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ORIGINAL ARTICLE

Stereomicroscopic Evaluation of Dentinal Microcracks After Instrumentation of Curved Canal with Rotary Files in Two Motions

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ABSTRACT

Objective: This study aimed to examine the effects of three distinct file systems with two motion types—rotary and reciprocation—on the development of dentinal microcracks after root canal preparation using a stereomicroscope. **Methods:** Sixty mandibular molars with a curvature of 30° were decoronated and divided into three groups (Vortex Blue, Mtwo, and ProTaper Next) and two subgroups (rotary and reciprocating motions). The samples were then instrumented with the files, dyed with 1% methylene blue dye, and sectioned horizontally at 3, 6, and 9 mm from the root apex. The dentinal microcracks were inspected using a stereomicroscope at 40× magnification. One-way analysis of variance and post hoc Tukey tests were used to perform statistical analysis. **Results:** Crack formation was statistically significant at the 6-mm and 9-mm levels from the root apex in both motions ($p < 0.05$). Among all the file system, Vortex Blue caused the highest dentinal microcracks in both motions at 6 mm from the root apex. **Conclusion:** The reciprocating motion resulted in fewer dentinal microcracks than the rotary motion. All file systems caused significant dentinal microcracks at the curvature of the root canal during both motions. Dentinal microcrack formation was not significant at the root apex.

Key words: dentinal microcracks, Mtwo, ProTaper Next, stereomicroscope, Vortex Blue file

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INTRODUCTION

In successful endodontic treatment, root canal preparation is the main step because of the debridement of debris, removal of microorganisms, and facilitation of ultimate obturation.[1] The biomechanical preparation provides a root canal with even taper, smooth walls, and optimal apical size that allow copious irrigation along with root canal filling in three dimension. This process provides successful endodontic treatment as an outcome result.[2]

The use of a rotary instrument during biomechanical preparation causes brief stress owing to the contact between the instrument and the dentinal wall within the canal, which might result in dentinal microcracks. At different root levels, these microcracks might be horizontal or vertical.[3] The masticatory function would eventually compromise the mechanical performance of the tooth because of dentinal microcracks.[4] Kim et al. discovered that rotary instrumentation produces more torque, which might greatly increase stress on dentine due to the increasing taper of these instruments.[5] These file designs influence apical stress and strain concentrations, which can eventually lead to vertical root fracture.[6]

Many novel systems are currently under development. ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) is built using M-wire technology (Sportswire LLC, Langley, OK), a fifth-generation Ni-Ti instrument that provides increased flexibility and cycle fatigue resistance; the rotating instruments (X1-X5) have an off-centered rectangular cross-section.[1] These design elements help remove debris; eliminate unnecessary gauging; and decrease taper lock, screw-

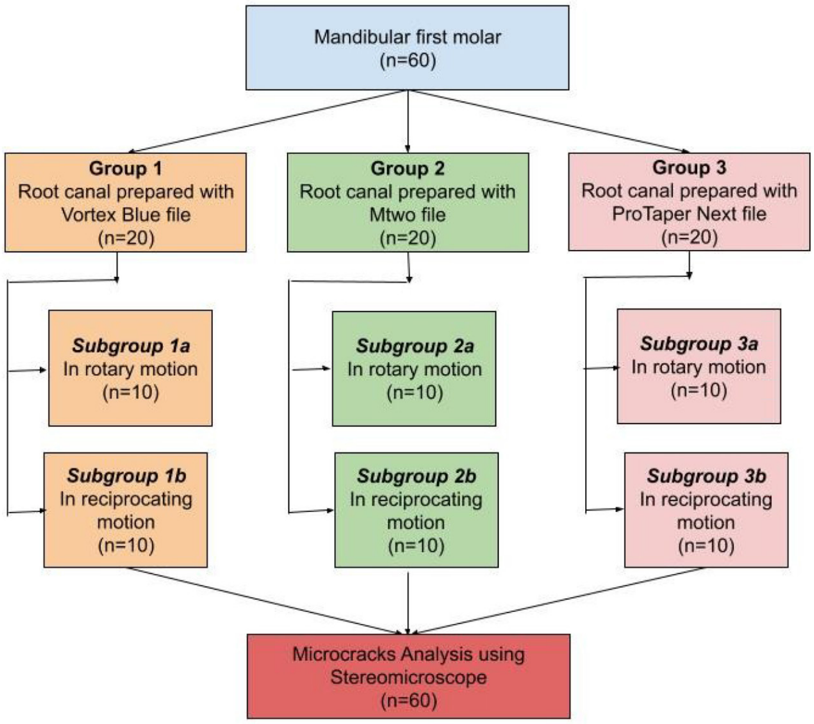

Figure 1. Workflow-chart of methodology.

in, and torque.[7] Mtwo (Dentsply Maillefer, Ballaigues, Switzerland) is a new generation of Ni-Ti rotary files with positive rake angles and non-cutting tips. Here, in S-shaped cross-sections, these qualities of Mtwo instruments manage their cutting efficiency, reduce instrument breakage, and produce symmetrical root canals.[8] Vortex Blue file is made of M-wire and features a triangular cross-section with no radial lands (Dentsply Tulsa Dental, Johnson City, TN). Manufacturers assert that by combining these metallurgical processing methods with various instrument designs, the desirable qualities of endodontic instruments have been improved and the risk of instrument breakage has decreased.[9]

However, different heat treatments, metallurgy, file designs, and kinematics of Ni-Ti files may impact dentinal microcrack formation, which is thought to be the beginning point for vertical root fracture.[10] Therefore, it would be necessary to compare different kinematic Ni-Ti systems to see which of them produces fewer microcracks at what level of the root. Various techniques have been used to detect dentinal microcracks, including stereomicroscopy, scanning electron microscopy (SEM), endoscopy, infrared thermography, and micro-computed tomography (micro-CT). However, direct assessment of dentinal cracks on the root surface is possible by root sectioning at various levels and viewing under a stereomicroscope, which also reveals information about the extension pattern and direction of cracks.[11]

To the best of our knowledge, the literature lacks information on how the three file systems mentioned above affect dentin when employed in the rotating and reciprocating motions. Hence, a null hypothesis was considered that there would be no differences caused by using two kinematics with different file systems on dentinal microcrack formation at various levels, keeping in mind that the study aimed to assess the formation of dentinal microcracks following the instrumentation of curved root canals of mandibular molars using Vortex Blue, Mtwo, and ProTaper Next file systems in different kinematics that are rotary and reciprocating.

METHODS

Human mandibular permanent first molar teeth with mature apices and a mesiobuccal curved root with a curvature of 30° were included in the study after being freshly removed due to poor periodontal condition. The study excluded teeth with caries, immature apices, resorption, calcified canals, cracked or micro fractures, other dental abnormalities, and root curvature of >30°. All samples were cleaned using ultrasonic scalers (Satellec, Acteon, France) to remove organic debris and deposits. All teeth were kept in 5.25% NaOCl (Septodont Health Care India Pvt. Ltd., Panvel, India) for 1 h and stored in 0.9% normal saline (Otsuka

Figure 2. Root canal preparation with rotary files in both the kinematics, rotary and reciprocating. A) Root canal preparation with Vortex Blue files in rotary motion. B) Root canal prepared with Vortex Blue files in reciprocating motion. C) Canal prepared with Mtwo files in rotary motion. D) Mesio-buccal canal preparation with Mtwo files in reciprocating motion. E) ProTaper Next files used for canal preparation in rotary motion. F) ProTaper Next files used for canal preparation in reciprocating motion.

Pharmaceutical Ltd., Ahmedabad, India) solution until use. A radiograph of teeth with long cone paralleling was obtained to verify the curvature of a permanent mandibular molar within 30° curvature. The radius and angle of curvature were measured using Schneider's method. The teeth with roots presenting a curvature in the mesiobuccal canal 30° were selected using radiovisiography curvature measurement tools, and the remaining teeth were discarded, leaving 60 mandibular first molars for the experimental procedure.

The crown of the selected tooth was removed using a diamond disk (DFS, Riedenburg, Germany) under water coolant such that the remaining root canal length was 12 mm in the mesiobuccal canal. The roots were then inspected under a stereomicroscope (Labomed, Los Angeles, CA, USA) at 40× magnification to exclude external defects/cracks. To imitate the periodontal ligament space and alveolar process, the root surfaces were coated with a thin coating of silicone-based impression material and implanted in acrylic resin blocks. The complete experimental procedure is shown in the flowchart (Figure 1).

Root canal preparation

A size 10 K-file (Dentsply Maillefer; Ballaigues, Switzerland) was used for the glide path. The working length was measured 1-mm short of the length at which the file tip was extruded apically. During the use of each file, 17% EDTA (RC Help, Prime Dental Products Pvt. Ltd., India) was used for lubrication, and the canals were irrigated with a 5.25% NaOCl solution. Recapitulation was performed after each file, and the last irrigation was performed using normal saline and a side-vented needle. After basic biomechanical preparation of 15/02 K-file, the 60 mesiobuccal roots were divided into three groups, which were further divided into two subgroups: the mesiobuccal root canal in one subgroup (n=10) was prepared with rotary motion and that in the other subgroup (n=10) was prepared with reciprocating motion using a rotary file system (Figure 2).

Group 1 (n=20): The Vortex Blue files (Dentsply Tulsa Dental, Johnson City, TN) were used to prepare the root canals.
Subgroup 1a (n=10): Canals were instrumented using the Vortex Blue file in sequence 15.04, 20.04, 25.04, and 25.06, with 500 rpm and 2 g/cm torque.
Subgroup 1b (n=10): Instrumentation of canal using the Vortex Blue file in sequence 15.04, 20.04, 25.04, and 25.06, with 170 counterclockwise (CCW) and 50 clockwise (CW) file motion.

Table 1A. A comparison between three different groups using rotary motion for evaluating microcracks at three different levels.

Microcracks at three different levels	Vortex Blue (n=10)	Mtwo (n=10)	ProTaper Next (n=10)	OneWay ANOVA		Posthoc Tukey Test		
				F value (*=welch test)	p	Vortex Blue vs Mtwo (p)	Vortex Blue vs ProTaper Next difference (p)	Mtwo vs ProTaper Next difference (p)
3mm Microcrack (apical third)	0.6±0.52	0.6±0.52	0.4±0.52	0.500	0.612	1	0.666	0.666
6mm Microcrack (middle third)	2.5±0.53	1.5±0.53	1.8±0.42	9.283*	0.002*	<0.001	0.010	0.377
9mm Microcrack (coronal third)	2.1±0.99	0.3±0.48	0.3±0.48	22.26	<0.001*	<0.001	<0.001	1

Group 2 (n=20): The mesiobuccal root canals were prepared using the Mtwo files (VDW Dental-Maillefer, Ballaigues, Switzerland).
Subgroup 2a (n=10): The Mtwo file was used in sequence 10.04, 15.05, 20.06, and 25.06, with 250–350 rpm and 100 g/cm torque.
Subgroup 2b (n=10): The canal was prepared using the Mtwo file in sequence 10.04, 15.05, 20.06, and 25.06, with 150-degree CCW and 30-degree CW file motion.

Group 3 (n=20): The root canals were enlarged using ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland).
Subgroup 3a (n=10): The ProTaper Next file system was used by considering the sequence of X1 and X2, at 350 rpm and 200 g/cm torque.
Subgroup 3b (n=10): The ProTaper Next file system was used in the sequence X1 and X2, at a 140-degree CCW and 45-degree CW file motion.

Dentinal crack analysis
The samples were rinsed with 2 ml of distilled water following canal preparation using a low-speed diamond-coated saw and cooling from the water. The samples were segmented at 3, 6, and 9 mm from the apex perpendicular to the long axis. Thereafter, all specimens were immersed in 1% methylene blue dye for 24 h. After the removal of the dye, the roots were rinsed with 2 ml of distilled water. The number of dentinal cracks on the slices was viewed using a stereomicroscope under 40× magnification. The number of cracks was counted at 3, 6, and 9 mm from the apex (Figures 3A,3B,4A,4B,5A,5B)

Statistical analysis
Using SPSS (version 20.0; SPSS Inc., Chicago, IL, USA), one-way analysis of variance (ANOVA) and post hoc Tukey tests were used to examine the dentinal microcracks of different rotary file systems employed in different motions. The Shapiro-Wilk test was used for normality. For numerical data, one-way ANOVA was used to compare the means of three or more groups of samples (using the F distribution). The post hoc Tukey test was performed to determine which of the three groups caused a significant difference. $p < 0.05$ was regarded as statistically significant.

RESULTS

When cracks were evaluated at different levels of rotary motion, it was discovered that, in all three groups, the middle and coronal thirds had significantly higher rates of crack production than the apical third. In the rotary motion, the highest microcrack formation was observed with the VortexBlue file at 6 and 9 mm from the root apex. Comparing the Vortex Blue with Mtwo file and ProTaper Next, a statistically significant difference was observed at the 6-mm and 9-mm levels of the root apex ($p < 0.05$; Table 1A; Figure 3).

Vortex Blue files in the reciprocating motion caused the greatest number of dentinal microcracks. When comparing the three file systems, the statistical significance value could be seen at the 6-mm level of the root apex ($p < 0.001$; Table 1B; Figure 3).

Comparing the three different file systems in two different motions, reciprocating motion caused fewer dentinal microcracks than rotary motion. Comparing the two motions for the Vortex Blue file, a statistically significant difference was noted at the 9-mm level ($p < 0.001$), with fewer microcracks in the reciprocating motion (0.5±0.53; Table 2).

The Mtwo file system showed the greatest number of dentinal microcracks (1.5±0.53) in rotary motion at the 6-mm level, with a statistically significant difference between the two motions ($p = 0.001$; Table 2).

Table 1B. A comparison between three different groups using reciprocating motion for evaluating microcracks at three different levels.

Microcracks at three different levels	Vortex Blue (n=10)	Mtwo (n=10)	ProTaper Next (n=10)	OneWay ANOVA		Posthoc Tukey Test		
				F value (*=welch test)	p	Vortex Blue vs Mtwo (p)	Vortex Blue vs ProTaper Next difference (p)	Mtwo vs ProTaper Next difference (p)
3mm Microcrack (apical third)	0.2±0.42	0.2±0.42	0.4±0.52	0.643	0.534	1	0.594	0.594
6mm Microcrack (middle third)	2.5±0.53	0.6±0.52	1.4±0.70	26.419	<0.001*	<0.001	0.001	0.014
9mm Microcrack (coronal third)	0.5±0.53	0.2±0.42	0.8±0.63	3.156*	0.059	0.432	0.432	0.047

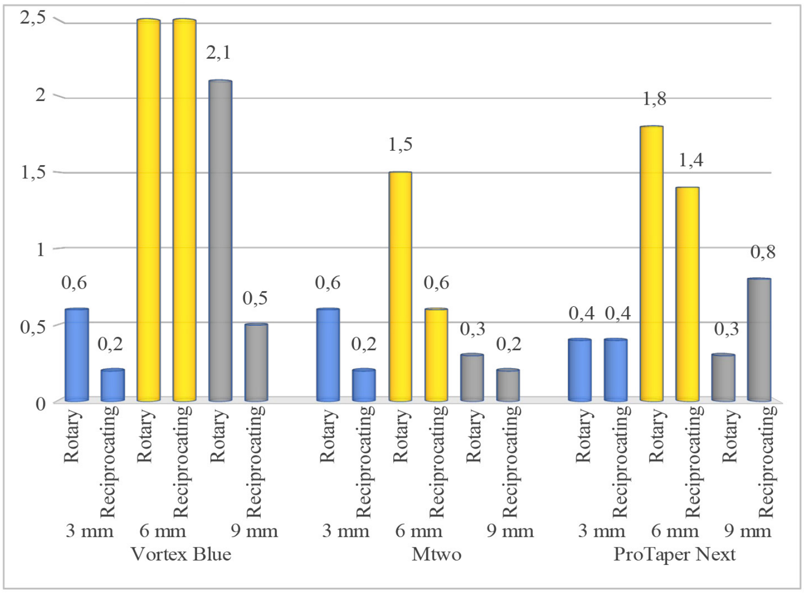

Figure 3. Three different file groups in two different kinematics for dentinal microcracks at three different levels 3mm, 6mm, 9mm.

Table 2. A comparison of different file systems using two different motions for evaluation of microcracks propagation at 3mm, 6mm, and 9 mm levels of the section using the independent t-test.

File systems	Dentinal microcracks at three different levels	Reciprocating (n=10) Mean±SD	Rotary (n=10) Mean±SD	t	p
Vortex Blue	3 mm Microcrack (apical third)	0.2±0.42	0.6±0.52	-1.897	0.074
	6 mm Microcrack (middle third)	2.5±0.53	2.5±0.53	0	1
	9 mm Microcrack (coronal third)	0.5±0.53	2.1±0.99	-4.496	<0.001*
Mtwo	3 mm Microcrack (apical third)	0.2±0.42	0.6±0.52	-1.897	0.074
	6 mm Microcrack (middle third)	0.6±0.52	1.5±0.53	-3.857	0.001*
	9 mm Microcrack (coronal third)	0.2±0.42	0.3±0.48	-0.493	0.628
ProTaper Next	3 mm Microcrack (apical third)	0.4±0.52	0.4±0.52	0	1
	6 mm Microcrack (middle third)	1.4±0.70	1.8±0.42	-1.549	0.142
	9 mm Microcrack (coronal third)	0.8±0.63	0.3±0.48	1.987	0.062

*Indicate statistically significant difference between groups.
F value = variance of group means /mean of within group variance.
t value = two group means /mean of within group variance.
$p < 0.05$

DISCUSSION

During rotation, the rotary instrument causes torsional stress in the root dentin, which is conveyed externally and may weaken its bond to the surrounding structure. This stress can spread vertically to the root apex. A fracture occurs when the tensile strength of dentin exceeds the tensile tension of the canal wall. The cause of such a flaw is related to the design and cross-section of the Ni-Ti instrument, as well as variations in the taper and flute shape.[1] A previous research has linked crack formation to instrument tip design, cross-sectional geometry, flute shape, constant or variable taper, and pitch.[12]

There are destructive and nondestructive techniques for observing and tracking microcracks in root canal dentin. Destructive techniques include stereomicroscope and SEM, whereas nondestructive techniques include micro-CT, infrared thermography, and endoscopy.[11] The complex specimen preparation for SEM, such as chemical fixation and metal ultra-thin coating, may cause dehydration, extra cracks, and artifacts, which could lead to incorrect findings interpretation.[13] Complete root canal cracks are more accessible to the endoscope than incomplete ones.[11] Large cracks are difficult for infrared thermography to detect.[14] The amount and direction of frictional heat produced by the ultrasonic vibration used in this method have an impact on the development and expansion of microcracks.[15] Although the method of using high resolution micro-CT scans is conservative and nondestructive, it is a complicated process that takes an hour or more, which may cause dehydration of the samples, leading to spontaneous cracks in dentin.[16] Due to these reasons, in this study, we used the stereomicroscope to detect dentinal microcracks.

The results of the present study showed that instrumentation with reciprocating motion creates fewer dentinal microcracks than that with continuous rotary motion. A repeated counterclockwise and clockwise reciprocating motion enables the instrument to be centered in the canal and decreases stress accumulation at the canal wall.[10] Previous studies have also suggested that instrumentation kinematics may impact the establishment of dentinal microcracks.[17,18]

Dentinal cracks during root canal preparation have various causes. The buccolingual direction, where there is a thin dentin wall on the concave side of the root, is where the most cracks are observed.[19] The range of 0%[20] to 38%[21,22] in the proportion of microcracks produced by Ni-Ti instruments in curved roots suggests that root canal curvature may be a variable that influences the emergence of dentinal microcracks. Additionally, greater root canal curvature may put more strain on the instrument and, as a result, on the root canal itself due to contact between the instrument and the root canal wall, which may result in unfavorable effects such as an increased chance of cracking.[23] Kim et al. examined the stress conditions during rotary instrumentation in a curved root for three Ni-Ti file designs using finite element analysis and discovered that the highest root stresses were often found at the most curved midroot canal wall.[24] In a study by Versluis et al., oval canals had unevenly distributed stresses, with high concentrations at the expansions of the buccal and lingual canals and higher stresses in the coronal and middle thirds of the canals than in the apical third.[25] These previous studies supported the findings of the current investigation of the presence of the greatest number of dentinal microcracks in the curvature of the root canal and in the coronal third.

In this study, ProTaper Next was used in the reciprocating motion at a speed of 45-degrees CW and 140-degrees CCW, with 2.5 N/cm torque, as suggested in the study by Priya et al.[26] In similar manner, the Reciproc reciprocating and Mtwo rotary files were used at speeds of 150-degrees CCW and 30-degrees CW, according to the manufacturer's recommendations, because both the Reciproc and Mtwo files have similar "S"-shaped cross-sections.[27] Due to the identical triangular cross-section, Vortex Blue was employed at a speed of 170-degrees CCW and 50-degrees CW, which is similar to the settings of Wave One reciprocating files.[28]

Table 1 shows a comparison between the three different rotary instruments in rotary motion for microcrack formation. Vortex Blue caused more dentinal microcracks than Mtwo and ProTaper Next files, with a mean difference that was statistically significant at the middle (at 6 mm) and coronal third of the root (at 9 mm). The M-wire technology used in the ProTaper Next system has an off-center rectangular cross-sectional shape that enables debris to be removed in the coronal direction, creating greater room around the instrument's flutes. Because of this design feature, the instrument might undergo a rotating phenomenon known as precession or swagger. This swaggering motion of the instrument degrades the screw effect, torque, and dangerous taper lock on the file, which eventually results in less stress on the dentinal wall.[19,29] The cross-sectional design of the Mtwo file is similar to that of the S-file.[30] It contains no radial lands, progressive blade pitch from tip to shaft, positive rake angles, and a non-cutting tip. The two cutting edges with minimum radial contact, allowing for maximal dentin removal area during canal preparation, lead to less stress on the dentinal wall.[31] Probably because of these characteristics, Mtwo and ProTaper Next showed less dentinal microcracks in rotary motion. While Vortex Blue has a triangular cross-section, it results in less area for dentine chips and decreased cutting efficiency, which contributes to an increase in torque, in addition to lower cleanability. Consequently, dentin is stressed and additional dentinal microcracks appear.[32,33]

Our results showed that the Vortex Blue group had the highest value for dentinal microcracks compared with the ProTaper Next and Mtwo files used in a reciprocating motion. This difference was statistically significant among all three groups in the middle third of the root. The M-wire, a metallurgically upgraded version of Ni-Ti, increases the instrument's flexibility.[34] The reciprocating movement, fixed speed, and various rotating angles reduce the risk of torsional fatigue due to compression and tension during movement, relieving stress on the instrument. Compared with a symmetrical file of the same taper, this method lowers cycle fatigue by 400%[35] and eventually reduces the stress on dentin by reducing the screwing effect. Thus, the null hypothesis was rejected.

While a previous study reported that reciprocating file systems result in less dentinal cracks than a multi-sequence rotary file instrument,[36] others found no statistically significant differences between the file systems.[37,38] However, another study claimed that a multiple file rotary system causes fewer dentinal cracks because when a single file is used for canal preparation, greater stress is imposed on the root canal wall as more dentinal mass is removed.[39] Therefore, further in vivo studies with more recent technologies, such as micro-CT, are required as there might be other clinical factors that also contribute to stress generation.

CONCLUSION

Based on the results of this study, it can be concluded that all files used in this study caused significant dentinal microcracks in the middle third (which has more curvature) and coronal third of the root, which is considered a dangerous area for the mesial root of the mandibular first molar. Reciprocating motion causes fewer dentinal microcracks than continuous rotary motion in both the areas.

CLINICAL SIGNIFICANCE

We can use a rotary file in the reciprocating motion, which reduces the formation of dentinal microcracks in the critical areas of the roots.

CONFLICT OF INTEREST

Authors declare that they have no conflict of interest.

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