group 4: Preparation with One Shape (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- One shape is a single file with continuous rotation that can be used with curved canals.
- One-Shape system consists of one instrument with a tip size of 25 and a constant taper of 0.06 File operates at Speed-350–450 RPM and Torque-2.5 N/cm2.
- Canal preparation is accomplished with a slow in-and-out pecking motion. This movement is repeated till the WL.
- After each use, the file was removed from the canal, and debris was cleaned from the flutes using gauze.
- The root canals were rinsed with 5 mL 3% sodium hypochlorite solution. After reaching the WL a final rinse of the canal was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.

Group 5: Preparation with Hero shaper (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- The root canal were instrumented with 20, 25 with 0.04 taper and 25/0.06 file till the working length.
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.

Group 6: Preparation with Race (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- Canal preparation was done in a crown down manner to a master apical file size of #25 / 0.06
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed.

Group 7: Preparation with Pro Taper Universal (n =15)

- Initial negotiation of root canal space was performed using a size 15 manual K-file using a watch-winding motion to assure the presence of a glide path.
- Pro Taper Universal file system was used in full instrumentation length in the following sequence as S1,

S2, F1, F2, F3, F4, and F5 and Pro Taper Universal shaping files enlarged and shaped the coronal 2nd/3rdof the canal and finishing files finish the apical third of the canal.

- In this group, the root canals were prepared with Pro Taper Universal instruments, which were used at 300 rpm with 2 Ncm torque.
- An SX file was used at one half of the WL, S1 and S2 files were used at two thirds of the WL, and F1 (20/.07) and F2 (25/.06) files were used at full WL.
- In the canals, the SX, S1, and S2 files were used with a brushing motion.
- The other files were used with a gentle in-and-out motion until the instrument had reached the full WL.
- Root canal irrigation was completed with 5 mL 3% sodium hypochlorite after each file and a final rinse was performed using a syringe and 30 G endo irrigation needle with side vent, placing it 1mm from the working length.
- Canal will be rinsed with distilled water after the completion of the procedure to avoid dehydration.

Stereomicroscope evaluation

After final irrigation, the canals were dried with absorbent paper points. All the samples in Group I, Group II, Group III, Group IV, Group V, Group VI and Group VII were taken and markings were made as 3mm, 6mm and 9mm from the root apex. Samples were then sectioned horizontally using carborundun discs. The surface was marked as coronal, middle and apical portion. Samples were then prepared for Stereomicroscopic examination. The dentinal wall of the apical thirds, middle third and coronal third of roots were observed at magnifications of up to 30X for the presence or absence of dentinal microcracks.

The results obtained from the stereomicroscope were subjected to ONE WAY ANOVA test followed by Cohran's Q test.

Statistical analysis: Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 Released 2013. Armonk, NY: IBM Corp., will be used to perform statistical analyses.

Descriptive Statistics: Descriptive analysis includes expression of presence of micro crack in terms of frequency and proportion for each group.

Inferential Statistics: Chi Square Test was used to compare the presence of micro crack between groups at difference distances from apex. Cochran's Q test was used to compare the presence of micro crack between distances from apex in each group.

The level of significance was set at $P<0.05$.

Result

Table 1: Comparison of presence of microcrack between diff. Distances from apex in each group

Comparison of presence of Microcrack between diff. distances from apex in each group using Cochran's Q Test						
Variable	Distance	Crack		No Crack		P-Value
		n	%	n	%	
Control	3mm	0	0.0%	15	100.0%	..
	6mm	0	0.0%	15	100.0%	
	9mm	0	0.0%	15	100.0%	
Hy flex EDM	3mm	7	46.7%	8	53.3%	0.47
	6mm	6	40.0%	9	60.0%	
	9mm	5	33.3%	10	66.7%	

Wave One	3mm	10	66.7%	5	33.3%	0.15
	6mm	8	53.3%	7	46.7%	
	9mm	5	33.3%	10	66.7%	
One Shape	3mm	13	86.7%	2	13.3%	0.37
	6mm	11	73.3%	4	26.7%	
	9mm	10	66.7%	5	33.3%	
Hero shaper	3mm	4	26.7%	11	73.3%	0.22
	6mm	3	20.0%	12	80.0%	
	9mm	2	13.3%	13	86.7%	
Race	3mm	2	13.3%	13	86.7%	0.37
	6mm	1	6.7%	14	93.3%	
	9mm	1	6.7%	14	93.3%	
Pro Taper Universal	3mm	3	20.0%	12	80.0%	0.55
	6mm	2	13.3%	13	86.7%	
	9mm	1	6.7%	14	93.3%	

The test results illustrate that One Shape files produced higher dentinal microcracks than all the other experimental groups. Least dentinal cracks were detected in Race file group followed by control group.

Figure 1: presence of microcracks in each groups at various distance from the apex

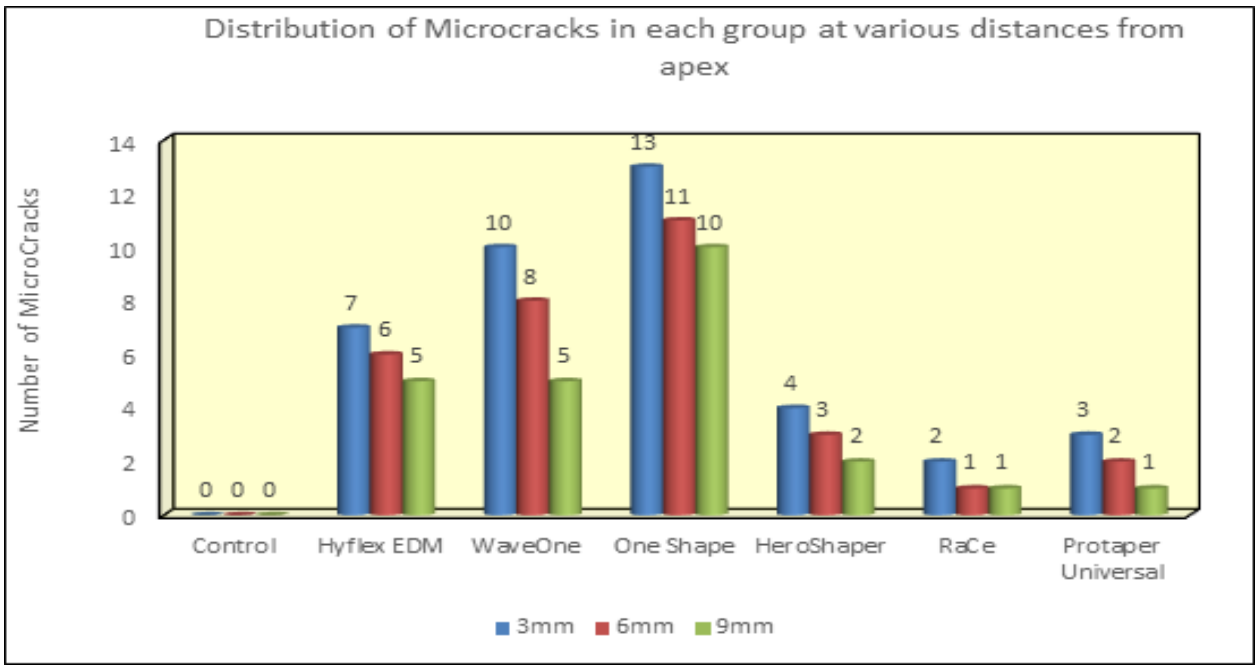

Table 2: multiple comparison of difference in the presence of cracks b/w groups at various distance from apex

Multiple comparison of difference in the presence of Cracks b/w groups at 3 mm distance using Chi Square Test											
Groups	G1 vs G2	G1 vs G3	G1 vs G4	G1 vs G5	G1 vs G6	G1 vs G7	G2 vs G3	G2 vs G4	G2 vs G5	G2 vs G6	G2 vs G7
P-Value	0.003*	<0.001*	<0.001*	0.03*	0.14	0.07	0.27	0.02*	0.26	0.04*	0.12
Groups	G3 vs G4	G3 vs G5	G3 vs G6	G3 vs G7	G4 vs G5	G4 vs G6	G4 vs G7	G5 vs G6	G5 vs G7	G6 vs G7	
P-Value	0.20	0.03*	0.003*	0.01*	0.001*	<0.001*	<0.001*	0.36	0.66	0.62	
Multiple comparison of difference in the presence of Cracks b/w groups at 6 mm distance using Chi Square Test											
Groups	G1 vs G2	G1 vs G3	G1 vs G4	G1 vs G5	G1 vs G6	G1 vs G7	G2 vs G3	G2 vs G4	G2 vs G5	G2 vs G6	G2 vs G7
P-Value	0.006*	0.001*	<0.001*	0.07	0.31	0.14	0.46	0.07	0.23	0.03*	0.10
Groups	G3 vs G4	G3 vs G5	G3 vs G6	G3 vs G7	G4 vs G5	G4 vs G6	G4 vs G7	G5 vs G6	G5 vs G7	G6 vs G7	
P-Value	0.26	0.06	0.005*	0.02*	0.001*	<0.001*	0.001*	0.28	0.62	0.54	
Multiple comparison of difference in the presence of Cracks b/w groups at 9 mm distance using Chi Square Test											
Groups	G1 vs G2	G1 vs G3	G1 vs G4	G1 vs G5	G1 vs G6	G1 vs G7	G2 vs G3	G2 vs G4	G2 vs G5	G2 vs G6	G2 vs G7
P-Value	0.01*	0.01*	<0.001*	0.14	0.31	0.31	1.00	0.07	0.20	0.07	0.07
Groups	G3 vs G4	G3 vs G5	G3 vs G6	G3 vs G7	G4 vs G5	G4 vs G6	G4 vs G7	G5 vs G6	G5 vs G7	G6 vs G7	
P-Value	0.07	0.20	0.07	0.07	0.003*	0.001*	0.001*	0.54	0.54	1.00	

Table 3: Distribution of microcrack in each group at various distances from apex

Distribution of Microcrack in each group at various distances from apex			
Groups	3mm	6mm	9mm
Control	0	0	0
Hy flex EDM	7	6	5
Wave One	10	8	5
One Shape	13	11	10
Hero Shaper	4	3	2
Race	2	1	1
Protaper Universal	3	2	1

Stereomicroscope analysis

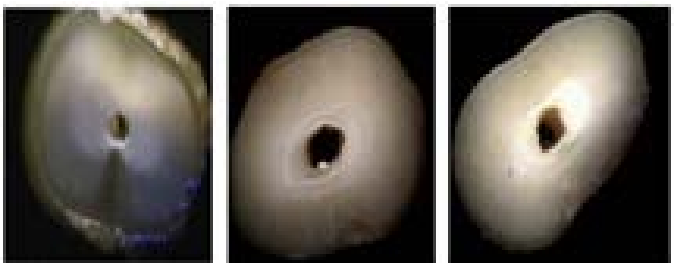

Figure 2: control group.

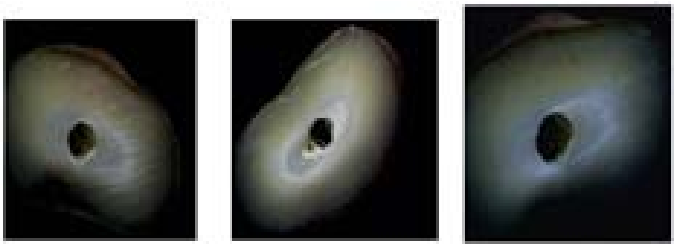

Figure 3: Hy flex edm group

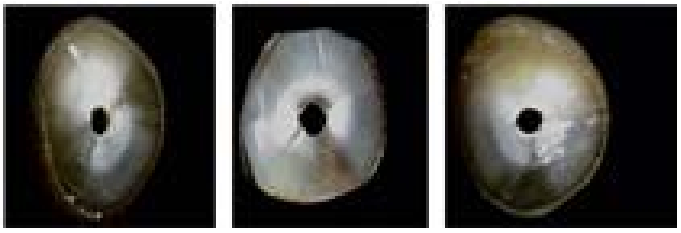

Figure 4: wave one group

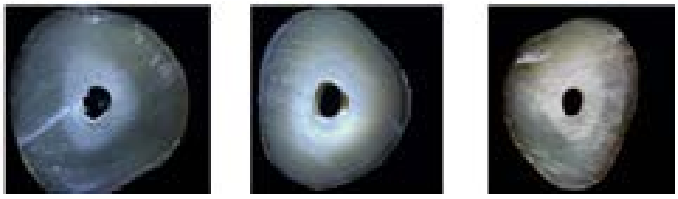

Figure 5: one shape group

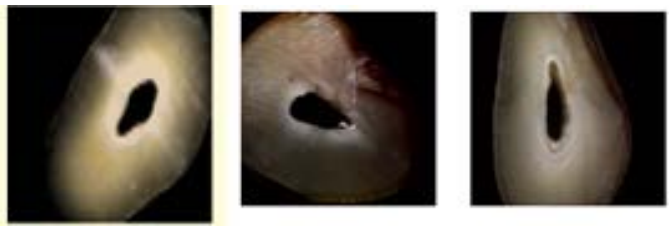

Figure 6: hero shaper group

Figure 7: race group

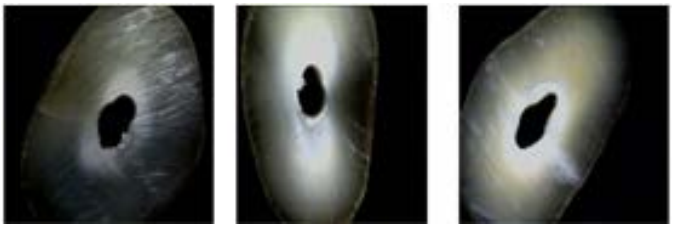

Figure 8: Protaper universal group

Discussion

Root canal therapy involves treating necrotic and vital pulp tissues so that patients can retain their teeth in normal form and function.[14]

Successful endodontic therapy depends upon triad of proper diagnosis, thorough biomechanical preparation and three-dimensional obturation of root canal system. Biomechanical is one of the most important factors for successful root canal treatment and determines the efficacy of all subsequent procedures.[15]

The main goal of chemo-mechanical root canal preparation is to eradicate microorganisms, debris, and organic tissue by enlarging the root canal and to create the canal space for adequate obturation. However, various procedural errors occur during root canal preparation such as perforations, canal transportation, ledge formation, zip formation, fracture of instruments, and dentinal cracks formation.[16]

Debris is the dentin chips, pulp remnants, and particles loosely attached to the root canal wall. The apical thirds of the root canal system are always most difficult to clean due to complex anatomies present like deltas, lateral canals, isthmuses and ramifications.[17]

In endodontic treatment, canal shaping is performed to provide sufficient space for efficient dentine disinfection. However, this step generates stresses that can also weaken the root and consequently lead to crack formation (especially in the apical portion of the root).[18]

The introduction of nickel–titanium (NiTi) alloys in the late 1980s led to a revolution in endodontics as these

files were shown to have considerable advantages over stainless steel (SS) files, especially in relation to the safety of instrumentation.[19]

The introduction of rotary nickel titanium (NiTi) instrumentation provided a faster and safer approach, with a lower risk of procedural errors compared to hand instrumentation.[20]

When NiTi rotary instruments are used, a rotational force is applied to root canal walls. Thus, they can create microcracks or craze lines in root dentin. The extent of such a defect formation may be related to the tip design, cross-section geometry, constant or progressive taper type, constant or variable pitch, and flute form.[21]

Some of the commonly used rotary files include: Hy Flex CM files, Hy Flex EDM files, BT-Race files, Pro Taper Universal files, Pro Taper Next files, Pro Taper Gold files, Hero shaper files, Wave One files, Wave One Gold files, Vortex Blue files, One Shape files, one curve files, 2 Shape file system, TRU shape files, Self-Adjusting files (SAF) etc.

In this present study following files were used: Hy Flex EDM files, Pro Taper Universal files, Race files, Wave One files, One Shape files, Hero shaper files.

These files were selected for this study because of the ease of the availability and to compare the dentinal microcracks formed between the single continuous, rotary and reciprocating files.

Defect is referred as the presence of craze line or microcracks or even complete crack that extends from the inner root canal space all the way to the outer surface of the root.[15]

Categories used to evaluate the crack type:

Type of crack Definition

No defect - Root dentin devoid of any craze lines or cracks where both the external surface of the root and the internal root canal wall will not have any evident defects

Defect - A craze line, a line extending from the outer surface into the dentin but will not reach the canal lumen

A partial crack - a line extending from the canal walls into the dentin without reaching the outer surface

A fracture - a line extending from the root canal space all the way to the outer surface of the root. [14]

The One Shape is made of a conventional austenite 55-NiTi alloy. The main characteristic is the asymmetrical cross-sectional design of the working portion. One Shape has three cutting edges in the tip region but in the middle the cross-sectional design progressively changes from a three-cutting-edges design to two cutting edges: at the shank it has two cutting edges with a S-shaped cross section.[22]

The Wave One single file reciprocating system. The Wave One Small file is used in fine canals. The tip size is ISO 21 with a continuous taper of 6%. The Wave One Primary file is used in the majority of canals. The tip size is ISO 25 with an apical taper of 8% that reduces towards the coronal end. The Wave One Large file is used in large canals. The tip size is ISO 40 with an apical taper of 8% that reduces towards the coronal end.[5]

The Wave One files are produced with the M-Wire NiTi alloy, using a heat procedure carried out at varying temperatures.[24]

The instruments are designed to work with a reverse cutting action. All instruments have a modified convex triangular cross section at the tip end and a convex triangular cross section at the coronal end. This design improves instrument flexibility overall. The tips are modified to follow canal curvature accurately. The variable pitch flutes along the length of the instrument considerably improve safety.

The Wave One motor is rechargeable battery operated with a 6:1 reducing handpiece. The pre-programmed motor is present for the angles of reciprocation and speed for Wave One instruments. The counter-clockwise (CCW) movement is greater than the clockwise (CW) movement. CCW movement advances the instrument, engaging and cutting the dentin. CW movement disengages the instrument from the dentin before it can (taper) lock into the canal. Three reciprocating cycles complete one complete reverse rotation and the instrument gradually advances into the canal with little apical pressure required.[5]

The Wave One cross section results in lower cutting efficiency and less chip space.[25] Wave One showed significant lesser degree of straightening in canals with curvature.[26]

Hy Flex EDM instruments are manufactured from the same controlled memory wire as Hy Flex CM but are produced via electro-discharge machining (EDM), a non-contact thermal erosion process that partially melts and evaporates the wire by high-frequency spark discharges.[27,28]

Metallographic analysis on the cross section of the EDM files revealed a microstructure similar to CM instruments[29], mostly composed of lenticular grains alternated to some large flat grains.

The EDM instruments exhibited remarkably different phase compositions. They primarily consisted of R-phase and martensite, which led to increased phase transformation temperatures and higher hardness when compared with conventional manufactured Hy Flex CM.[29]

Hy Flex EDM exhibited greater resistance to cyclic fatigue fracture, micro-hardness, maximum torque, and distortion angle than Hy Flex CM.[30] Hyflux EDM is a single file system used with a continuous rotary movement. The file has 3 different horizontal sections along the working part: quadratic in the apical part and trapezoidal and triangular in the middle and coronal parts.[31]

Hero shaper is a new NiTi rotary system with a triple helical cross section and helix angle that increases from tip to shank, aimed to reduce threading, and a pitch that varies according to taper, claiming to increase its efficiency, flexibility and strength.[32]

Hero shaper file system edge during manufacturing has been purposely dulled to reduce the screwing-in action.[17] Its name is HERO Shaper for body shaping with “adapted pitch” concept & HERO Apical for finishing apical root canal.[33]

Hero shaper files have a relatively lower flexibility leading to more amount of defect formation in the root canal dentin. They also have a relatively high level of torque and bending force.[21]

Protaper Universal system has instrument design with a triangular cross section and a variable progressive taper.[34] Protaper Universal (PTU) is a well-described NiTi rotary system of instruments manufactured with progressive taper over the length of the cutting blades, convex triangular cross sections, and noncutting tips. PTU files were found to induce significantly lower torque and force.[35]

The PTU instruments have a convex triangular cross-sectional design, a non–cutting safety tip and a flute design that combines multiple tapers within the shaft. Instruments with such a cross sectional design are claimed to cut dentine more effectively and are composed of conventional NiTi alloy. [36,37]

Race rotary endodontic instruments have triangular cross sections except for #15/.02 and #20/.02 instruments. The file has alternating cutting edges; this design reduces file threading into the canal wall. The instrument surface has

been electro polished. Instrument is used in 600 rpm and 2 N/cm torque.[38]

This design of Race file is said to have 2 functions: it eliminates screwing in and blocking during continuous rotation and it decreases the working torque.

In addition, the surfaces of Race instruments are treated electrochemically to enhance cutting efficacy, and they have a noncutting tip.[39]

In the present study, the crack formation at the apical 3mm of the root canal was highest in one shape file system with 86.7 % followed by Wave One system with 66.7 % then Hy Flex EDM with 46.7%, Hero shaper file with 26.7 %, Protaper universal file with 20.0% and Race file with 13.3%. The control group showed no amount crack formation in the root dentinal walls. The crack formation at the apical 6mm of the root canal showed One Shape file with 73.3% microcrack followed by Wave One file with 53.3%, then Hy Flex EDM with 40.0%, Hero shaper with 20.0%, Protaper Universal with 13.3% and Race file with 6.7% microcracks. The control group at apical 6mm showed 0.0% crack formation. The microcrack formation at the apical 9mm showed that the One Shape group had 66.7% microcrack followed by Wave One and Hy Flex EDM files with 33.3% microcracks then Hero shaper files with 13.3% microcracks followed by Protaper and Race file system with 6.7% microcracks. [Refer table 01, figure 01]

In the present study, the One Shape file system produced more dentinal cracks in the root canal system than the Wave One file system. [Refer table 01, figure 01]

This was in accordance with the study done by Li ML et al who compared the dentinal microcracks formation by One Shape, Wave One and few other files during the root canal preparation using micro-computed tomographic method. The results showed that the One Shape files produced more microcracks than the wave One files.[23]

This was also in accordance with the study conducted by Pathak VK et al who compared the dentinal microcrack formation between the reciprocating and continuous single file system. The result showed that the reciprocating file system showed less microcracks than the continuous file system.

WO also exhibits a parallelogram cross-section design with a unique 85-degree vigorous trimming border at every other one and two-point contact. WO is manufactured with an ingenious thermal treatment procedure giving it super elastic properties, flexibility which accounts for decreased screwing effect, vulnerable taper lock. These properties thereby reduce the touch between file and dentin which only cause small scale cracks.

OS system have a S-shaped cross-sectional design with dedicated cutting borders and non-cutting spike.[40]

The Hy Flex EDM produced lesser cracks than the wave One and One Shape file system in the apical 3mm of the root canal system. [Refer table 01, figure 01]

This was in accordance with the study conducted by Pedulla E et al who compared the dentinal crack formation by six different file systems and concluded that Hy Flex EDM file produced least cracks than the other file systems.

HEDM produces fewer, but not significantly different, cracks compared with WO.

This result is probably caused by the less taper of WO compared with HEDM and the high flexibility of HEDM caused by the synergistic effect of the Controlled Memory wire and the electrical discharge machining manufacturing process.[41]

In the present study, among the rotary file systems, the Hero shaper files created almost similar cracks as that of

the Protaper Universal files. Race files produced least microcracks than the other two files of the rotary files. [Refer table 01, figure 01]

This result was in accordance to study done by Yoldas et al. who compared the dentinal microcrack formation using different NiTi rotary instruments and self-adjusting files.

He concluded that Hero shaper files and Protaper files had similar amount of crack formation and it was more than the self-adjusting files.[21]

The Race file system produced least microcracks than the Protaper Universal file system. [Refer table 01, figure 01]

This result was in accordance to the study done by Ceyhan Li et al who compared Protaper, Race and Side safer files on induction of dentinal microcracks.

It was reported that the Protaper Universal files produced more dentinal microcracks than the Race files. This was because of the instrument design. Use of more tapered instrument for the preparation of the canal, weakens the canal which then further increases the chance of crack formation in the root dentinal walls. Moreover, rotational movement of instruments with a higher torque increased the stress distribution on dentine.[42]

According to this study, when G1 (control group) and G2 (Hy Flex EDM) groups was compared at 3mm, 6mm and 9mm distance, group 2 showed more cracks than group 1 and it is statistically significant at $p = 0.003$, $p = 0.006$ and $p = 0.01$ respectively. [Refer table 02]

This was in accordance with the study conducted by Mandava J et al who conducted a micro-computed tomographic evaluation of dentinal cracks between Hy Flex EDM and other file systems and concluded that Hy Flex EDM caused greater increase in dentinal defects. Formation of defects might be associated with the tip design, cross-sectional geometry, taper type (constant or progressive), flute form and pitch (constant or variable) of the rotary file.

Hy Flex EDM file has 3 different (rectangular in the apical part and two different trapezoidal cross-sections in the middle and coronal part) cross-sectional zones over the entire working length of the instrument. This design feature might generate screwing effect and dangerous taper lock can maximize the contact between the file and the dentin causing formation of dentinal defects.[63]

When G1(control group) and G3 (wave One) groups was compared at 3mm, 6mm and 9mm distance, group 3 showed more microcracks than group 1 and it is statistically significant at $p < 0.001$, $p = 0.001$ and $p = 0.01$ respectively. [Refer table 02]

This was found to be in accordance to the study done by Abdul Hamed s et al who did a stereomicroscopic analysis of dentinal microcracks after the root canal preparation using various different rotary file system and concluded that wave One files produced more microcracks in the apical region of the root canal system than the other files.

The largest amount of dentinal defects promoted by wave One file system may be related to its high level of flexibility due to heat treatment of NiTi alloys and its parallelogram shaped cross section.[43]

When G1(control group) and G4 (One Shape) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 1 and it is statistically significant at $p < 0.001$, $p < 0.001$ and $p < 0.001$ respectively. [Refer table 02]

This was in accordance to the study done by Chand Wani n et al. who compared various file system for the microcrack formation under scanning electron microscope and reported that one shape file system had more cracks in the apical third of the root canal dentin

than control groups. It has a triangle cutting edge in the apical part, 2 cutting edges in the coronal part, and a cross-section that progressively changes from 3 to 2 cutting edges between the apical and coronal parts. This design may affect shaping forces on root dentin these forces may cause root fracture. This could be the probable reason for more cracks in the apical region.[44]

When G1(control group) and G5 (Hero Shaper) groups was compared at 3mm, 6mm and 9mm distance, group 5 showed more microcracks than group 1 and it is statistically significant at p = 0.03, p = 0.07 and p = 0.14 respectively. [Refer table 02]

This was in accordance to the study done by Yoldas O et al who compared dentinal microcrack formation during root canal preparation by different NiTi rotary instruments. It was concluded that the control group produced no dentinal microcracks. Hero shaper file produced more amount of dentinal microcracks. It was because of the file design, spped and torque in which the instrument was used. In the HERO Shaper group, a torque and speed-controlled motor at a torque and speed recommended by the manufacturer (300 rpm).[21]

When G1(control group) and G6 (Race) groups was compared at 3mm, 6mm and 9mm distance, group 6 showed more microcracks than group 1 and it is statistically significant at p = 0.14, p = 0.31 and p = 0.311 respectively. [Refer table 02]

This was in accordance to the study done by Elnazzer HM et al who did a comparative evaluation of dentinal microcrack after root canal preparation using different NiTi rotary file systems. It was concluded that the control had no microcracks compared to all other group and the Race system produced more of complete and incomplete cracks. This was due to the file design, speed and torque used for the preparation of the root canal system.[45]

This was also in accordance to the study done by Davale MR et al who studied the effect of instrumentation length and instrumentation system using hand and rotary file on apical crack formation.

It was concluded that Race files produced the highest number of cracks when instrumented. The Race files have a sharp cutting edge with convex triangular cross-section. They have asymmetrical longitudinal design. A set of cutting-edge alternates with the second set pitched at a different angle leading to two different cutting edges on the same file. This could cause stress concentration at specific points rather than distribute it along the entire length of file. This concentration of stresses could have led to comparatively more cracks seen with this system.[46]

When G1(control group) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 7 showed more microcracks than group 1 and it is statistically significant at p= 0.07, p = 0.14 and 0.31 respectively. [Refer table 02]

This was found to be in accordance to the study done by Chole D et al who did a study on effects of different file system on crack formation in dentin after the root canal preparation. It was concluded that the Protaper Universal files produced more amount of dentinal microcracks in the apical part of the root canal system than other groups. It was the tip design of rotary instruments, cross-sectional geometry, constant or variable pitch and taper, and flute form could be related to crack formation. Protaper Universal rotary files have a convex triangular cross-sectional design and various percentage tapers that enable an active cutting motion and the removal of relatively more dentin coronally. Protaper Universal rotary files are made from a conventional super elastic NiTi wire.[47]

When G2 (Hy Flex EDM) and G3 (wave One) groups was compared at 3mm, 6mm and 9mm distance, group 3 showed more microcracks than group 2 and it is statistically significant at p= 0.27, p = 0.46 and p = 1.00 respectively. [Refer table 02]

This was in accordance to the study done by Vamishetty H et al who compared rotary and reciprocating file for dentinal microcrack formation using micro computed tomographic analysis and concluded that Hy Flex EDM files produced lesser microcracks than the wave One file system. This was contributed to the tip design of rotary instruments, cross-sectional geometry, constant or variable pitch and taper, and flute form.

Hy Flex EDM is a new generation single-file system with continuous rotation motion. Throughout their entire working part, they have three different horizontal cross sections: a quadratic in the apical region, trapezoidal in the middle, and almost triangular in the coronal region. These files are made of a controlled memory alloy using electro discharge machining technology, which significantly improved its flexibility. And hence they produced lesser crack than other files used in the study.

wave One file is used in reciprocating motion and is repeatedly heat treated and cooled, having parallelogram cross section, providing increased flexibility and cyclic fatigue resistance.[48]

When G2 (Hy Flex EDM) and G4 (One Shape) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 2 and it is statistically significant at p= 0.02, p = 0.07 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by Das S et al who compared the dentinal microcrack formed by One Shape, Hy Flex EDM and Protaper file. He concluded that Protaper Next and HEDM produced significantly less cracks than One Shape files.

The design of file may affect shaping forces on root dentin; these forces may cause root fracture. One Shape has asymmetrical cross-section over entire length and variable pitch, noncutting safety tip.

HEDM files are produced by control memory treatment just like Hy flex CM file. EDM process created a rough and hard surface that could improve cutting efficiency of these files.

This file has three different cross-sections over the entire length of working part (rectangular) in apical part, trapezoidal cross-section in middle part, triangular in coronal part to increase fracture resistance, and cutting efficiency.

Protaper Next and HEDM have rectangular cross-sectional design. One Shape has almost triangular cross-sectional design. Thus, this difference in design could be attributed to more cracks in One Shape. Instruments manufactured from M-wire alloy and controlled memory NiTi wire have more flexibility than conventional NiTi wire. Hence, Protaper Next and HEDM manufactured from these wires would have contributed to less number of cracks than OneShape.[49]

This was also in accordance to the study done by Mohammed MN et al who compared different NiTi files for incidence of dentinal microcrack formation in the root canal. One shape produced maximum amount of dentinal microcracks than all the file systems. The results of higher crack formation by One Shape could be influenced by their asymmetrical cross-section over entire length, constant taper, variable pitch and noncutting safety tip.[50]

When G2 (Hy Flex EDM) and G5 (Hero shaper) groups was compared at 3mm, 6mm and 9mm distance, group 2 showed more microcracks than group 5 and it is statistically significant at p= 0.26, p = 0.23 and p = 0.20 respectively. [Refer table 02]

This was in accordance to the study done by Pinto JC et al compared the dentinal microcrack by micro –CT after root canal preparation concluded that Hy Flex EDM files produced maximum number of microcracks in the radicular dentin after the root canal preparation.

The increased percentage of microcracks could be attributed to the taper, the hard surface induced by the surface treatment, the tip design, the cross-sectional geometry, the variable pitch or the flute form.

The propagation of microcracks in HEDM instrumentation was probably caused by tensions inside the root canal, which were transmitted to the external root surface, thus increasing a preexisting defect.

HEDM files also have CM characteristics, they are manufactured using electrical discharge machining. HEDM instruments maintain their integrity after multiple use, and are associated with high resistance to cyclic fatigue.[51]

When G2 (Hy Flex EDM) and G6 (Race) groups was compared at 3mm, 6mm and 9mm distance, group 2 showed more microcracks than group 6 and it is statistically significant at p= 0.04, p = 0.03 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by Sundaram KM et al who reported that Race showed the least fatigue resistance. This might be attributed to the fact that Race files have alternating cutting edge, which tends to increase the torsional resistance and not the flexural resistance. This led to reduced dentinal microcrack formation.[52]

When G2 (Hy Flex EDM) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 2 showed more microcracks than group 7 and it is statistically significant at p= 0.12, p = 0.10 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by Vora EC et al who tested effect of three different rotary files on the dentinal microcrack formation. He reported that in the apical third, Hy Flex EDM group had maximum number of dentinal defects while Protaper Universal had lesser number of dentinal defects. In the middle third, Protaper Universal had maximum number of dentinal defects while Hy Flex EDM showed lesser number of dentinal defects. In the cervical third, Protaper Universal showed maximum number of dentinal defects and Hy Flex EDM showed no or minimal dentinal defects cases.

Protaper Universal files are available with progressive taper. This progressive taper prevents a “taper-lock” situation. Instruments are triangular cross-sectionally, reducing the contact area between the file and dentin. They have modified guided tips, varying tip diameters, varying helical angles and pitches.

The Protaper system has shaping files with partially active tips while the finishing files have noncutting tips. Protaper Universal system is shown to have a lower risk of instrument separation when compared to other system due to its triangular file design. Protaper lowers the screw-in effect causing less apical transportation and has better canal centering ability.

Also, it was reported that high level of stiffness of the rotary Protaper Universal files which is explained by a larger cross-section design because of its progressive taper generates higher stress concentrations in the root dentin resulting in excessive removal of the dentinal wall raising the risk of dentinal defects leading to root cracking and weakening of the instrumented root.

Hy Flex EDM instruments are manufactured from M-wire alloy, they exhibit high flexibility and would have thus contributed to smaller number of cracks in middle and coronal third.

Hy Flex EDM group compared with that of Protaper Universal group have higher flexibility, relatively higher cutting efficacy, and extended fatigue resistance.[53]

When G3 (wave One) and G4 (One Shape) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 3 and it is statistically significant at p= 0.20, p = 0.26 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by Li ML et al who did a micro computed tomographic evaluation of dentinal microcrack during the root canal preparation using single file NiTi systems.

He reported that One Shape files produced more evident dentinal microcracks than the wave One files.

The wave One instruments, which is the main example of commercially available single-file reciprocating Ni-Ti systems for root canal preparation that alternate between different values of counterclockwise and clockwise rotation movements, which allows for 360˚ preparation subsequent to a series of reciprocating movements.

Whereas, the One Shape instrument was designed using a single file and a rotary movement to complete preparation. In the study, it was speculated that the number of the files, the taper and the speed and torque had no effect on the formation of microcracks, whereas the preparation movement may affect the development of dentinal microcracks.

The One Shape system generated microcracks in the apical and coronal parts of the root, and the most common morphology was microcracks confined in the dentine. The thread design in the medial part of the One Shape system is a transition region that changes from three blades to two blades.[23]

When G3 (wave One) and G5 (Hero shaper) groups was compared at 3mm, 6mm and 9mm distance, group 3 showed more microcracks than group 5 and it is statistically significant at p= 0.03, p = 0.06 and p = 0.20 respectively. [Refer table 02]

This was in accordance to the study done by Frater M et al who compared the effect of instrumentation with different nickel titanium rotary systems on dentinal cack formation and reported that wave One files created maximum dentinal microcracks at the apical 3mm of the root canal dentin. wave One files are commercially available as single-file reciprocating systems.

The reason for this is probably that the apical part is the narrowest part of the canal, therefore any instrument contacts with the greatest canal surface in this part.

Crack formation cannot be traced back to a single factor. Instead, it is a result of multiple, possibly additive and/or synergistic factors, such as tip design, cross-sectional design, taper, manufacturing process of the NiTi alloy, etc.[54]

When G3 (wave One) and G6 (Race) groups was compared at 3mm, 6mm and 9mm distance, group 3 showed more microcracks than group 6 and it is statistically significant at p= 0.003, p = 0.005 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by De-Deus G et al who studied relationship between the root canal preparation and dentinal microcrack formation. He concluded that the wave One files produced more microcrack than the Race file system.

The potential to promote dentinal defects may be related to the design of the instrument. An increased file taper can contribute to the formation of dentinal defects because of the increased stress on the canal walls.

wave One files are commercially available as single-file reciprocating systems for root canal preparation that alternate different values of counterclockwise and clockwise rotation movements, allowing 360

preparations after running a series of reciprocating movements.[55]

When G3 (wave One) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 3 showed more microcracks than group 7 and it is statistically significant at p= 0.01, p = 0.02 and p = 0.07 respectively. [Refer table 02]

This was in accordance to the study done by Arumugam S et al who compared various files for the formation of dentinal microcracks and reported that more of dentinal microcracks was seen in the wave One group than the other groups. This was because of the file tip design, cross sectional geometry etc. wave One file are used in reciprocating motion. They have a parallelogram cross section, providing increased flexibility and cyclic fatigue resistance.[56]

This was also in accordance to the study done by Bur Klein S et al studied incidence of dentinal defects after root canal preparation using various file system. He reported that wave One files produced more amount of dentinal defects than the Protaper file system.

The reciprocating movement of the file is claimed to relieve stress on the instrument by special counterclockwise (cutting action) and clockwise (release of the instrument) movements, and it is assumed that this movement reduces the risk of cyclic fatigue caused by tension and compression.

Wave one are characterized by a triangular or modified triangular cross section that results in a lower cutting efficiency and less chip space. An increased cutting ability is usually associated with an improved cleaning efficacy. The reciprocal motion seems to enhance debris transportation toward the apex and may increase torsional forces.[57]

When G4 (One Shape) and G5 (Hero shaper) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 5 and it is statistically significant at p= 0.001, p = 0.001 and = 0.003 respectively. [Refer table 02]

This was in accordance to the study done by Van Pham K et al who compared the cutting efficiency and dentinal defects using different NiTi files system. It was reported that One Shape files more significant amount of dentinal defects than the other file system used in the study. These instruments possessed large volumes and great tapers, and therefore, these instruments could create dentinal defects.

The working time of One Shape files was longer. This proved that One Shape retained its cutting efficiency, and this might be due to the special designs of this instrument with appropriate changes along the root long axis as well as electropolishing procedure.[58]

When G4 (one Shape) and G6 (Race) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 6 and it is statistically significant at p< 0.001, p< 0.001 and p = 0.001 respectively. [Refer table 02]

This was in accordance to the study done by Saberi E et al who compared three NiTi files in curved canals for the dentinal microcrack formation and reported that one Shape showed maximum transportation in the internal wall of the curvature in the coronal third, which can weaken the canal wall and increase the risk of strip perforation and microcrack formation.

one Shape have higher tendency to remove dentin from the internal wall of the curvature of the root canal.[59]

When G4 (one Shape) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 4 showed more microcracks than group 7 and it is statistically significant at p< 0.001, p = 0.001 and p = 0.001 respectively. [Refer table 02]

This was in accordance to the study done by Priya NT et al who compared dentinal microcracks after root canal preparation between hand, rotary and reciprocating files. He reported that the one Shape files produced more microcracks on the dentinal walls than the Protaper files. one Shape files are used in continuous rotation motion, with a rotational speed of 450 rpm and a torque of 2.50 Ncm, using an X-Smart endodontic motor. Hence it applies higher pressure on the dentinal walls than other files and produced more dentinal defects.[60]

When G5 (Hero shaper) and G6 (Race) groups was compared at 3mm, 6mm and 9mm distance, group 5 showed more microcracks than group 6 and it is statistically significant at p = 0.36, p = 0.28 and p = 0.54 respectively. [Refer table 02]

This was in accordance to the study done by Bal SS et al who compared dentinal microcrack formation in radicular dentin reported that Hero shaper files resulted in highest incidence of dentinal defects. This was due to the cross section, taper and pitch of the file system.

The helical angle of cutting edges in Hero Shaper varies from tip to shank and adapted pitch, that is, pitch varies by taper and positive rake angle, large inner core, and three edges. The increased stress development on the dentin combined with low flexibility generates more cracks.[61]

When G5 (Hero shaper) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 5 showed more microcracks than group 7 and it is statistically significant at p= 0.66, p = 0.62 and p = 0.54 respectively. [Refer table 02]

This was in accordance to the study done by Shori DD et al who did a stereomicroscopic evaluation of the dentinal defects caused by few newer file system. He concluded that Hero shaper files produced more amounts of dentinal defects than the Protaper Universal file system.

The design of the rotary files is not the only factor for defect formation in root dentin. The forces of shaping the root dentin can be affected by the file design. Risk of root fracture is increased due to the forces generated during the root canal preparation.

Relatively low flexibility of the Hero Shaper may have contributed to the maximum number of defects in Hero Shaper group. Rotational force is applied to the canals of the root by NiTi rotary instruments, thus creating craze line or microcracks in root dentin.[62]

When G6 (RaCe) and G7 (Protaper Universal) groups was compared at 3mm, 6mm and 9mm distance, group 7 showed more microcracks than group 6 and it is statistically significant at p= 0.62, p =0.54 and p = 1.00 respectively. [Refer table 02]

This was in accordance to the study done by Ceyhan Li K.T et al who compared Protaper Universal, RaCe and Side safer files for the dentinal crack formation, concluded that Protaper Universal files produced more microcrack than the Race files.

The tapered design of Protaper Universal instruments and the use of these instruments at higher torque values may explain the significantly higher number of cracks than the RaCe files.

RaCe files have high rotational speeds which enhanced cutting efficiency and decreased defect formation.[42]

According to the present study, one Shape files produced highest dentinal microcracks at 3mm, 6mm and 9mm of root canal segment. And RaCe files produce least dentinal microcracks followed by control group.

According to the present study, Single file systems used are preferred over rotary files, as they are four times faster than rotary files. But the main disadvantage is that

they can increase the percentage for stress or stress concentration than full-sequence rotary and hand file systems. The increase in stress ratio accounts for micro crack formation. The root canal instrumentation with reciprocating movement is a better choice than continuous rotation instrumentation.

Conclusion

Under the limitations of this in-vitro study, it can be concluded that:

- All the rotary file systems were able to produce some amount of dentinal microcracks in the root canal dentin, except the control group which was prepared using Hand K-files.
- Among the single file system and rotary file system, the single file system induced more amount of dentinal microcracks than the rotary file system.
- Among the single file system, the continuous file system caused more amount of dentinal microcrack than the reciprocal file system.

References

1. Liu W, Wu B. Root canal surface strain and canal center transportation induced by 3 different nickel-titanium rotary instrument systems. Journal of endodontics. 2016 Feb 1;42(2):299-303.

2. Çiçek E, Koçak MM, Sağlam BC, Koçak S. Evaluation of microcrack formation in root canals after instrumentation with different NiTi rotary file systems: a scanning electron microscopy study. Scanning. 2015 Jan;37(1):49-53.

3. Gündoğar M, Özyürek T. Cyclic fatigue resistance of one Shape, Hy Flex EDM, wave One Gold, and Reciproc Blue nickel-titanium instruments. Journal of endodontics. 2017 Jul 1;43(7):1192-6.

4. Pedulla E, Savio FL, Boninelli S, Plotino G, Grande NM, La Rosa G, Rapisarda E. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. Journal of endodontics. 2016 Jan 1;42(1):156-9.

5. Webber J, Machtou P, Pertot W, Kuttler S, Ruddle C, West J. The wave One single-file reciprocating system. Roots. 2011 Jan;1(1):28-33.

6. Bürklein S, Benten S, Schäfer E. Shaping ability of different single-file systems in severely curved root canals of extracted teeth. International endodontic journal. 2013 Jun;46(6):590-7.

7. Gawdat SI, El Nasr HM. Shaping ability and surface topography of wave One Gold and one Shape single files. Endo-don tic Practice Today. 2018 Jun 1;12(2):109-8.

8. Capar ID, Arslan H, Ak cay M, Uysal B. Effects of Protaper Universal, Protaper Next, and Hy Flex instruments on crack formation in dentin. Journal of endodontics. 2014 Sep 1;40(9):1482-4.

9. Wu J, Lei G, Yan M, Yu Y, Yu J, Zhang G. Instrument separation analysis of multi-used Protaper Universal rotary system during root canal therapy. Journal of endodontics. 2011 Jun 1;37(6):758-63.

10. Veltri M, Mollo A, Mantovani L, Pini P, Balleri P, Grandini S. A comparative study of Endo flare–Hero Shaper and Mtwo NiTi instruments in the preparation of curved root canals. International Endodontic Journal. 2005 Sep;38(9):610-6.

11. Aydin C, Inan U, Yasar S, Bulucu B, Tunca YM. Comparison of shaping ability of RaCe and Hero Shaper instruments in simulated curved canals. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology. 2008 Mar 1;105(3): e92-7.

12. Paqué F, Musch U, Hulsmann M. Comparison of root canal preparation using RaCe and Protaper rotary Ni-Ti instruments. International endodontic journal. 2005 Jan;38(1):8-16.

13. Vadhana S, Saravana Karthikeyan B, Nandini S, Velmurugan N. Cyclic fatigue resistance of RaCe and Mtwo rotary files in continuous rotation and reciprocating motion. Journal of endodontics. 2014 Jul 1;40(7):995-9.

14. Langaliya AK, Kothari AK, Surti NR, Patel AR, Doshi PR, Pandya DJ. In vitro comparative evaluation of dentinal microcracks formation during root canal preparation by different nickel-titanium file systems. Saudi Endodontic Journal. 2018 Sep 1;8(3):183.

15. Dheeraj M, Bharti P, Bhagat N, Jan dial T, Chauhan S. Assessment of dentinal cracks in root canal surface with Protaper Next and 2 Shape rotary system. Journal of Advanced Medical and Dental Sciences Research. 2021 Oct 1;9(10):51-3.

16. Soujanya E, Verma N, Kaushik M, Naga Maheshwari X, Mehra N, Prasad LK. Effect of three different rotary file systems on dentinal crack formation–A stereomicroscopic analysis. Endodontology. 2020 Oct 1;32(4):220.

17. Sood N. To compare different file system in removing root canal debris-An vitro study. Journal of Advanced Medical and Dental Sciences Research. 2019 Jun 1;7(6):106-8.

18. Anous WH, Al-Ashry S, Ali MM, Kataia MM. Effect of different kinematic cutting motion in multiple versus single-file concept on dentinal crack formation: An in vitro study. Journal of International Oral Health. 2020 Jan 1;12(7):30.

19. Tabassum S, Zafar K, Umar F. Nickel-titanium rotary file systems: What's new? European endodontic journal. 2019;4(3):111.

20. Conceição I, Ferreira I, Braga AC, Pina-Vaz I. Simulated root canals preparation time, comparing Protaper Next and wave One Gold systems, performed by an undergraduate student. Journal of Clinical and Experimental Dentistry. 2020 Aug;12(8): e730.

21. Yoldas O, Yilmaz S, Atakan G, Kuden C, Kasan Z. Dentinal microcrack formation during root canal preparations by different NiTi rotary instruments and the self-adjusting file. Journal of endodontics. 2012 Feb 1;38(2):232-5.

22. Dagna A. Nickel-titanium single-file system in endodontics. J Contempt Dent Pract. 2015 Oct 1;16(10):834-9.

23. Li ML, Liao WL, Cai HX. A micro-computed tomographic evaluation of dentinal microcrack alterations during root canal preparation using single file Ni Ti systems. Experimental and therapeutic medicine. 2018 Jan 1;15(1):494-9.

24. Topcu KM, Karatas E, Ozsu D, Ersoy I. Efficiency of the Self-Adjusting File, wave One, Reciproc, Protaper and hand files in root canal debridement. European journal of dentistry. 2014 Jul;8(03):326-9.

25. Gergi RM, Osta NE, Naaman AS. Dentinal crack formation during root canal preparations by the twisted file adaptive, Reciproc and wave One instruments. European journal of dentistry. 2015 Oct;9(04):508-12.

26. Simpsy GS, Sajjan GS, Mudunuri P, Chittem J, Prasanthi NN, Balaga P. Shaping ability of reciprocating motion of wave One and Hy Flex in moderate to severe curved canals: A comparative study with cone beam computed tomography. Journal of conservative dentistry: JCD. 2016 Nov;19(6):578.

27. Jameson EC. Electrical discharge machining. Society of Manufacturing Engineers; 2001.

28. Kwak SW, Shen Y, Liu H, Wang Z, Kim HC, Haapasalo M. Heat treatment and surface treatment of nickel-titanium endodontic instruments. Frontiers in Dental Medicine.:78.

29. Iacono F, Pirani C, Generali L, Bolelli G, Sassatelli P, Lusvarghi L, Gandolfi MG, Giorgini L, Prati C. Structural analysis of Hy Flex EDM instruments. International endodontic journal. 2017 Mar;50(3):303-13.

30. Oh S, Kum KY, Kim HJ, Moon SY, Kim HC, Chaniotis A, Perinpanayagam H, Pedulla E, Chang SW. Bending resistance and cyclic fatigue resistance of wave One Gold, Reciproc Blue, and Hy Flex EDM instruments. Journal of Dental Sciences. 2020 Dec 1;15(4):472-8.

31. Uslu G, Özyürek T, Yilmaz K, Gündoğar M, Plotino G. Apically extruded debris during root canal instrumentation with Reciproc Blue, Hy Flex EDM, and XP-endo Shaper nickel-titanium files. Journal of endodontics. 2018 May 1;44(5):856-9.

32. Fayyad DM, Sabet NE, El-Hafiz ES. Computed tomographic evaluation of the apical shaping ability of Hero Shaper and Revo-S. Endodontic Practice Today. 2012 Jun 1;6(2).

33. Kohli A, Shetty R, Chandrashekhar P, Adlakha T, Prabhu S, Podar R. A comparative in-vitro evaluation of debris removal using different rotary instrument files systems. Ind J Conserv Endod. 2016 Apr;1(1):1-8.

34. 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. Journal of endodontics. 2015 Oct 1;41(10):1718-24.

35. Arias A, Singh R, Peters OA. Torque and force induced by Protaper Universal and Protaper Next during shaping of large and small root canals in extracted teeth. Journal of endodontics. 2014 Jul 1;40(7):973-6.

36. Harandi A, Mirzaeerad S, Mehrabani M, Mahmoudi E, Bijani A. Incidence of dentinal crack after root canal preparation by ProTaper universal, Neolix and SafeSider systems. Iranian endodontic journal. 2017;12(4):432.

37. Koçak MM, Çiçek E, Koçak S, Sağlam BC, Yılmaz N. Apical extrusion of debris using ProTaper Universal and Protaper Next rotary systems. International endodontic journal. 2015 Mar;48(3):283-6.

38. Aminsobhani M, Ghorbanzadeh A, Dehghan S, Niasar AN, Kharazifard MJ. A comparison of canal preparations by Mtwo and RaCe rotary files using full sequence versus one rotary file techniques; a cone-beam computed tomography analysis. Saudi Endodontic Journal. 2014 May 1;4(2):70.

39. García M, Duran-Sindreu F, Mercadé M, Bueno R, Roig M. A comparison of apical transportation between Profile and RaCe rotary instruments. Journal of endodontics. 2012 Jul 1;38(7):990-2.

40. Pathak VK, Jain K, Sharma A, Singh K, Saxena T, Gangli K. Comparative evaluation of dentinal crack after using reciprocating and continuous single file systems: An invitro study. University journal of dental sciences. 2020;6(3):22-6.

41. Pedulla E, Genovesi F, Rapi sarda S, La Rosa GR, Grande NM, Plotino G, Adorno CG. Effects of 6 single-file systems on dentinal crack formation. Journal of endodontics. 2017 Mar 1;43(3):456-61.

42. Ceyhanli KT, Erdilek N, Tatar I, Celik DA. Comparison of Protaper, RaCe and Safesider instruments in the induction of dentinal microcracks: a micro-CT study. International endodontic journal. 2016 Jul;49(7):684-9.

43. Abdul-Hamed S, Jehad RH, Abdul-Ameer ZM, Al-Hashemi J. A Stereomicroscopic Analysis of Dentinal Micro Cracks after Root Canal Preparation Using Four Different Rotary Instruments. Indian Journal of Forensic Medicine & Toxicology. 2020 Jan 1;14(1):397.

44. Chand Wani N, Ranka A, Jadhav GR, Jag Yasi D, Bopche P, Golchha A. Effect of various single file systems on microcrack formation in root canals: Scanning electron microscope study. Dental Research Journal. 2021;18.

45. Elnazzer HM, Sheriff DA, Labib AH. Incidence of Dentinal Cracks in Root Surface by Different Ni–Ti Rotary File Systems. J Oper Dent Endod. 2020 Jul;5(2):63-8.

46. Devale MR, Mahesh MC, Bhandary S. Effect of instrumentation length and instrumentation systems: Hand versus rotary files on apical crack formation–an in vitro study. Journal of clinical and diagnostic research: JCDR. 2017 Jan;11(1): ZC15.

47. Chole D, Kamble S, Bakle S, Gandhi N, Hatte N, Bawa P. Effects of 3 Single-File System (Protaper Universal, Protaper Next, Protaper Gold) on crack formation in dentin after root canal preparation–An in vitro study. IOSR-JDMS. 2019; 18:47-50.

48. Vemisetty H, Priya NT, Singh B, Yenubary P, Agarwal AK, Surakanti JR. Synchrotron radiation-based micro-computed tomographic analysis of dentinal microcracks using rotary and reciprocating file systems: An in vitro study. Journal of Conservative Dentistry: JCD. 2020 May;23(3):309.

49. Das S, Pradhan PK, Lata S, Sinha SP. Comparative evaluation of dentinal crack formation after root canal preparation using Protaper Next, one Shape, and Hy flex EDM. Journal of conservative dentistry: JCD. 2018 Mar;21(2):153.

50. Mohammed, M.N., Kamel, W.H. and Rokaya, M.E., 2020. Comparison of the Cleaning Effectiveness and Incidence of Dentinal Defects after Biomechanical Preparation Using Different Ni Ti Rotary Instruments in Root Canals. Al-Azhar Dental Journal for Girls, 7(2 April-Restorative Dentistry issue (Removable Prosthodontics, Fixed Prosthodontics, Endodontics, Dental Biomaterials, Operative Dentistry)), pp.165-170.

51. Pinto JC, Coaguila-Llerena H, Torres FF, Lucas-Oliveira É, Bonagamba TJ, Guerreiro-Tanomaru JM, Tanomaru-Filho M. Influence of voxel size on dentinal microcrack detection by micro-CT after root canal preparation. Brazilian oral research. 2021 Oct 11;35.

52. Sundaram KM, Srinivasan N, Ebenezer RA, Narayanan LA, Rajkumar K, Maha laxami S. Comparative evaluation of the effects of multiple autoclaving on cyclic fatigue resistance of three different rotary Ni-Ti instruments: An in vitro study. Journal of conservative dentistry: JCD. 2013 Jul;16(4):323.

53. Vora EC, Bhatia R, Tamgadge S. Effect of three different rotary instrumentation systems on crack formation in root dentin: an in vitro study. Endodontology. 2018 Jul 1;30(2):103.

54. Fráter M, Jakab A, Braunitzer G, Tóth Z, Nagy K. The potential effect of instrumentation with different nickel titanium rotary systems on dentinal crack formation—An in vitro study. Plos one. 2020 Sep 9;15(9): e0238790.

55. De-Deus G, Silva EJ, Marins J, Souza E, de Almeida Neves A, Belladonna FG, Alves H, Lopes RT, Versiani MA. Lack of causal relationship between dentinal microcracks and root canal preparation with reciprocation systems. Journal of Endodontics. 2014 Sep 1;40(9):1447-50.

56. Arumugam S, Yew HZ, Baharin SA, Qamaruz Zaman J, much tar A, Kanagasingam S. Micro-computed tomography evaluation of dentinal microcracks following canal preparation with thermomechanical Ly heat-treated engine-driven files. Australian Endodontic Journal. 2021 May 6.

57. Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation:

reciprocating versus rotary instrumentation. Journal of endodontics. 2013 Apr 1;39(4):501-4.

58. Van Pham K, Nguyen NQ. Cutting efficiency and dentinal defects using two single-file continuous rotary nickel–titanium instruments. Saudi Endodontic Journal. 2020 Jan 1;10(1):56.

59. Saberi E, Farhad-Mollashahi N, Bijari S, Daryaeian M. Comparative evaluation of root canal transportation by three NiTi single-file systems in curved canals: a cone beam computed tomography study. International journal of dentistry. 2018 May 14;2018.

60. Priya NT, Veeramachaneni Chandrasekhar SA, Tummala M, Raj TP, Badami V, Kumar P, Soujanya E. "Dentinal microcracks after root canal preparation" a comparative evaluation with hand, rotary and reciprocating instrumentation. Journal of clinical and diagnostic research: JCDR. 2014 Dec;8(12): ZC70.

61. Bal SS, Pare S, Unnikrishnan A, Shetty D, Kumar HG, rag her M. Detection of dentinal microcracks in radicular dentin after shaping with XP-endo Shaper, Neo Endo flex files, and Hero Shaper using scanning electron microscope: An in vitro study. Journal of Pharmacy & Bio allied Sciences. 2020 Aug;12(Suppl 1): S259.

62. Shori DD, Shenoi PR, Baig AR, Kubde R, Makade C, Pandey S. Stereomicroscopic evaluation of dentinal defects induced by new rotary system: "Pro Taper NEXT". Journal of conservative dentistry: JCD. 2015 May;18(3):210.

63. Mandava J, Yelisela RK, Arikatla SK, Ravi RC. Micro-computed tomographic evaluation of dentinal defects after root canal preparation with Hy flex edm and vortex blue rotary systems. Journal of clinical and experimental dentistry. 2018 Sep;10(9): e844.