Research Article

Comparative Evaluation of Root Dentin Integrity after Root Canal Preparation with Rotary File Systems of Different Ni-Ti Alloys

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Abstract

Background: Rotary biomechanical root canal preparation is usually associated with dentin micro-cracks. **Aim:** to assess and compare the effect of file systems manufactured with different Ni-Ti technologies on root dentin micro-cracking as a measure for integrity. **Materials and methods:** seventy single canalled premolar root specimens of equal length were divided into seven equal groups (n=10) according to the canal preparation system used. G1 (Protaper universal), G2 (Protaper next), G3 (Protaper gold), G4 (Vortex Blue), G5 (XP Shaper), G6 (Hand K- files) and G7 left unprepared (control). The specimens were thereafter horizontally sectioned at three levels from root apex and accordingly groups were subdivided into 3 subgroups. Subg1 (3 mm), subg2 (6 mm) and subg3 (9 mm). The root sections were dye stained and examined under stereo light microscope for crack detection. The collected data were statistically analyzed. **Results:** Only group 4 & group 5 (single-file rotary groups) were comparable to the control group which showed a lower crack incidence than all other groups (hand files and multi-file rotary groups). **Conclusion:** The XP shaper and Vortex blue file systems have a tendency to cause fewer dentinal cracks compared with the Protaper Universal, Protaper Next and Protaper Gold file systems.

Keywords: Dentin micro-cracks; Hand files; Rotary files; Root canal preparation

Introduction

Successful endodontic treatment is mainly dependent on effective biomechanical root canal preparation. [1] This process is concerned with root canal debridement through the elimination of organic and inorganic debris, necrotic tissues, infected root dentin and prepares the canal space for proper obturation. [2]

Stainless steel instruments have long been used for the shaping of root canals. More recently Ni-Ti instruments had been introduced with their high flexibility and shape memory. These instruments had largely replaced stainless steel files in root canal cleaning and shaping, [3] because they have been claimed to overcome the shortcomings encountered with conventional files like canal ledging and apical transportation. [4]

However, as a result of dentin contact with the files "especially the rotary Ni-Ti" during root canal shaping procedures, momentary stress accumulation may occur and has the potential to induce crack formation. [5] It has been also claimed that these micro-cracks can later propagate inducing vertical root fractures if the tooth is subjected to repeated stresses from endodontic or restorative procedures with subsequent treatment failure. [6]

Improving the flexibility of endodontic files increases its ability to conform to the canal lumen thus decreasing stresses imposed on the root canal dentin. This would reduce the potential for micro-crack development and other iatrogenic errors like ledging and canal transportation, which would increase the safety and efficiency of root canal treatment. [7]

Several approaches have been developed by the manufacturer to improve the flexibility and resistance to fracture of Ni-Ti rotary endodontic instruments. [8-10] These approaches include changing the taper over the length of the cutting blade, modifying the instrument's cross-sectional design, and enhancement of the manufacturing process or the use of new alloys. [7,8,11]

Therefore, various types of rotary nickel-titanium (Ni-Ti) file systems have been designed by the manufacturers and introduced into the market. Among these files is the ProTaper Universal (PTU, Dentsply Tulsa Dental Specialities, Tulsa, OK) Ni-Ti rotary system that is machined from conventional superelastic (SE) austeNi-Tic Ni–Ti wire. The system has three shaping and three finishing files with variable taper over the entire cutting blade length. It has convex triangular cross-sections which reduces the contact area between the file and the dentin. Also its cutting efficiency has been improved by balancing the pitch and helix angle, preventing inadvertent threading of the instruments into the canal. [12]

Later, ProTaper Next (PTN, Dentsply Maillefer) rotary instrument which was based on M-wire technology have been introduced. It has an off-centered rectangular design and progressive and regressive percentage tapers on a single file which gives the file a snake-like "swaggering" movement inside the root canal. [13]

Recently ProTaper Gold (PTG, Dentsply Maillefer, Ballaigues,

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Switzerland) instruments were introduced. It is considered as a twin of PTU as it has similar file sequence and design. Its advanced metallurgy with two stage-specific transformation behavior and high austenite finish temperature is responsible for its increased flexibility. [14] The file also has a shorter 11 mL handle for improved accessibility to the teeth. The distinctive gold appearance of the PTG files is the result of a unique heat treatment process applied after manufacture. [15]

The Vortex Blue rotary system (Dentsply Tulsa Dental speciality, USA) utilizes a special Ni-Ti wire processing method to produce a distinctive "blue colour" titanium oxide surface layer. These instruments exhibit greater flexibility with controlled shape memory and improved fatigue resistance. [16] They have a cutting blade with triangular cross-section and variable helical angle. This facilitates debris removal through its coronal portion with less number of flutes and increases strength and minimize dentinal cracking at its more fluted apical portion. [17]

The XP-endo Shaper instrument (XPS) (FKG Dentaire, La Chaux-de-Fonds, Switzerland) is another newly launched single file system that is manufactured from MaxWire alloy (MaxWire, Martensite-Austenite Electropolish Flex, FKG Dentaire) and has a 0.30 mm tip diameter and 0.01 mm taper. The MaxWire alloy undergoes phase change with temperature changes and consequently the XPS file changes its shape. At a temperature of 20°C the file stands straight in its martensite phase. When the file is exposed to the body temperature in the root canal, it changes to the austeNi-Tic phase, expands from its original size to at least size #30/0.04 assuming a snake shape. The manufacturer also claims that this single file system adapts easily to canal irregularities, applies minimal stress to dentin walls and can lonely achieve a final minimum canal preparation of 30/0.04. [18,19]

Up to the best of our knowledge, there is no studies in the literature comparing the microcrazing effect of canal preparation utilizing ProTaper Universal (PTU, Dentsply Tulsa Dental Specialities, Tulsa, OK), ProTaper Next (PTN, Dentsply Maillefer), ProTaper Gold (PTG, Dentsply Maillefer, Ballaigues, Switzerland), Vortex Blue rotary system (Dentsply Tulsa Dental Speciality, USA) and the newly launched XP-endo Shaper instrument (FKG Dentaire, La Chaux-de-Fonds, Switzerland) that are manufactured from different technologies of Ni-Ti alloys. Thus, the aim of the present study was to assess and compare the effect of these file systems on dentinal micro-crack formation using digital microscopy.

Methods

Sample selection

After obtaining approval from Research Ethics Committee, College of Dentistry, King Khalid University (No: SRC/ETH/2018-19/012), 70 single rooted mandibular premolars that were extracted for orthodontic or periodontal reasons were used in this study.

All the roots were observed with a stereomicroscope (Novex, Arnhem, Holland) with 25x magnification to detect any preexisting external defects or cracks. Also, radiographs were taken in mesiodistal and buccolingual directions for all teeth. Teeth having more than a single root canal and a single apical foramen, previously endo-treated, internal/external resorption, immature or open root apices, root caries, cracks or fractures, and those with root canal curvature more than 10° was excluded from the study. [20] The selected teeth were cleaned mechanically from soft tissue remnants and calculi then stored in saline solution till the time of experiment.

The teeth were decoronated at the level of cemento-enamel junction to standardize root length to 13 mm using an Isomet low-speed saw (Isomet 1000; Buehler, Lake Bluff, IL) under water cooling.

Apical patency of the canals was verified using ISO #10 K-file, while ISO #15 k-file was used to standardize the working length 1 mm short of the apex.

Periodontal ligament simulation

Aluminum foil was used to cover the root surface of all samples which were then embedded in acrylic resin blocks (Procryla; President Dental, Munich, Germany) until resin setting. The root samples were then taken out from the resin blocks and uncovered from the foil. The blocks were thereafter filled with a light body silicon impression material (Express XT Light Body Quick; 3M ESPE, Neuss, Germany) followed by reseating the teeth back into the acrylic block in order to create a periodontal ligament-mimic layer around the root specimens. [21]

Sample grouping and root canal preparation

The samples were randomly assigned into seven groups (n=10). Five of them were prepared with rotary files, one with hand files and the remaining one was left unprepared as a Control group [Table 1].

In groups 1-5, root canals were prepared according to the manufacturer's instruction for each file system. Instrumentation was done with the aid of an endodontic electric endomotor (Endo-Mate DT, NSK, Nakanishi Inc., Tokyo, Japan). The motor settings for different rotary files are listed in Table 2. In group 6, step back root canal preparation with hand k-files (HF) was carried out till an apical master file size #30 while specimens in group 7 received no canal preparation (control). [22-24]

Sample sectioning and microscopic examination

The roots of each group (10 specimens) were horizontally

Table 1: Root canal preparation groups.

Group	File system used for canal preparation	Apical preparation size
1	Conventional NiTi ProTaper Universal (Dentsply, Maillefer, Ballaigues, Switzerland)	# F3
2	M-wire Protaper Next (Dentsply Maillefer, Ballaigues, Switzerland)	# X3
3	Controlled memory wire Protaper Gold (Dentply Maillefer, Ballaigues, Switzerland)	# F3
4	Controlled memory wire Vortex Blue (Dentsply Tulsa Dental Speciality, USA)	# 30/06
5	MAX wire XP Shaper (FKG Dentaire SA,Switzerland)	# 30/01
6	Hand K-Files (HF) (Dentsply Maillefer, Ballaigues, Switzerland)	# 30/02
7	No preparation (Control)	No preparation

sectioned at 3, 6, and 9 mm from the apex with the isomet low-speed saw under water cooling (3 subgroups), so a total number of 210 specimens were examined. To enhance crack detection, the slices were dye-stained (VOCO Caries Marker, Cuxhaven, Germany) and then examined under a stereomicroscope at 25x magnification for the presence of dentinal cracks. Digital images of each slice were captured using a digital camera attached to the stereomicroscope [Figure 1]. If the specimen showed a craze line extending from the its outer surface inward but not reaching the canal lumen or a dentinal crack extending from the dentin lining the canal outwards but not reaching the external surface or having a micro-fracture line that involved both sides of the specimen, it was assigned as having a crack. Specimens that were free from the aforementioned defects were considered having no cracks. [25] The data was collected and expressed as the number and percentage of cracked roots in each group and subgroup.

Table 2: Motor settings for different rotary file systems.

Group	File size	RPM	Torque adjustment
Protaper Universal (PTU)	S1, S2, SX	300	3 N/cm
	F1, F2, F3		2 N/cm
Protaper Next (PTN)	X1, X2, X3	300	2 N/cm
Protaper Gold (PTG)	S1, SX	300	5 N/cm
	S2, F1		1.5 N/cm
	F2, F3		3 N/cm
Vortex Blue (VB)	#30/04	500	1 N/cm
XP Shaper (XPS)	#30/01	800	1 N/cm

Statistical analysis

The collected data was analyzed using Kruskal-Wallis to stand on the significance of difference among the test groups. On the other hand; Mann-Whitney's test was done for pair wise comparison of different subgroups. All data analyses were performed using Past software (Natural History Museum) version 2.17 to determine the significance of differences detected between groups at α=0.05.

Results

The results of Kruskal Wallis test revealed a significant difference among the test groups (p=0.009527). on the other hand, Mann-Whitney's pair wise comparisons between subgroups [Table 3] showed a lower incidence of cracks in groups 4 (VB), 5 (XPS),

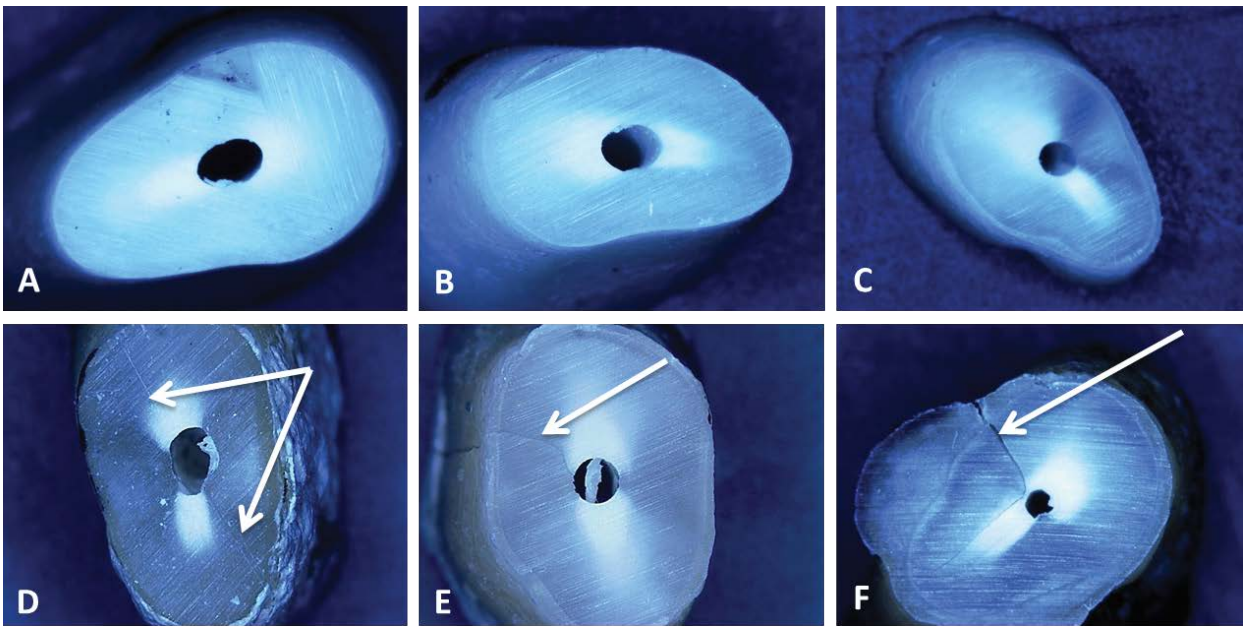

Figure 1: Representative samples for specimens with and without cracks at different sections. (A&D, 9 mm), (B&E, 6 mm), (C&F, 3 mm) from the root apex at 25x magnification.

Table 3: Mean SD & Mann-Whitney's pair wise comparisons of crack incidence between groups for each subgroup.

Group	Mean ± SD for crack incidence		
	SubG.1 3 mm N (%)	SubG.2 6 mm N (%)	SubG.3 9 mm N (%)
PTU (Group 1)	1.4 ± 0.5^{a}	1.4 ± 0.5^{a}	1.4 ± 0.5^{a}
PTN (Group 2)	1.2 ± 0.4^{a,b}	1.2 ± 0.4^{a,b}	1.4 ± 0.5^{a}
PTG (Group 3)	1.2 ± 0.4^{a,b}	1.4 ± 0.5^{a}	1.1 ± 0.3^{a,b}
VB (Group 4)	1 ± 0^{b}	1.2 ± 0.4^{a,b}	1 ± 0^{b,c}
XPS (Group 5)	1 ± 0^{b}	1.1 ± 0.3^{a,b}	1 ± 0^{b,c}
HF (Group 6)	1 ± 0^{b}	1.3 ± 0.5^{a,b}	1.2 ± 0.4^{a,b,c}
Control (Group 7)	1 ± 0^{b}	1 ± 0^{b}	1 ± 0^{b,c}

One common superscript letter indicates non-significant differences between each pair of values within each subgroup

Table 4: Mean, SD & Mann-Whitney's pair wise comparisons of the crack incidence between groups regardless the subgroups.

Group	PTU (G1)	PTN (G 2)	PTG (G3)	VB (G4)	XPS (G5)	HF (G6)	Control (G7)
Mean ± SD	1.4 ± 0.52^{a,b}	1.4 ± 0.53^{a,b}	1.5 ± 0.52^{a,b}	1.2 ± 0.42^{b}	1.1 ± 0.32^{b}	1.4 ± 0.52^{a,b}	1 ± 0^{b}

One common superscript letter indicates non-significant differences between each pair of values

6 (HF) & 7 (Control) than group 1 (PTU) at the level of 3 mm sections (subgroup 1).

At the level of 6 mm section (subgroup 2), a significantly higher crack incidence was recorded only for group 1 (PTU) & group 3 (PTG) as compared to the control group (G.7). However, at the level of 9 mm sections (subgroup 3), groups 1 (PTU), group 2 (PTN) & group 6 (HF) showed a higher crack incidence than that recorded for groups 4 (VB), 5 (XPS) &7 (Control).

Mann-Whitney's pair wise comparisons between the incidence of cracked specimens of each group regardless the section levels (subgroups) demonstrated that, only group 4 & group 5 (single-file rotary groups) were comparable to the control group which showed a lower crack incidence than all other groups (hand files and multi-file rotary groups) [Table 4].

Discussion

The primary aim of chemo-mechanical root canal preparation includes the preservation of original course of the canal and cleaning of the entire root canal system. One common complication associated with mechanical canal preparation is root dentin cracking that might proceed to vertical root fracture and tooth loss. [26]

Some previous studies emphasized the role of metallurgical characteristic of various Ni–Ti file systems and recognized it as one of the determinant factors in its dentin damaging potential during canal preparation. [14] Therefore, The aim of this study was to assess and compare the effect of canal preparation with ProTaper Universal (PTU, conventional superelastic Ni–Ti alloy), ProTaper Next (PTN, M-wire technology), ProTaper Gold (PTG, two-stage-specific transformation behavio), Vortex Blue rotary system (Ni-Ti wire processing with a distinctive "blue colour" titanium oxide surface layer) and the newly launched XP-endo Shaper instrument made of a proprietary alloy (MaxWire, Martensite-Austenite Electropolish Flex) that are manufactured from different forms of Ni-Ti alloy on dentinal microcrack formation using digital microscopy. The rotary files used in the current study represents different attempt to improve the flexibility and resistance to fracture of Ni-Ti rotary endodontic instruments. [8,10,16,18]

The sectioning method used in the current study has been claimed to permit direct vision of dentinal cracks in root dentin slices and has been previously used for similar purposes. [27-30] All the teeth in the present study were examined and selected only if free of defects or external cracks or craze lines, the root specimens were also embedded in silicon impression material to simulate stress distribution to the periodontal ligament. [31]

Stereomicroscopic examination of the unprepared samples (control group) revealed no crazing or cracking indicating that the sectioning method used in the study had no impact on the induced cracks in the test specimens. [25,32] also dye-staining of the specimens enhanced discovering cracks in craze lines in the examined specimens as reported in some previous studies. [29,33]

The results of the present study demonstrated that, only group 4 (VB) and group 5 (XPS) (single-file rotary groups) were comparable to the control group (G7) which showed a lower crack incidence than all other groups (hand files and multi-file rotary groups).

These results agree with the previous finding that full-sequence Ni-Ti rotary systems involving sequential use of instruments in root canal preparation like PTU, PTN & PTG were associated with high number of dentin defects as it involves the use of prolonged mechanical procedures and hence more contact time and more stress concentration on dentinal wall of the canal with subsequent formation of micro-crack. [31] Other supporting studies showed that single-file rotary systems produced fewer numbers of cracks than multi-file systems. [34-36]

The better results for both XPS and VB single-rotary files might be also attributed to their better metallurgical properties where XP-endo Shaper instrument (XPS) consists of a rotary snake-shaped instrument made of a special Ni-Ti alloy (MaxWire, Martensite-Austenite Electropolish Flex, FKG Dentaire). The properties of this new alloy permit the file to change its shape in accordance with temperature changes due to phase changes. In the cooled state the alloy is in its martensitic phase and the file is straight with a tip size #30 but with only 0.01 iNi-Tial taper. When exposed to body temperature during its use, the alloy changes to its austeNi-Tic phase and the file assumes a snake shape that can prepare the canal to size #30/0.04 when used alone. This file was also claimed by the manufacturer to apply minimal stress to the dentin walls and adapts easily to root canal anatomy. [18]

Also, The Vortex Blue rotary system (VB) is made up of a new Ni-Ti wire processed by a special complex heating and cooling procedures to produce a distinctive "blue colour" titanium oxide surface layer. These files exhibited controlled shape memory with greater flexibility and improved fatigue resistance. [16] They have a cutting blade with triangular cross-section and variable helical angle. This design allows more efficient debris removal in the coronal portion of the file because of less number of flutes (lower helical angle) and at the same time guarantees good strength properties, efficient canal preparation with less chance of dentinal cracking at the apical portion of the file with more flutes (higher helical angle). [17]

The results also showed a significantly lower incidence of cracks in groups 4 (VB), 5 (XPS), 6 (HF) & 7 (Control) than group 1 (PTU) at the level of 3 mm sections (subgroup 1). In addition, at the level of 6 mm section (subgroup 2), a significantly higher crack incidence was recorded only for group 1 (PTU) & group 3 (PTG) as compared to the control group (G.7). Moreover, at the level of 9 mm sections (subgroup 3), groups 1 (PTU), group

2 (PTN) & group 6 (HF) showed a higher crack incidence than that recorded for groups 4 (VB), 5 (XPS) &7 (Control).

The higher incidence of cracks in PTU observed at all section levels might be due to its relative stiffness as compared to all other rotary Ni-Ti systems used in this study which led to more stress generation and concentration of stress especially in the apical root area with subsequent more crack iNi-Tiation. [37]

Although PTG has super elasticity as compared to PTU, both have showed insignificant difference in the number of induced cracks. [28] This might be referred to the fact that they have the same file design and working sequence also a higher torque is needed for PTG according to the manufacturer which might induce higher stresses and hence lessens the effect of its super elasticity. This explanation is supported by the conclusion of a previous study that, cracking was higher in groups that were prepared using high-torque rotary systems than those prepared with low-torque systems. [38]

The significantly lower incidence of cracks produced by XPS and VB systems than PTU and PTN in the coronal (9 mm) sections might be due to some collective reasons. Among these reasons is the high taper of the instrument where both PTU and PTN have a variable taper (F1, F2, F3 0.07, 0.08, and 0.09, respectively) which is greater than ProTaper Next (X1, X2, and X3; 0.04, 0.06, and 0.07, respectively) which could explain the incidence of cracks observed in this study and previously reported in some studies. [34,39,40]

Also, PTN though manufactured from Ni-Ti alloy with M-Wire technology, it showed high incidence of cracks because it has variable tapers and an off-centered rectangular cross-section which generates a mechanical wave of motion similar to the oscillation noted along a sinusoidal wave. This in turn results in a bigger envelope of cutting motion than a similar sized file with a symmetrical mass and axis of rotation. [41-43]

Moreover, the triangular or modified triangular cross section design of ProTaper decreases the cutting efficiency and provides less space for dentine chips, thus generating stresses on root canal walls. [44]

Other contributing factors for better results obtained with XPS and VB might include the higher speed used with both of them compared to that used with other rotary system. This higher speed had been claimed by some investigators to increase the cutting efficiency [45] and hence decrease the potential for dentinal cracking. [5] Also the torque settings used with PTU, PTN and PTG are higher than that used with both XPS and VB systems which might be responsible for higher crack incidence with these systems as compared to XPS and VB systems. [38] These factors on the other hand might be considered also as limitations of the current study together with difficulty in standardizing the downward cutting movement of different file systems and operator blindness.

Conclusion

Within the limitations of this *in vitro* study, the instrumentation of root canals with all the tested file systems can cause crack formation in root canal dentin. The XP shaper and Vortex blue file systems have a tendency to cause fewer dentinal cracks compared with the ProTaper Universal, Protaper Next and Protaper Gold file systems.

Conflict of Interest

The authors disclose that they have no conflicts of interest.

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