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An SEM-based study of dentinal defects caused by four advanced rotary file systems

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Abstract

Introduction: The research examined and compared dentinal microcracks after biomechanical preparation using Protaper Next, Hyflex EDM, Waveone Gold, and Jizai rotary file systems in middle, apical, and coronal root canal levels.

Material and Methods: 100 human-extracted permanent mandibular premolars have been divided into one control group and four experimental groups of 20 teeth each. The roots have been sectioned at 3, 6,9 millimeters from apex and studied under scanning electron microscope. A Fisher's Exact Test and Chi-Square have been utilised to record and analyse dentinal defects.

Results: No microcracks were found in control group. All studied groups exhibited comparable distribution of dentinal microcracks in coronal, middle and apical section. Dental defects in middle third were more common in ProTaper Next than in the control group.

Conclusions: In the study, all tested rotary systems resulted in some degree of dentinal microcracks. The middle third of the root canal was the most affected region, showing a statistically significant increase in defect formation.

Keywords: Dentinal microcracks; Hyflex EDM; Protaper Next; Waveone Gold; Jizai; Scanning electron microscope

Introduction

The evolution of mechanical debridement has significantly advanced endodontic procedures. Traditional stainless-steel (SS) instruments like Gates Glidden burs and Peeso reamers have been effective but posed high risk of perforation due to their rigidity [1]. In 1988, Nickel-Titanium (NiTi) files revolutionised root canal therapy, enhancing efficiency and minimizing procedural errors. However, concerns regarding NiTi instrument fracture due to torsion or flexural fatigue led to the development of reciprocating motion techniques, reducing stress and enhancing durability.

Modern advancements have focused on single-file shaping techniques, simplifying instrumentation while minimising procedural risks. However, root canal preparation remains associated with complications like canal transportation, ledge formation, and instrument fracture. Studies suggest that rotary instrumentation increases stress on dentin, potentially leading to dentinal microcracks and vertical root fractures. Impact of different instrumentation systems varies depending on file shape, metallurgy, taper, and movement kinematics [2,3].

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Manufacturers have introduced innovative NiTi systems to enhance safety and efficiency. ProTaper Next (Dentsply Maillefer) features variable tapers and a unique cross-section to optimise shaping while minimising stress. WaveOne Gold (WOG) operates with reciprocating motion and gold heat-treated technology, offering improved flexibility and reduced dentinal damage. HyFlex EDM (Coltene/Whaledent) utilises electro-discharge machining for superior fracture resistance and precision. Jizai files (MANI) incorporate Control Memory technology and a radial land design to minimise excessive engagement with canal walls, improving procedural safety.

Despite these advancements, NiTi instruments remain prone to unexpected fractures and stress accumulation, potentially leading to microcracks in dentin. Conflicting study results regarding dentinal crack formation necessitates further research. No research has examined dentinal microcracks induced by Hyflex EDM, Protaper Next, Waveone Gold, and Jizai rotary file systems. This study will use a SEM (scanning electron microscope) to explore dentinal microcracks induced by distinct rotary file systems with variable tapers. The objective is to identify the file system that causes the least amount of dentinal damage, offering important insights for improving root canal preparation methods. Null hypothesis states that fracture formation will be similar across groups.

Materials and Methods

In distilled water, 100 freshly extracted permanent non-carious mandibular premolars with straight root canals, mature apices, and curvature of 10^0 or less were preserved. Proximal radiographs of teeth confirmed a single canal, canal patency, and no abnormalities. Teeth were decoronated under water coolant at the CEJ level to achieve a standardised root length of 16millimeter. Cracks were checked on all specimens under a 12X stereomicroscope. After excluding such teeth, more premolar teeth were obtained to replace them.

We estimated sample size using chi-square analysis with a 0.05 significance level. To ensure a balanced distribution, five groups of 20 teeth each were formed. The samples were then randomly assigned to one control group and four experimental groups performing biomechanical preparation with different rotary file systems. #10 K-File established canal patency. For establishing working length, deduct 1mm from length of the size #10-K file put in canal until tip is seen at apical foramen. A silicon impression material was applied to the cemental surface of roots to mimic the periodontal ligament space. All the roots were then encased in acrylic blocks. Twenty teeth were prepared with hand files, serving as a control group, and the canals of the remaining teeth were instrumented using Hyflex EDM, Protaper Next, WaveOne Gold, and Jizai rotary system.

Group 1 - Control group: The specimens in this group were sequentially prepared with hand files. The initial glide path has been developed by utilizing a 10 K-file (21mm), followed by instrumentation with 15 K-files, 20 K-files, and 25 K-files up to the maximum operating length. Recapitulation was performed with the preceding file before progressing to the next, accompanied by an irrigation protocol using sodium hypochlorite and normal saline.

Group 2 - Hyflex Edm File System: In group 2, all root canals have been treated with Hyflex EDM (Colténe/ Whaledent, Altstatten, Switzerland) rotary files. The glidepath file was inserted to working length using a Hyflex EDM orifice opener as per manufacturer's directions. The canal was shaped to the full working length with the Hyflex EDM one file (25/0.08). Using the manufacturer's speed and torque settings, HyFlex EDM files have been gently operated in a gentle in-and-out motion.

Group 3 - Protaper next: Group 3 utilised Protaper Next (Dentsply Tulsa Dental, USA) rotary files to form biomechanical preparation in all root canals. The canal received the Proglider at the working length. For root canal expansion, instruments X1 (17/0.04), X2 (25/0.06) have been sequentially used until working length has been reached. Manufacturer's torque and speed specifications were strictly followed.

Group 4 - Waveone gold: Group 4 used the WaveOne Gold reciprocating file system (Dentsply, Sirona, Switzerland) for root canal preparation. Following manufacturer's instructions, instruments were sequenced: First, WaveOne Gold Glider file has been used until working length was reached. Primary 25/07 WaveOne Gold file has been used with gentle inward motion until maximum working length has been reached, followed by brushing action by the handpiece controlled by an endomotor at manufacturer's recommended torque and speed.

Group 5 - Jizai Rotary File System: Japanese Jizai rotary files from Mani Inc. were used to create root canals with a power-driven endomotor in this group. The glide path file has been set to working length per manufacturer's recommendations. The 25/.04 instrument was thereafter used full length. A power-driven endomotor was used for all instrumentation, following the manufacturer's speed and torque specifications.

SEM analysis and dentinal defects:

- After preparation, teeth were sectioned at 3mm, 6mm, and 9mm from the apex and dehydrated for SEM evaluation. Two experienced observers independently assessed the photos under single-blindness. In accordance to Wilcox et al. (1997), dentinal defects have been classified as 'no defect', 'fracture', 'all other defects'.
- **No defect: -** Root dentine devoid of any lines or cracks where both the external surface of the root and the internal root canal wall had no defects (Figure 1a).

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- **Fracture: -** A line extending from the root canal space to the outer surface of the root (Figure 1b).
- **Other defects: -** All other lines observed that did not extend from the root canal to the outer root surface such as

c1) A craze line- line extending from the outer surface into the dentine that did not reach the canal lumen (Figure 1c).

c2) A partial crack - Extends from the canal wall into the dentine without reaching the outer surface of the root (Figure 1d).

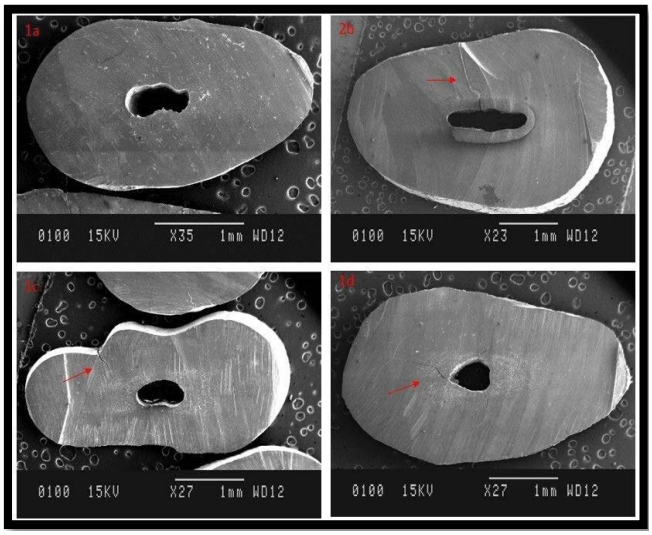

Figure 1: SEM sample demonstrating dentinal defects. 1a - No Defects, 1b – Fracture, 1c- Craze line, 1d - Partial crack

Statistical analysis

Fractures and other defects have been compared between groups utilising Fisher's Exact Tests and Chi-Square test. Statistical significance has been tested at a 5% probability level or less (i.e., the test statistics were declared to be significant if p-value is less than or equal to 0.05). Data analysis has been carried out via suitably customized computer programs as developed/ adapted in the R-language (Version 4.4.1). Additionally, percentage and number of defective roots in every group have been assessed.

Results

Results demonstrated that all the tested groups exhibited a comparable distribution of dentinal defects across middle, coronal, and apical thirds of root canal (Figure 2). This suggests that none of the evaluated file systems differed significantly in their overall ability to preserve dentinal integrity. However, middle third of root canal emerged as the most critical region, exhibiting a statistically significant increase in defect formation (p less than 0.05) as shown in table 1.

ProTaper Next (PTN) system had more middle-third dentinal microcracks than the control group. Although this localized increase was significant, the overall pattern of dentinal defects across all thirds remained similar among the different instrumentation systems.

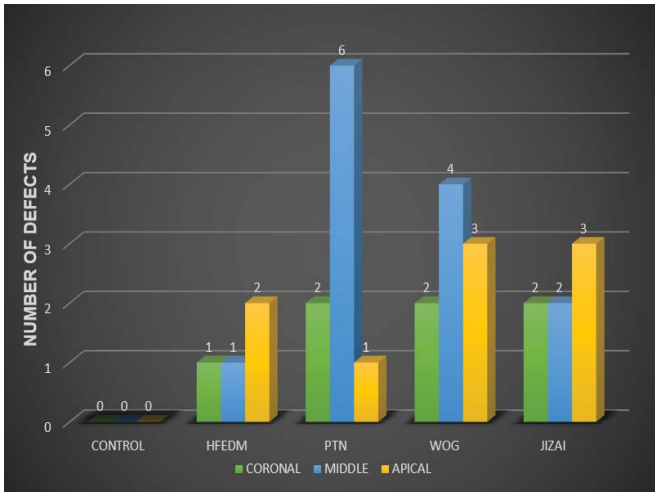

Figure 2: Master bar graph showing distribution of dentinal microcracks across all the groups.

Table 1: Number of Microcracks at Different Levels and Percentage of Roots with Microcracks per Group

Groups (n= 20)	Number of microcracks			Roots with microcracks per group (%)
	3mm	6mm	9mm	
Control	0	0*	0	0
Hyflex EDM	2	1	1	10
ProTaper Next	2	6*	1	5
WaveOne Gold	3	4	2	15
Jizai	3	2	2	15
P value	0.65	0.03	0.38	

*Symbol indicates significant difference between groups (p<0.05).

Discussion

All rotary and reciprocating groups exhibited more cracks than the hand file group, confirming that mechanical instrumentation increases dentinal stress [4,5]. PTN showed significant crack formation in the middle third, likely due to its asymmetrical rotary motion and high cutting efficiency [6,7]. WOG produced more cracks in the apical third, which may be due to its reciprocating motion and greater taper in certain sections [8]. HFEDM and Jizai showed fewer cracks, attributed to their enhanced flexibility and adaptive motion, respectively [8].

Taper plays a crucial role in crack formation. Files with larger or continuous tapers removed more dentin and increased stress, raising the risk of vertical root fractures [9,10]. Reciprocating files, although reducing torsional

fatigue, exhibited greater crack formation due to alternating stress application [11,12].

The sectioning technique presents a notable drawback due to its destructive characteristics and the potential for microcrack formation. Nevertheless, in our investigation, we hypothesized that this issue did not occur, as no microcrack defects have been observed in the control group.

SEM analysis has been chosen for its superior ability to visualize microcrack characteristics at the microscopic level, ensuring that even the smallest defects are identified with accuracy. SEM remains one of the most reliable techniques for studying microstructural changes in dentin, making it a valuable tool for our investigation [13].

The present research demonstrated that reciprocating and rotary NiTi files induced additional microcracks than manual instrumentation. Surface interaction between the instrument and dentinal walls may explain this finding. The ongoing rotational movement of rotary files creates numerous stress concentrations along the walls of root canal, potentially resulting in development of microcracks. Rotary systems stress dentinal walls more than manual instrumentation due to their continuous cutting action and higher torque, according to prior studies [4,14].

Waveone Gold and Jizai files had more apical cracks than Hyflex EDM and Protaper Next. Despite differences in geometric features among the instruments used in this study, these variations did not appear to significantly impact occurrence of microcracks.

Significant increase in dentinal defects in middle third observed with ProTaper Next could be attributed to its design and cutting efficiency. The increased torsional and flexural stress applied in this region may have contributed to microcrack formation. The other three experimental groups had middle third faults, but their distribution was not statistically significant compared to the control group. This supports previous findings that reciprocating and heat-treated NiTi files may stress dentin and cause cracks [5]. Coronal and apical thirds had similar defect distributions across groups.

Our findings confirmed that rotary NiTi instruments cause some level of damage to the dentine and result in defects within the root canal to some extent [15]. Other studies found that rotary NiTi files for root canal preparation caused more microcracks than manual files and that file designs affected microcrack severity which is consistent with this study [5].

Conclusion

In the research, all rotational methods caused dentinal microcracks. Middle section of root canal had greatest defects, statistically significant. PTN file system showed the most middle-third microcracks compared to the control group. Reciprocating files caused more cracks than continuous rotary files. No substantial defect difference was found between Hyflex EDM, Waveone Gold, and Jizai.

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