ORIGINAL RESEARCH

Comparative Evaluation of Potential Dentinal Microcracks Related to Instrumentation alongside Bypassed Broken Instruments: An *In Vitro* Study

Mohammad Yaman Seirawan[1], Mohammad Kinan Seirawan[2], Mazen Doumani[3]

Abstract

Aim and objective: To investigate the occurrence of microcracks in the canals containing broken instruments in the middle and apical thirds after instrumentation with various systems.

Materials and methods: One-hundred and fifty mature mandibular premolars with single straight canal were collected and stored in distilled water. Samples were checked out from any preexisting deformation or cracks, and then standardized in length. Thirty teeth were never instrumented (NI) as a control group, 60 teeth have received a broken instrument in the middle third, and 60 ones at the apical third. Teeth were placed in resin blocks with simulation of periodontal ligaments. After bypassing the instruments, samples were divided into four groups $n = 30$; first group was prepared manually MN until 25/0.02, while the other three groups were prepared until 25/0.04 using three different rotary systems; Race RC—2Shape TS—Hyflex CM HCM. Roots were cut transversely at levels of broken instruments and examined under 40× microscopic magnification.

Results: All the rotary groups produced microcracks. No significant difference of the partial cracks was observed among all groups at the middle and apical levels $p > 0.05$. TS produced more complete cracks compared to each of NI, MN, RC at middle level and NI, MN at apical level; $p < 0.05$. No significant differences of microcracks incidence were observed between two middle and apical levels among the five groups.

Conclusion: Dentinal microcracks could be obviously resulted after rotary instrumentation alongside broken instruments, while manual shaping was less likely to cause microcracks.

Clinical significance: Manual files were less likely to induce microcracks alongside broken instruments in comparison with rotary files which could be considered much safer.

Keywords: Bypassed broken instruments, Dentinal microcracks, Microscopic magnification.

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Introduction

Biomechanical canal preparation is very essential in root canal treatment to remove the microorganisms, pulp tissue and debris, and it also determines the outcome of endodontic treatment,[1] where it cleans and enlarges the canal, and refines the apical zone to receive a dense obturation,[2] but a balance between removal of the affected dentin and preservation of the dentin structure should be ensured during canal instrumentation.[3]

Many clinicians prefer flexible NiTi rotary systems because they allow faster root canal preparation compared to manual files and have higher cutting efficiency,[4] but they may cause greater dentinal defects,[5] such as microcracks which are very frequent complications that may routinely occur after instrumentation and can be attributed to friction between files and canal walls.[2]

Although rotary files remove less dentin,[6] one of its downsides is the stress applied to the dentin which relates to cutting blade layouts with variable depths of flutes, diameter and taper of the body, cross-section designs, and all that can lead to crack formation.[2]

The more dangerous form is the propagation of these microcracks that cause a vertical root fracture (VRF), especially after the application of occlusal forces,[7] because there is a potential relation between the design of rotary files and the prevalence of crack considering that the file design affects the apical stress and accumulates the tensile stress during canal preparation.[8]

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Rotary systems have several types, sizes and sequences, and work with diverse settings for movement, speed and torque, as well as they differ from each other in the cutting blades design, cross sections and tapering, where the files with large taper are more likely to cause complete and incomplete dentinal cracks.[7] However, the metallurgical phase that files are made of is the most influential factor affecting the possibility of microcracks formation.[9]

Nickel-titanium (NiTi) rotary files have been improved, and one of the most famous systems is Race rotary system (FKG Dentaire SA, La Chaux De Fonds, Switzerland) which has been developed from conventional austenitic Ni-Ti alloy with the concept of alternating cutting edges in addition to convex triangular cross-section which reduced to the screw-in effect resulting in less engagement of the file with the canal walls.[10]

2Shape rotary system (Micro-Mega, Besancon, France) has been introduced later with two shaping files in continuous rotation and machined from heat-treated T Wire alloy with an asymmetric triangular cross-section allowing for a softer structure, greater flexibility, and fracture resistance.[11]

Hyflex CM rotary system (Coltene-Whaledent, Allstetten, Switzerland) is a controlled memory NiTi system in continuous rotation manufactured from a novel generation of heat-treated NiTi that makes the files extremely flexible and fracture-resistant by virtue of straightness of the spirals, which avoids binding to the canal walls.[12]

It is known that removing broken files has many dangerous consequences in terms of root wear, thinning the thickness of the walls, and the possibility of fractures,[13] which makes bypassing fragments suitable alternative treatment option,[14] but unfortunately it is not guaranteed, and preparing canals beside the broken files may lead to damage in the dentinal walls.

To our knowledge, no study has been reported the effect of instrumentation beside broken files, so this study aimed to evaluate the potentially partial and complete microcracks caused by instrumentation with three rotary systems made of different metallic alloys compared to manual files in canals containing broken files in middle and apical thirds, in addition to compare the incidence of partial and complete cracks among two levels (middle-apical) of the tested groups.

Materials and Methods

This experimental *in-vitro* study was approved by the Research and Ethics Committee of Faculty of dentistry, Damascus university (Ethics Approval Number: 36—Date: July 24, 2018). It was performed on 150 freshly extracted mandibular mature premolars with single straight canal which had been extracted according to orthodontic requirements. Teeth were inspected under a stereomicroscope for any preexisting deformation (internal or external root resorption, carious lesions, or external cracks), and then they were X-rayed to check for any calcification in the canals.

Teeth were cleaned of remaining soft tissues and debris, and disinfected by immersion in 0.5% sodium hypochlorite for 24 hours, and then kept in distilled water. The crowns were sectioned and finished by a low-speed handpiece under coolant. Teeth were standardized in length = 15 mm, then a K-file (#15) was introduced into each canal to confirm the smooth glide path, and it is noteworthy that teeth with an apical gauge greater than 0.15 mm were excluded.

K-files (#30) were inserted into 60 canals after being notched 3 mm away from their tips, and the files were rotated counterclockwise after being stuck in the middle third until they fractured, then the same was done in the apical third of another 60 canals but with K-files (#20), then the positions of the broken files were checked with X-rays, where the roots with incorrectly positioned fragments were excluded and replaced (Fig. 1).

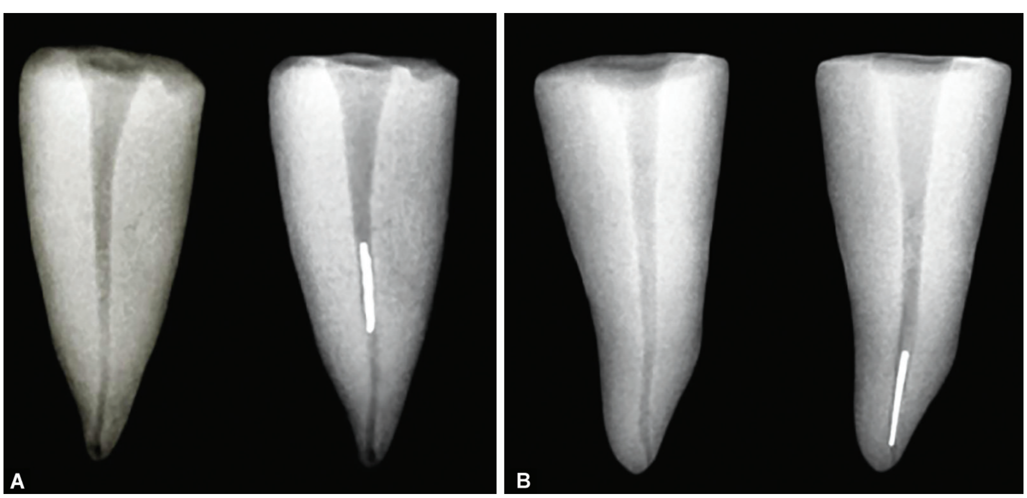
An attempt was made to bypass the broken files in the studied roots using K-file (#10), and once the catching was felt, a limited input and output movement was performed with copious irrigation of 2.5% sodium hypochlorite.[13] As long as there was an opportunity to push the fragment beyond the apex, and some fragments might not be bypassed, therefore these roots were excluded and replaced with new ones.

Since it was necessary to simulate the periodontal ligament to find out the effect of forces on the formation of the cracks, in addition to its role in dissipating the stress applied on the teeth,[15] the roots were immersed in self-polymerized acrylic resin after being wrapped with a layer of aluminum foil, and before it hardened completely, the aluminum foil was removed and replaced with a thin layer of polyvinyl siloxane impression material (light-body).[3]

Grouping

From the beginning, 30 roots were randomly selected as a control group without broken files, while another 120 roots were also randomly selected to receive broken files as mentioned previously (60 broken files in the middle third and 60 in the apical third).

After bypassing the broken files and matching the canals up to size #15, other parallel radiographs were taken to confirm the pathways of the canals. The 120 roots were randomly divided into



Figs 1A and B: The levels of broken files (A) Left without and right with broken file at the middle level; (B) Left without and right with broken file at the apical level four groups ($n = 30$), and each group contains 15 broken files at the middle level and 15 files at the apical level. So that the distribution of the five groups is as follows:

- Group I: no instrumentation "control group."
- Group II: instrumentation with the manual files (Mani, Tochigi, Japan), according to the following sequence: (#15/0.02, #20/0.02, #25/0.02).
- Group III: instrumentation with the Race "full sequential file system" (FKG Dentaire SA, La Chaux De Fonds, Switzerland) according to the following sequence: Scout Race (#15/0.02, Speed = 600 rpm, Torque = 1.5 N cm), Race (#15/0.04, #20/0.04, #25/0.04, Speed = 600 rpm, Torque = 1.5 N cm).
- Group IV: instrumentation with the 2Shape "double-file system" (Micro-Mega, Besancon, France) according to the following sequence: One G (#14/0.03, Speed = 400 rpm, Torque = 1.2 N cm), TS1 (#25/0.04, Speed = 400 rpm, Torque = 1 N cm).
- Group V: instrumentation with the Hyflex CM "full sequential file system" (Coltene-Whaledent, Allstatten, Switzerland) according to the following sequence: Hyflex EDM Glide path file (#10/0.05, Speed = 300 rpm, Torque = 1.8 N cm), Hyflex CM (#20/0.04, #25/0.04, Speed = 500 rpm, Torque = 2.5 N cm).

All preparations were performed by one examiner, and each file was used only one time per canal. Finally, the roots were pulled from acrylic models and cleaned from the impression material in order to prepare the horizontal cross-sections at the middle and apical levels with the low-speed saw under coolant.

Dentinal Microcrack Evaluation

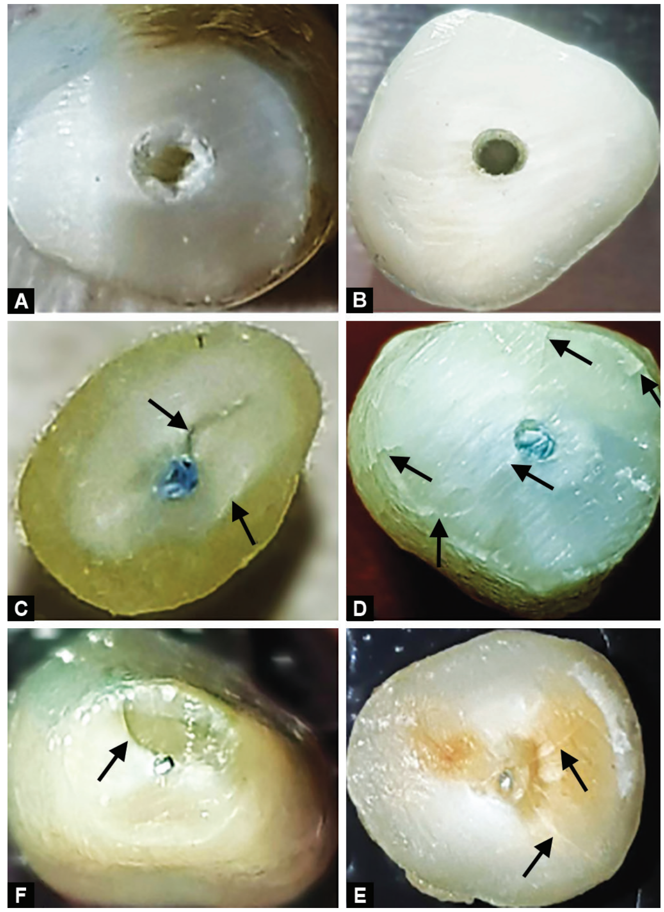
The sections were inspected under 40× magnification using a stereomicroscope (Olympus CX21FS2, Japan) with high source of illumination, and pictures were taken with a digital camera, and the defects were classified as "no defect," "all other defects," and "fracture" as follows:

- No defect: it was described as the absence of any lines or cracks that can be observed either from the outer surface of the root or the inner surface of the canal wall (Figs 2A and B).
- Other defects "partial crack": it was demonstrated by the presence of a craze lines or any line that starts from the outer surface but does not extend into the canal lumen or starts from the canal wall but does not reach the external root surface (Figs 2C and D).
- Fracture "complete crack": it was considered as a line extending from the canal wall to the external surface of the root or extending from the outer surface of the root to the canal lumen (Figs 2E and F).[16–18]

Sections were inspected by three independent operators blinded to the instrumentation protocol, and the score of microcracks was based on the preponderance of the arbitrators' opinions.

Statistical Analysis

SPSS software was used to analyze data (PASW Statistics 24; SPSS, Inc., Chicago, Illinois, USA), and the data were subjected to Chi-square test to evaluate the occurrence of microcracks in four experimental groups compared with the control group and with each other in two levels (middle-apical) after instrumentation. The level of statistically significant difference was set at the confidence level of 95% and p-value = 0.05. Then, the occurrence of microcracks between two levels (middle-apical) was studied, and the analysis results are shown in the Results section.



Figs 2A to F: Stereomicroscopic digital photographs of tooth section representing (A) No defect at the apical level; (B) No defect at the middle level; (C) Partial crack and craze line at the apical level; (D) Partial cracks extend from canal wall and from outer surface at the middle level; (E) Complete crack at the apical level; (F) Two complete cracks at the middle level (black arrow—pointing the defects; 40× magnification)

Results

Tables 1 and 2 show that there are no statistically significant differences of partial cracks at both the middle and apical levels between the five groups (Figs 3 and 4).

Table 1 shows that there are statistically significant differences of complete cracks at the middle level between each of control group, manual group, and Race group in comparison with 2Shape group, where the p-values (0.005, 0.020, 0.040) were less than the significance level of (0.05), and these differences are not in favor of 2Shape group, while there are no statistically significant differences related to other binary comparisons, where the p-values were greater than the significance level (0.05) (Fig. 3).

Table 2 shows that there are statistically significant differences of complete cracks at the apical level between control group compared with both Race and 2Shape groups, where the p-values (0.040, 0.005) were less than the significance level of (0.05), and these differences are against both Race and 2Shape groups; also, there are significant differences against 2Shape group compared

Table 1: Chi-square test results at the middle level between the five groups

	Binary comparisons between groups	*Chi-square value*	*p value*	*Decision*
Partial cracks	Control group vs Manual	0.556	0.355	No significant differences
	Control group vs Race	0.144	0.500	No significant differences
	Control group vs 2Shape	2.143	0.136	No significant differences
	Control group vs Hyflex CM	0.556	0.355	No significant differences
	Manual vs Race	0.136	0.500	No significant differences
	Manual vs 2Shape	0.536	0.358	No significant differences
	Manual vs Hyflex CM	1.2	0.233	No significant differences
	Race vs 2Shape	0	1	No significant differences
	Race vs Hyflex CM	0.136	0.500	No significant differences
	2Shape vs Hyflex CM	0.536	0.358	No significant differences
Complete cracks	Control group vs Manual	0.556	0.456	No significant differences
	Control group vs Race	1.313	0.519	No significant differences
	Control group vs 2Shape	10.476	0.005	Significant differences
	Control group vs Hyflex CM	3.333	0.189	No significant differences
	Manual vs Race	1.077	0.584	No significant differences
	Manual vs 2Shape	7.850	0.020	Significant differences
	Manual vs Hyflex CM	2.286	0.319	No significant differences
	Race vs 2Shape	6.0	0.040	Significant differences
	Race vs Hyflex CM	0.696	0.706	No significant differences
	2Shape vs Hyflex CM	2.917	0.233	No significant differences

Table 2: Chi-square test results at the apical level between the five groups

	Binary comparisons between groups	*Chi-square value*	*p value*	*Decision*
Partial cracks	Control group vs Manual	0.536	0.358	No significant differences
	Control group vs Race	0.136	0.500	No significant differences
	Control group vs 2Shape	0.136	0.500	No significant differences
	Control group vs Hyflex CM	0	1	No significant differences
	Manual vs Race	0.133	0.500	No significant differences
	Manual vs 2Shape	0.133	0.500	No significant differences
	Manual vs Hyflex CM	0.536	0.358	No significant differences
	Race vs 2Shape	0	1	No significant differences
	Race vs Hyflex CM	0.136	0.500	No significant differences
	2Shape vs Hyflex CM	0.136	0.500	No significant differences
Complete cracks	Control group vs Manual	1.886	0.390	No significant differences
	Control group vs Race	6.0	0.040	Significant differences
	Control group vs 2Shape	10.531	0.005	Significant differences
	Control group vs Hyflex CM	3.6	0.165	No significant differences
	Manual vs Race	2.267	0.322	No significant differences
	Manual vs 2Shape	4.658	0.031	Significant differences
	Manual vs Hyflex CM	1.286	0.526	No significant differences
	Race vs 2Shape	1.067	0.587	No significant differences
	Race vs Hyflex CM	0.620	0.734	No significant differences
	2Shape vs Hyflex CM	3.077	0.215	No significant differences

with manual group, where the p-value (0.031) was less than the significance level of (0.05), while there are no statistically significant differences related to other binary comparisons, where the p-values were greater than the significance level (0.05) (Fig. 4).

Tables 3 and 4 show that there are no statistically significant differences between the incidence of partial and complete cracks among two levels (middle—apical) of the five groups, where the p-values (0.201–0.871) were greater than the significance level of 0.05 (Fig. 5).

It can be summarized from the above that 2Shape system was the most common cause of complete cracks in the middle and apical thirds, followed by Race system, which caused fewer cracks, while Hyflex system was less than both of them and the least of all was the manual system.

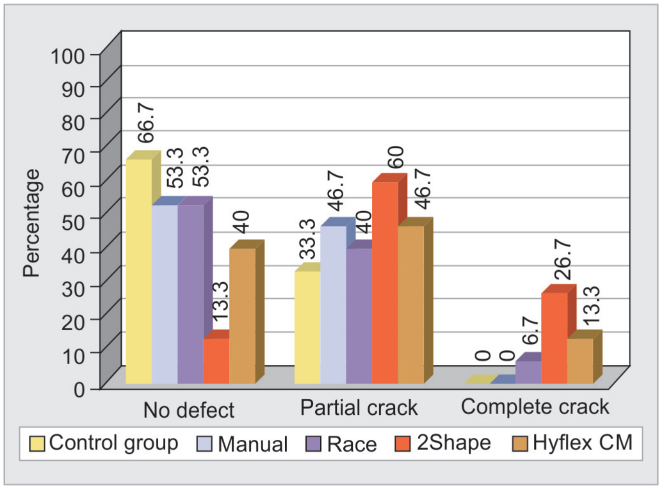


Fig. 3: Microcracks incidence percentages in the middle third of the five groups

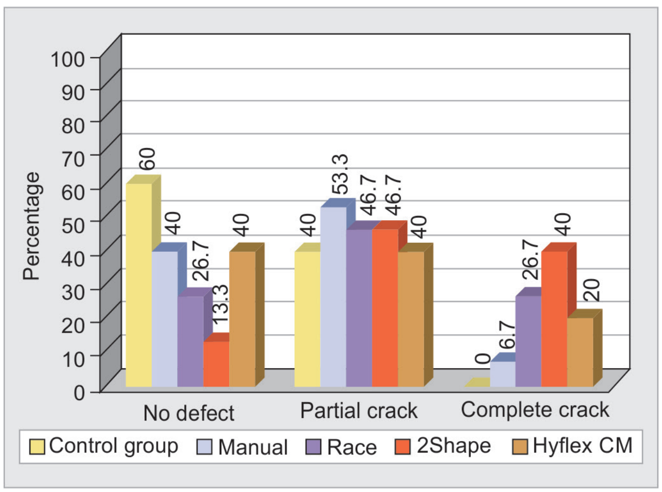


Fig. 4: Microcracks incidence percentages in the apical third of the five groups

Discussion

VRF is a perilous complication following the outbreak of microcracks in dentin as a result of endodontic procedures, so minimally invasive instrumentation may increase the teeth survival rate.[9]

The dentinal defects may occur as a result of routine instrumentation, canal obturation and retreatment procedures.[19] In addition, sodium hypochlorite in a high concentration may affect the dentinal structure.[20]

Since the partial cracks include craze lines, it is rare that there is a prepared or nonprepared sample without these cracks, and therefore, it is logical that all experimental groups were equivalent without statistical differences even with the control group.

Despite the great tendency to the microcomputed tomography imaging technique used to detect the potential dentinal damage in comparison with the sectioning technique,[21] a recent study showed that there was no significant difference between micro-CT and the sectioning method adopted in this study to evaluate the occurrence of microcracks.[22]

Many studies reported that sectioning procedures may cause new microcracks,[23–25] while other studies attributed the occurrence of microcracks to the preexisting undetected dentinal defects,[26–29] but most studies have agreed that microcracks occur more frequently after mechanical instrumentation.[2,7,15,22,26,27,30–32] However, complete cracks in the current study were absent in the control group that was not instrumented with files, while they were present in the rotary file groups, and this indicates that the mechanical instrumentation caused complete cracks at both the middle and apical level in accordance with previous studies.

Hand files did not cause any complete cracks at the middle level, while they were the least implicated group in the occurrence of complete cracks at the apical level compared to the rotary systems, this is in agreement with previous studies of Bier et al.[7] and Shori et al.,[18] and this can be explained by the lower number of rotations required to prepare the canal with manual files compared to rotary systems, in addition to the slight taper of manual files (0.02) compared with the rotary systems (0.04).

Table 3: Comparison of microcracks ratios between the middle and apical thirds

		Duplicates				*Percentage*			
	Groups	*No defect*	*Partial crack*	*Complete crack*	*Total*	*No defect*	*Partial crack*	*Complete crack*	*Total*
Control group	Middle third	10	5	0	15	66.7%	33.3%	0%	100%
	Apical third	9	6	0	15	60%	40%	0%	100%
	Total	19	11	0	30	63.3%	36.7%	0%	100%
Manual	Middle third	8	7	0	15	53.3%	46.7%	0%	100%
	Apical third	6	8	1	15	40%	53.3%	6.7%	100%
	Total	14	15	1	30	46.7%	50%	3.3%	100%
Race	Middle third	8	6	1	15	53.3%	40%	6.7%	100%
	Apical third	4	7	4	15	26.7%	46.7%	26.7%	100%
	Total	12	13	5	30	40%	43.3%	16.7%	100%
2Shape	Middle third	2	9	4	15	13.3%	60%	26.7%	100%
	Apical third	2	7	6	15	13.3%	46.7%	40%	100%
	Total	4	16	10	30	13.3%	53.3%	33.3%	100%
Hyflex CM	Middle third	6	7	2	15	40%	46.7%	13.3%	100%
	Apical third	6	6	3	15	40%	40%	20%	100%
	Total	12	13	5	30	40%	43.3%	16.7%	100%

Table 4: Chi-square test results between two levels across the five groups

Groups	*Chi-square value*	*p value*	*Decision*
Control group	0.144	0.705	No significant differences
Manual	2.352	0.509	No significant differences
Race	3.210	0.201	No significant differences
2Shape	0.650	0.723	No significant differences
Hyflex CM	0.277	0.871	No significant differences

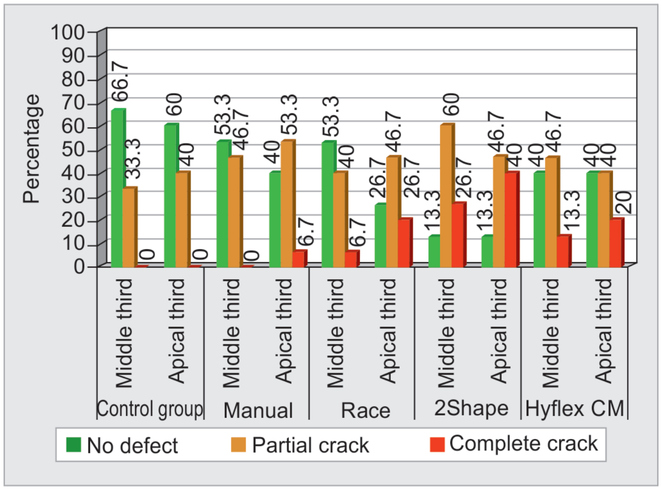


Fig. 5: Comparison of microcracks ratios between the middle and apical thirds

NiTi alloys are generally introduced in the austenitic phase which exhibit high elasticity, and they may even lead to defects and microcracks in the dentinal walls of the root canal,[15] whereas alloys manufactured in martensitic phase by additional heat treatment have superior flexibility and fine distribution of Ni–Ti particles in the matrix which reduces the screw-in effect, thereby reducing the touch between the file and the dentin walls and thus reducing cracks.[33]

It is important to consider that the metallurgical characteristic of Ni–Ti alloys used to manufacture the various file systems is a more crucial factor that determines the potential implicit damage in the dentin compared with the movement mechanism of the files, so the files fabricated from flexible alloys are less implicated in microcracks occurrence compared to those made from conventional Ni–Ti alloys.[9,18,34] Therefore, Race (conventional superelastic Ni–Ti alloy), 2Shape (T-wire technology), and Hyflex CM (heat treated alloy) file systems were used in the current study based on their metallic differentiation.

As it is known, files with larger taper are more likely to cause higher stress concentration in the root dentin and thus potentially cause microcracks.[7,8] Hence, the well-symmetrical tapered files (0.04) were chosen across all experimental groups in the current study to reduce the variables, and this can be considered as an explanation for the absence of significant difference between the three studied systems at the apical level.

2Shape system caused higher percentage of microcracks at the middle level with statistically significant differences compared to the Race system which could be justified by the high screw-in effect, high cutting efficiency of its sharp blades, and most importantly, the sudden shift from the path file to the main file (One G to TS1), considering that this is the distinctive features of 2Shape system "two files to shape the canal" compared with the gradual transition between successive diameters of the Race system files which is a full sequential file system where each of its files easily creates space for the next file without the need to force the file further, and this relieves stress and fatigue that applied on the file and the dentinal walls, especially in the conditions of the present study, which necessitated the file rotation in contact with both the broken instrument and the canal walls. This point is largely consistent with the results of the Shantiaee study.[3]

The results of the current study differ partly from the previous studies, as the Hyflex CM system was similar to the Race group with no significant differences although it is more flexible, which can be explained by the well-designed Race system based on distinctive blades with helix angles that change continuously during rotation, reducing the screw-in effect which relieves the file engagement with the canal walls.[10] Add to that its high speed which allows the job to be done quickly without having to keep the file for a long time in the canal.

Kim et al.[8] stated that the rotary files with stiffer designs generate a higher stress in the dentin, which increases the possibility of microcracks occurrence, and this is in agreement with the current results which showed that the 2Shape system was associated with a higher microcracks ratio even though the 2Shape and Hyflex CM systems were made of martensitic alloys, but the T-wire is much stiffer than the heat treated alloy.

Although the rotation speed of the 2Shape system was lower than that of the Race and Hyflex CM systems, 2Shape system caused a higher percentage of microcracks in both levels compared to the other systems, and this indicates that it is more stressful for the dentinal walls, and this differs from the Uslu study which claimed that increasing the rotational speed may cause thermomechanical stress on both the file and canal walls.[35]

There was no statistical difference between the incidence of microcracks at the middle level compared to the apical level in all studied groups, and this matter is logical, as the taper of files is proportional to the measurement of canals, and therefore, the incidence of microcracks is the same between the middle and apical thirds.

Generally, the highest proportion of microcracks associated with the 2Shape system compared to other systems at both the middle and apical levels may be justified by several reasons, and the most important of which is their design variation in addition to the abrupt shift between two instruments, and this controversial matter should be reconsidered as long as the full sequential systems were more secure.

Although this study had performed using different systems, sequence, design, speed and torque, and that may affect the results of this study. Add to that the difference in the original diameter of the canals and the tiny space created between broken file and canal wall may be various and not similar across all samples which can be considered as a limitation of the current study.

Conclusion

Full sequential systems such as Race and Hyflex CM were less likely to induce microcracks in both the middle and apical levels, alongside the broken instruments that were bypassed, making them safer, and this result is limited by this study and requires further studies to confirm its validity.

Disclosures

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Ethics Committee Approval: The study was approved by the Ethics Committee of Faculty of Dentistry, Damascus University (Ethics Approval Number: 36—Date: July 24, 2018).

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