RESEARCH ARTICLE

Kinematics-induced Microcrack Propagation: A Four-dimensional X-ray Microscopic Study

Vibha R Hegde[1], Sharmika R Joshi[2]

Abstract

Aim: To evaluate the microcrack propagation after root canal instrumentation using instruments operating in rotary, reciprocating, translinear, and centrifugal motions.

Materials and methods: An estimated 80 mandibular molars were divided into three experimental groups ($n = 20$). Group I—rotary motion (ProTaper Universal Dentsply, Maillefer, Ballaigues, Switzerland, and F2 file). Group II—reciprocating motion (WaveOne Dentsply, Maillefer, Ballaigues, Switzerland, Primary Files ISO 25, and 8% taper). Group III—translinear motion (Self-Adjusting File, ReDent Nova, Ra'anana, Israel). Standard access cavities were prepared and the canals were manually prepared up to a 15-K file to establish patency. Shaping and cleaning was performed according to manufacturer's instructions for each group, keeping the irrigation protocol constant. The samples were then scanned in a four-dimensional X-ray microscopy machine (ZEISS Xradia 510 Versa) and were virtually sectioned. The *Z* test was applied for statistical analysis.

Results: No significant difference was found between rotary (ProTaper Universal) and reciprocating groups (WaveOne) ($p = 0.3112$). Translinear motion (Self-Adjusting File) showed statistically significant least microcracks ($p = 0.000$).

Conclusion: (1) Self-adjusting file proved to be the most minimally invasive file system. (2) Reciprocation showed lesser samples with cracks than rotary motion. (3) Apical sections showed significantly higher cracks than the other sections. (4) Four-dimensional X-ray microscopy could be a promising tool for dental imaging.

Clinical significance: The stress induced by aggressive preparation procedures of certain file systems have led to microcrack propagation, reduction in the resistance form, and subsequently failure of endodontic therapy owing to vertical root fracture. Literature suggests that kinematics of the file influences crack propagation in a radicular dentin. Hence, this study has been undertaken to compare and evaluate the effect of four different kinematics of nickel–titanium file systems on microcrack propagation in a radicular dentin.

Keywords: Kinematics, Microcrack, Reciprocation, Rotary, Self-adjusting file.

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Introduction

The goal and objective of cleaning and shaping techniques is directed at removing the bacteria and infected the dentin in the root canal space. As has been classically put forth by Schilder, a continuous taper of the canal is essential for facilitating optimum disinfection and obturation of the root canal system.[1] It has been observed that teeth undergoing an endodontic therapy are challenged owing to the presence of pathology, caries, trauma, or fracture. Further subjecting these teeth to cleaning and shaping procedure can weaken the tooth to a greater extent. The interaction of the shaping instruments create many momentary stress concentrations in the dentin. Such stress concentrations may induce dentinal defects and microcracks or craze lines in endodontically treated teeth, which can materialize into vertical root fractures. Originally, the failure of endodontically treated teeth was attributed to a dehydrated dentin after an endodontic treatment.[1] Although the loss of vitality has been shown to reduce water lesser (9%) than a healthy counterpart, the predominant factor that triggers fractures could not be ascribed to water loss.[2] Bier et al.[3] and Shemesh et al.[4] were the first to infer the relationship between microcrack formation and canal preparation or filling procedures.

Over the past two decades, rotary nickel–titanium-based preparation has become the mainstream approach in mechanically enlarging the root canal space, overcoming most of the conventional preparation drawbacks, such as canal transportation and perforation.[5] Nevertheless, recently, an important concern has been raised and confirmed by several studies, namely the creation of dentinal defects due to motor-driven nickel–titanium (NiTi) instrumentation. Kim et al.[6] reported that rotary instrumentation significantly increased the stress on the dentin as a result of higher torque and increased taper of these instruments. They concluded that the file design affected apical stress and strain concentrations during root canal instrumentation, resulting in a vertical root fracture.

This situation is critical, considering the plethora of different designs, tapers, preparation protocols, number of files, and kinematics of the available NiTi systems. The experimental models used earlier to detect microcracks embraced sectioning procedures and postoperative observations under a stereomicroscope. Versiani in 2015[5] questioned these destructive techniques to view such defects. Hence, this study has incorporated the use of FDXM (Four

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dimensional X-ray microscopy)—a novel noninvasive imaging technique to decipher microcrack propagation. The aim of this study was to compare and evaluate the microcrack propagation after root canal preparation, using instruments operating in rotary, reciprocating, and translinear motions.

Materials and Methods

Freshly extracted intact human mandibular molars with straight roots were selected. The teeth were examined with a stereomicroscope (under ×10 magnification) to detect craze lines or cracks; such defective teeth were excluded from the study. This resulted in 60 specimens. To simulate the periodontal ligament, root surfaces were dipped into melted wax to a depth of 2 mm below the cementoenamel junction to produce a thin layer and then vertically embedded in polyvinyl cylinders with self-cure acrylic (to simulate the alveolar bone). The wax spacer was later substituted with light-body Addition Silicone (to simulate the periodontal ligament). Access was achieved and canal patency was established with a #10 K-File. The working length was standardized to 20 mm. Teeth were divided into three groups ($n = 20$).

- Group I—rotary motion (ProTaper Universal Dentsply, Maillefer, Ballaigues, Switzerland)
- Group II—reciprocating motion (WaveOne Dentsply, Maillefer, Ballaigues, Switzerland, and Primary Files ISO 25 and 8% taper)
- Group III—translinear motion (Self-Adjusting File, ReDent Nova, Ra'anana, Israel)

Shaping and cleaning were performed according to the manufacturer's instructions respectively for each group. The irrigation protocol was kept constant for each group. The samples were then scanned in the ZEISS Xradia 510 Versa. Postoperative sections were evaluated at 3 mm, 6 mm, and 9 mm from the apex to evaluate crack propagation in the apical third, middle third, and coronal third, respectively. All sections were observed by two observers for the presence of microcracks. "No defect" was defined to a section as root dentin devoid of any craze lines or microcracks originating from the canal lumen. "Defect" was defined to a section if any craze lines, mirocracks, or fractures originating from the canal lumen were present. A total of 60 sections were examined in each group.

Results

The data for the intergroup comparison and that for the comparison between apical, middle, and coronal sections was then subjected to a statistical analysis using the *Z* test for the proportion comparison. The intergroup comparison suggested that there were no samples showing microcracks in the Translinear (group III) motion group when compared to Rotary and Reciprocating motion (p value = $0 < 0.5$). A comparison between rotary (group I) and reciprocating (group II) movement showed no statistically significant difference in microcracks (p value = $0.3 > 0.05$) (Tables 1 and 2, Fig. 1). The apical third showed significantly more number of cracks when compared to the coronal third (p value = $0.0463 < 0.05$) (Tables 3 and 4, Fig. 2).

Table 1: Groups and samples showing microcracks

	Total samples	*Samples showing cracks*
Rotary motion	20	15
Reciprocating motion	20	12
Translinear motion	20	0

Table 2: Statistical analysis

Comparison		*Z test*	*p value*	*Interpretation*
Group I	Group II	1.01	0.3112	Statistically not significant
Group I	Group III	4.9	0.000	Statistically significant
Group II	Group III	4.14	0.0000346	Statistically significant

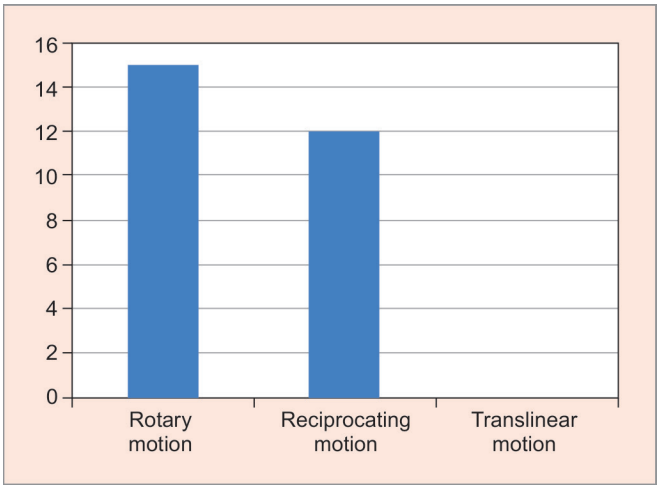

Fig. 1: An intergroup comparison of number of samples showing microcracks

Table 3: Number of samples among apical, middle, and coronal third showing microcracks

	Apical	*Middle*	*Coronal*
Rotary motion	15	9	8
Reciprocating motion	9	7	5
Translinear motion	0	0	0

Discussion

The mechanical goals put forth by Schilder[7] in his classical research were aimed at complete shaping of the root canal system yet maintaining the resistance form of the tooth. With the advent of nickel–titanium instruments, several studies have reported the development of dentinal defects such as microcracks and craze lines after root canal preparation. These dentinal defects have shown to stand as a trigger point for vertical root fractures and may influence the long-term survival of endodontically treated teeth. Kim et al. reported that rotary instrumentation significantly increased the stress on the dentin as a result of higher torque and increased the taper of these instruments.[8] They also concluded that the file design affected apical stress and strain concentrations during root canal instrumentation, resulting in a vertical root fracture. Literature suggests the variability in the file design affects crack propagation, but there is a lack of literature on the effect of kinematics and various motions on microcrack propagation on the radicular dentin. Hence, this study was conducted to evaluate the effect of the kinematics of three file systems on the microcrack propagation.

Table 4: Statistical analysis

			Z test	*p value*	*Interpretation*
Group I	Apical	Middle	1.94	0.053	Nonsignificant
	Apical	Coronal	2.2389	0.0252	Significant
	Middle	Coronal	0.3198	0.7491	Nonsignificant
Group II	Apical	Middle	0.6454972	0.5186050	Nonsignificant
	Apical	Coronal	1.325987	0.184844	Nonsignificant
	Middle	Coronal	0.6900656	0.4901530	Nonsignificant
Group III	Apical	Middle		All values are zero	
	Apical	Coronal			
	Middle	Coronal			
Total	Coronal	Middle	1.42	0.16	Nonsignificant
	Coronal	Apical	1.99	0.0463	Significant
	Middle	Apical	0.5862	0.5578	Nonsignificant

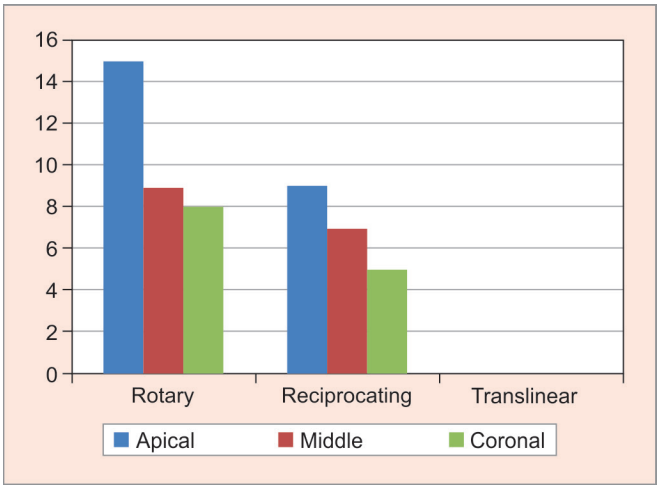

Fig. 2: An intragroup comparison of number of samples showing microcracks among apical middle and coronal third

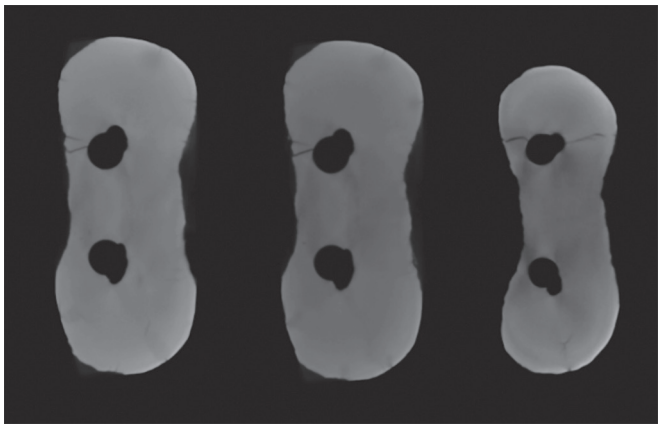

Fig. 3: FDXM slices showing microcracks in the coronal, middle and apical third: rotary motion

The rotary and reciprocating file systems used in the present study were of the same taper and cross section. ProTaper rotary files showed maximum samples of microcracks at all three levels (Fig. 3). These results were in accordance with those of the study by Ashwinkumar et al.,[9] who attributed these results to the continuous rotational force and constant torque applied by Ni-Ti rotary file on the root canal walls, which results in significantly increased microcrack formation. On the other hand, reciprocating motion was shown to have lesser number of samples showing microcracks than rotary, though the difference was not statistically significant. These results were similar to those of the studies by Berutti et al.,[10] who attributed the result to the reciprocating motion of WaveOne, which aids in stress release before the file progresses within the canal. Moreover, the time required for root canal preparation per sample using WaveOne reciprocating files was less than that for ProTaper rotary files. This might also be responsible for a greater number of microcracks in the latter group. The ProTaper Universal system is a second-generation file system with active cutting edges, which made it more aggressive.[11]

The WaveOne belongs to the fourth generation, made of M wire and works in a reverse balanced force action, and hence generates lesser stress on the radicular dentin. However, there was no statistically significant difference in the number of samples showing microcracks. The reciprocating motion was found to be more centered in the canal;[12] by repeating the clockwise and counter-clockwise rotation, the reciprocating motion allowed a continuous release of the file when it is engaged in the inner surface of the root canal during the cutting and shaping procedure.[13] Furthermore, flexural and torsional stresses acting on the dentin are also reduced as the counter-clockwise motion disengages the instrument blades and reduces stresses.[10] In this study, WaveOne is presented with the least number of samples showing dentinal cracks (Fig. 4). The M-wire technology imparts more flexibility to WaveOne instruments, which might contribute to lesser dentinal cracks in this group.[10] Also, WaveOne primary files have a noncutting modified convex triangular at the tip and a unique convex triangular cross-section design along the length of their active portions.[14]

The self-adjusting file system, unlike the other rotary systems, does not rotate within the confines of the root canal. Instead, it works with a back-and-forth motion that removes the dentin from the canal walls in a scraping action owing to a nickel–titanium abrasive coating. In addition, it neither has a cutting edge nor does it have flutes. The self-adjusting file comes in an intimate contact with the inner canal wall as a result of compressible and expansive structure of the lattice.[15,16] As opposed to continuous rotary cutting action, the self-adjusting file works like a sandpaper, which scrapes the dentin, thus effectively enlarging the canal. Furthermore, this system is used with continuous irrigation delivered through the

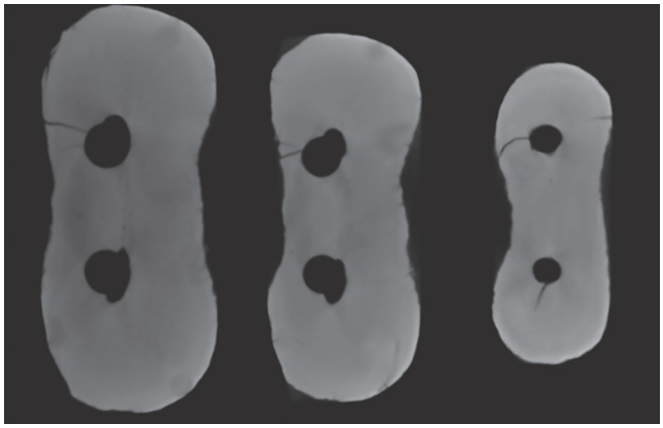

Fig. 4: FDXM slices showing microcracks in the coronal, middle and apical third: reciprocating motion

Fig. 5: FDXM slices showing microcracks in the coronal, middle and apical third: translinear motion

hollow file, which minimizes the generation of frictional stresses.[15,16] The results obtained in the present study were similar to previous studies in which minimal microcracks were found in teeth prepared with the self-adjusting file (Fig. 5).[17–19] Metzger reported that the stress created by this file system is minimal (i.e., 10 MPa), which is considerably lower than the tensile strength of the dentin.[20]

The intergroup comparison between coronal, middle, and apical third showed maximum samples showing cracks in the apical third. Literature suggests that working length, master apical file size, and apical enlargement increase the chances to produce apical cracks. A working length of 1 mm short of the apical foramen was shown to produce fewer cracks in the apical region. Also, step-wise enlargement at working length may increase dentinal detachment at the apical root surface.[21–23]

Previously, methods used for evaluating microcracks were stereomicroscopy and scanning electron microscopy.[5] These methods have proved to be destructive and affect the crack propagation, giving false positive or negative findings.[5] Four-dimensional X-ray microscopy has the ability to create virtual slices, eliminating the destructive step of sectioning, making evaluation of microcracks more accurate and simple.

Conclusion

Within the limitation of this *in vitro* study, it can be concluded that self-adjusting file proved to be the most minimally invasive file system. Reciprocation proved to induce lesser stress on the radicular dentin than rotary motion. The apical portion of the root canals' system is the area most prone to crack propagation. Four-dimensional X-ray microscopy could be a promising tool for dental imaging.

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