ORIGINAL RESEARCH

Evaluation of Microcracks formed During Root Canal Preparation by Different File Systems Using Micro-computed Tomography: An *In Vitro* Study

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Abstract

Aim: The purpose of this study was to evaluate and compare the incidence of dentinal microcracks after instrumentation with various types of nickel-titanium (NiTi) files in rotary and reciprocating motion.

Materials and methods: Fifty human extracted mandibular molars were taken and divided into five groups (n = ten teeth per group). Group I included ProTaper Gold, group II included OneShape, group III included WaveOne Gold, group IV included Reciproc, and group V included hand K files. The teeth were desectioned at the cemento-enamel junction (CEJ) and dentinal microcracks were observed under Micro-computed tomography. Postoperative Micro-computed tomography analysis of the samples was conducted to inspect cracks in the images obtained before and after preparation.

Result: Results confirmed that there was a statistically significant difference between the study groups (p <0.05). The highest percentage of microcracks was seen in ProTaper Gold followed by OneShape. WaveOne Gold and Reciproc showed closely similar percentage of microcracks followed by hand K files that showed the least.

Conclusion: Both rotary file systems showed higher number of microcracks than reciprocating file systems. Hand K files showed least microcracks formation among all studied groups.

Clinical significance: Among all the tested methods and systems, hand K files demonstrated least incidence of dentinal microcracks. However, these hand K files systems are not advanced and have certain practical limitations. Reciprocating systems usually exhibits clinically acceptable microcracks therefore they may be judiciously utilized. Rotary file systems showed excellent biomechanical outcomes with redundant microcrack formation. Hence, precise selection of a particular system must be solely dependent upon the clinical decision making and circumstantial requirements.

Keywords: Endomotor, Microcracks, Micro-computed tomography, NiTi Files, OneShape Rotary.

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Introduction

The main goal of chemo-mechanical preparation is eliminating microorganisms, infected pulpal tissue and debris from the root canal system thereby preparing the root canal diameter to receive the obturating material.[1] Introduction of NiTi rotary instruments drastically improved the root canal preparation and reduced the time factor. Numerous characteristics have been included by the manufacturers since the invention of these NiTi instruments to satisfy major issues like increased flexibility. However, researches show that they resulted in more dentinal microcracks on the root canal wall.[2] Vertical root fractures could be initiated from these dentinal cracks that might result in extraction of the tooth.[3] Several factors of NiTi files, such as different heat treatments, designs, cross-sectional shape, and kinematics may influence the generation of cracks. To reduce the micro-crack formation, researchers are trying numerous advancements in the instrumentation techniques. In recent times, ProTaper Gold files are manufactured with incorporated metallurgical features like improved transformation behavior and high austenite finish temperature.[4] PTG systems, consisting of three shaping files (SX, S1 and S2) and five finishing files (F1, F2, F3, F4, and F5), have triangular cross-sections and progressive tapers. However, more files generated greater stress concentration on the root canal walls leading to more craze lines.[3] Advances in NiTi instruments and their kinematics have led to the generation of single-file systems activated in rotary or reciprocating motion. The single files reduced the stresses on the root canal walls.[5] Oneshape (Micro-Mega, Besancon, Cedex, France) shaped the root canals using the single-file technique with or without the use of a glide path file in continuous clockwise rotation. It is made up of

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conventional austenite NiTi. It has three dynamic cross-sections across the blade. It generates traveling waves of motion along the active part of the file that facilitates shaping without removal of excess amount of dentin.[4] To relieve the stresses on the instrument, reciprocating single file systems were introduced. The reciprocating movement is claimed to prepare the canals by the "balanced force" concept. This is brought about by special counterclockwise and clockwise movements. It is assumed that this movement reduces the risk of cycle fatigue caused by tension and compression.[6] Recent technological advances led to the introduction of reciprocating the single-file NiTi systems Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) that prepare canals with only one instrument, thereby requiring lesser time than rotary full-sequence systems. The Reciproc file has a sharp cutting edge with an S-shaped geometry. The WaveOne Gold file has parallelogram-shaped cross-section with two cutting edges making the file more flexible. These files are made of a special nickel-titanium alloy called M-wire. This M-wire alloy provides increased flexibility and improves resistance to cycle fatigue of the instruments. Moreover, Wave One Gold has a new heat treatment; the Gold Wire.[7] Micro-computed tomography imaging technique is recommended for analyzing dentin and its alterations without damaging the tooth structures. Some of the micro-computed tomography studies reported that the instrumentation systems with rotary and reciprocation motions have no relation to the formation of dentinal microcracks.[8] However, several studies have reported the development of dentinal defects, such as microcracks and craze lines after root canal preparation with NiTi-based instruments.[9] Therefore, the present study was designed to determine and compare the incidence of dentinal microcracks before and after the use of these file systems using high-resolution micro-computed tomography analysis. The null hypothesis was that there would be no differences among the different file systems in terms of dentinal microcrack formation.

Materials and Methods

This study was conducted in the Department of Conservative Dentistry and Endodontics, Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow, India. A total of 50 permanent human mandibular first and second molars were taken. Teeth were primarily extracted for their clinically unacceptable mobility (underlying periodontal pathology). The samples were checked using radio-visiography in buccal and proximal directions to ensure that all mesial roots had two separate canals. The root canals with reduced pulp spaces, pulp stones, calcified root canals with hypercementosis, root caries, anomalies, and occlusal wear were discarded from the study. The soft tissue remnants and calculi on external root surface were removed mechanically. The teeth samples were disinfected in 0.1% thymol solution over 24 hours and kept in purified water for 30 days preceding the micro-computed tomography analysis. The specimens were scanned after 2-hour drying time to prevent false-positive results during dentinal crack formation. The roots of the teeth were decoronated at the CEJ under water cooling with the help of diamond disks, leaving approximately 15–16 mm of root length from the apex.

Preoperative Micro-computed Tomography Analysis

Micro-computed tomography was performed (SkyScan 1174; SkyScan bvba, Aartselaar, Belgium) with a low isotropic resolution of 26.59 µm, 49kV, 200 µA, and a frame rate of 0.5 mm of thick aluminum filter. The entire scanning was done with a rotation of 180 degrees resulting in approximately 45 minutes per each scan of the tooth. Two-dimensional images were generated that were reconstructed to a three-dimensional (3D) version (NRecon software for reconstruction, version 1.6.9.4, Bruker micro-CT, Skyscan). The reconstructed images were then transferred to the Data Viewer program (version 1.5.2.4, Bruker micro-CT) and a 3D reimaging was performed. In this way, coronal, sagittal, and transaxial axes images were obtained for each sample. Between 600 and 700 transverse cross-sectional micro-computed tomography slices were obtained for each root. Canal patency was checked with #10 K file that was used to measure the working length of both mesiolingual and mesiobuccal canals using radiographic method. A #15 K file was used to prepare the glide path, and each canal was irrigated by 2 mL of 2.5% sodium hypochlorite followed by 2 mL of 17% EDTA during instrumentation. Normal saline was used in between to flush out the debris.

Sample Distribution and Canal Instrumentation

The teeth were divided into five study groups with 10 teeth present in each experimental group. The samples in each group were prepared by using different file systems. The control group had 10 samples that were prepared from hand K files.

- Group I: ProTaper Gold rotary file system
- Group II: OneShape rotary file system
- Group III: WaveOne Gold reciprocating file system
- Group IV: Reciproc reciprocating file system
- Group V: Hand K-files (control group)

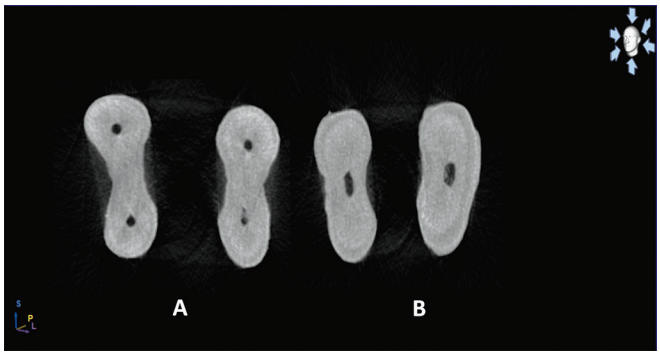
All samples in the first four groups were initially prepared with the #15 K file. In group 1, all the PTG instruments were used at 300 rpm with a torque of 3 N-cm for SX and S1 instruments, 1.5 N-cm for F1 instruments, and 2 N-cm for F2 instruments with a progressive taper of 0.06, 0.07, and 0.08. In group II, OneShape rotary file was used #25, 0.06 taper at a constant speed of 400 rpm was used in continuous rotation with slow pecking motions with amplitude of 3 mm and a torque of 2.5 N-cm. The flutes of the instrument were cleaned after three pecking motions. In group III, a single Wave One Gold Primary (25/0.07) file with in-and-out pecking movements was used until reaching the working length at 350 rpm and 5 N-cm of torque. In group IV, root canals were prepared with R25 instrument (25/0.08) file in slow in-and-out pecking motion at 300 rpm with an amplitude of 3 mm. Teeth in group V, the positive control group had apical preparation of the samples done till #25 hand K files using step back technique. The root canals were flushed with 2 mL of 2.5% NaOCl solution and saline between different files was used (Figs 1 and 2). The final rinse was done with 2 mL of distilled water in all the experimental groups.

Postoperative Micro-computed Tomography Analysis

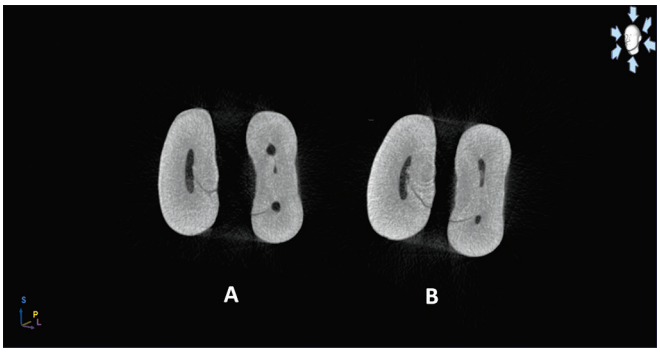
Postoperative micro-computed tomography analysis of the samples was performed and the images obtained before and after preparation were opened simultaneously and checked. Data were analyzed using CTAn, that is, CT analyzer by two-blinded observers. Chi-square test was used to determine the significant differences before and after instrumentation with $p < 0.05$ considered statistically significant (Figs 3 and 4).

Results

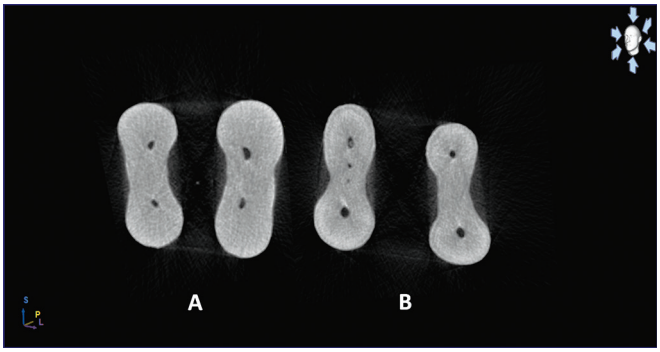
Data were compiled and analyzed with SPSS version 21 (IBM Inc., Armonk, New York, USA). ProTaper Gold and OneShape systems



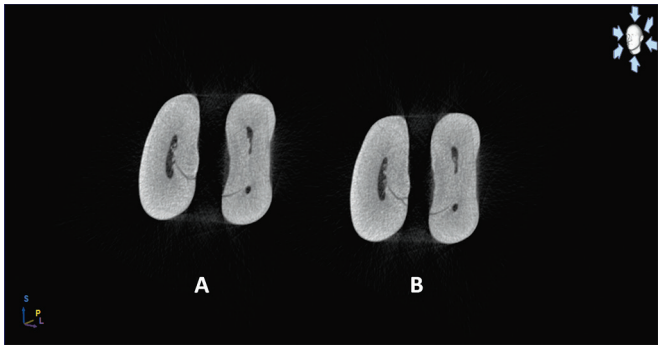
Figs 1A and B: Preinstrumentation micro-CT scan images of (A) ProTaper Gold rotary; and (B) OneShape rotary file system



Figs 3A and B: Postinstrumentation micro-CT scan images of (A) ProTaper Gold rotary; and (B) OneShape rotary file system



Figs 2A and B: Preinstrumentation micro-CT scan images of (A) WaveOne Gold reciprocating; and (B) Reciproc reciprocating file system



Figs 4A and B: Postinstrumentation micro-CT scan images of (A) WaveOne Gold reciprocating; and (B) Reciproc reciprocating file system

showed 0.7% of microcracks in the preinstrumentation phase (each). Likewise, Wave One Gold and Reciproc systems exhibited 0.5% and 0.3% of microcracks, respectively, in the preinstrumentation phase. In the postinstrumentation phases, ProTaper Gold and OneShape systems demonstrated 5.5% and 3.3% of microcracks. Similarly, WaveOne Gold and Reciproc systems showed 2.5% and 2.2% of microcracks, respectively, in this phase. Overall, both rotary file systems (group I and group II) showed more microcracks than reciprocating file systems (group III and group IV). Comparing the pre- and postinstrumentation microcracks, the Chi-square test showed higher frequency (%) of microcracks in postinstrumentation as compared with preinstrumentation in all groups with the highest increase in ProTaper Gold (4.8%, $\chi^2 = 22.80$, $p < 0.001$), followed by Oneshape (2.6%, $\chi^2 = 10.69$, $p = 0.001$), WaveOne Gold (2.0%, $\chi^2 = 8.01$, $p < 0.005$), Reciproc (1.9%, $\chi^2 = 8.08$, $p < 0.005$) and the least in hand File (0.8%, $\chi^2 = 5.00$, $p = 0.025$). There was a significant difference among groups in the frequency of cracks ($p < 0.05$, Table 1). Thus, the microcrack formation by different file systems used in the present study can be summarized as: group V < group IV < group II < group II < group I.

Discussion

Literature has well stated that root canal is shaped by the intimate contact between cutting edges of armamentarium and dentin surfaces during biomechanical preparations. These processes generate numerous temporary stress concentrations in dentin. Bier and associates stated that such force concentrations can develop dentinal deficiencies and microcracks particularly in the angulated canals.[10] A direct correlation exists between the amount of dentin removed and crack formation. However, the elimination of bacteria and infected debris from the root canal must result in minimal damage to the sound dentin. Micro-computed tomography is an imaging technique that is recommended for analyzing dentin and its alterations without damaging the tooth structure. It was used to evaluate the presence of dentinal microcracks in this study as this approach is highly accurate due to its nondestructive nature. This technique allows 3D noninvasive assessment and visualization of microcracks and facilitates pre- and postoperative analysis of the same specimens that serve as their own control. Moreover, De-Deus and colleagues mentioned that reliable results can be obtained without damaging the tooth structure.[8] These inferences were in contrast to our methodology as we prepared samples by the sectioning process. In the recent past, various endodontic instruments (i.e., rotary and reciprocating instruments) were introduced to counter the drawbacks of stainless steel instruments and NiTi hand instruments. Ustun and coworkers confirmed that NiTi engine-driven systems remove greater total volume of dentin from root canals when compared to hand filing that generated more defects.[5] In an *in vitro* study conducted by Priya et al., dentinal microcracks induced by reciprocating and conventional full-sequence rotary systems were evaluated and it was found that no new microcracks were observed after preparation with different NiTi file systems.[4] These inferences were not in agreement with our results. In our study, greater number of microcracks was caused by the PTG file system. These differences could be attributed to

Table 1: Pre- and Post-frequency of microcracks of five groups

File system (group)	*Microcracks pre-instrumentation (n = 600) %*	*Microcracks post-instrumentation (n = 600) %*	*% increase in microcracks (Post–Pre)*	χ^2 *value*	*p value*
ProTaper Gold (GI)	4 (0.7)	33 (5.5)	4.8	22.80	<0.001
OneShape (GII)	4 (0.7)	20 (3.3)	2.6	10.69	0.001
WaveOne Gold (GIII)	3 (0.5)	15 (2.5)	2.0	8.01	0.005
Reciproc (GIV)	2 (0.3)	13 (2.2)	1.9	8.08	0.005
Hand K File (GV)	0 (0.0)	5 (0.8)	0.8	5.00	0.025
χ^2 value	4.33	25.67	–	–	–
p value	0.364	<0.001	–	–	–

more rotations with progressively increasing taper with increasing number of files that was a contributing factor in increasing tension on the root canal walls. Furthermore, Nishad et al. showed that PTG files have a convex triangular cross-sectional design that resulted in increased stresses on the canal walls by reducing the remaining dentin thickness.[11] Liu et al. mentioned that single-file systems reduces the stresses caused by more number of instruments. Their results were further supported by Abou et al. wherein they confirmed that single-file systems create less stress on the root dentin resulting in fewer of microcracks.[12] Their outcomes were highly comparable with our results particularly for the ProTaper system. Abou et al. confirmed that single NiTi instrument provides simpler preparation, have greater cost effectiveness, and reduce instrument fatigue.[13] OneShape is one such file system that has three cutting edges near the tip, two cutting edges at the middle, and two cutting edges near the shaft that has an increased rotational speed as compared to PTG. This increases the cutting efficiency of the instruments. Saberi et al. believed that higher cutting efficiency usually related to less crack formation.[14] The formation of more microcracks in the PTG group than OneShape file group may be due to the higher and progressive taper along with the convex-triangular cross-section design that produced higher stress on dentinal walls.[11] However, single file like OneShape regardless of the kinematics exert more stress on dentin and cause more cracks in apical third of root.[12] Ashwin Kumar et al. stated that these files are subjected to cycles of tensile and compressive stress (in curved canals) resulting in their fracture.[15] Torsion and flexion occur with continuous rotating NiTi instruments while preparing the root canals leading to instrument fracture.[16] To avoid this, reciprocating movement was introduced. The reciprocating motion minimizes the stresses on the instrument by counter clockwise (cutting action) and clockwise (release of instrument) movements.[13] Kim et al. mentioned that it reduces the screwing effect of the instrument and allows the instrument to cut and consecutively disengage the root dentin resulting in increased file durability.[17] The reciprocating file system generate minimum torsional stresses on the dentin by its clockwise counter clockwise rotations leading to fewer microcracks compared to rotary instruments. Hence, reciprocating motion resulted in less dentinal damage than continuous rotation motion.[18,19] The results were comparable with our outcomes. In the study conducted by Saber et al., reciprocation motion of WaveOne Gold and Reciproc provided lower magnitude of forces leading to fewer microcrack formation.[20] Their inferences were somewhat similar to our results. WOG file has an offset parallelogram-shaped cross-section that alternately touches the dentin with 2 and 1 blades during the 360° spin. The armamentarium is repetitively heat treated and cooled, providing the file a characteristic yellow color. This procedure augments the elasticity and cyclic fatigue resistance of the armamentarium.[21] Reciproc possesses a markedly small core diameter and greater chip space than that of WaveOne. Gergi et al. studied Reciproc and WOG systems and mentioned that increased chip space is associated with an increased debris removal capacity and efficiency of instruments.[22] However, it eventually results in lesser microcrack formation in Reciproc file systems as compared to WOG. In the present study, authors noticed only minute deference among these two systems (Reciproc file: 1.9%; WOG: 2.0%). WOG files have a parallelogram-shaped cross-section with a neutral rake angle whereas Reciproc files have S-shaped geometry with 2 sharp cutting edges. This feature may also increase cutting efficiency of Reciproc.[20] Saber et al noticed no significant difference between two reciprocating instruments (WOG and Reciproc) on the microcrack formation.[20] The differences in the incidence of dentinal defects between the tested groups could be explained on the basis of preparation techniques and cross-sectional designs. In another study, Gergi et al. concluded that hand instruments have lesser taper 0.02% as compared with rotary and reciprocating instruments causing less dentinal defects.[23] In addition to this, softer movement of hand files as compared to rotary files also create minimum microcracks.[24] Better tactile sensation and less stress also causes least damage to the root canal walls resulting in fewer microcracks.[25] In the limitations of the study, authors performed teeth sectioning, which is a destructive method that can promote the development of microcracks. Microcrack propagation can also be associated with other significant factors like teeth age and dehydration status, storage condition, tooth length, canal shape, and canal volume. These are very crucial aspects that can possibly affect the results. Hence, all these points are recommended to be further investigated in similar future studies.

Conclusion

Within the limitations of this study, it can be concluded that the hand K file system causes least dentinal microcracks when compared with Rotary (ProTaper Gold and OneShape) and reciprocating (WaveOne Gold and Reciproc) file systems. Among the rotary file systems, PTG showed more microcracks than the OneShape single-file system. In the reciprocating system, Reciproc showed lesser microcrack formation than the WOG file system. Hand K files resulted in the least microcrack propagation among all tested groups.

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