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Cleaning effectiveness of different heat-treated rotary systems

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Abstract

Objective: This study aimed to evaluate the cleaning efficacy of different rotary systems during root canal treatment.

Methods: Forty-five extracted mandibular molars were randomly divided into three groups according to the rotary system applied: Group 1, EDMax; Group 2, EdgeFile X1; and Group 3, Neoniti. The samples were irrigated with 5.25% NaOCl and normal saline as the final rinse. Roots were sectioned longitudinally and examined under scanning electron microscopy (SEM). The debris and smear that remained in the root canals were assessed using a five-score index and compared between groups and root sections. The statistical analysis was performed by Kruskal-Wallis, Friedman, Wilcoxon Signed Ranks, and Mann-Whitney U tests at $P < 0.05$.

Results: There was a statistically significant difference in debris scores between groups at the apical third ($P=0.003$), but no significant difference was found in other root sections ($P>0.05$). The sequential rotary EDMax group had more apical debris compared to the single-file reciprocating EdgeFile X1 and single-file rotary Neoniti groups ($P< 0.05$). No significant difference was observed between the study groups in smear layer scores ($P>0.05$). However, the smear layer score was significantly greater in the apical than in other root sections in all groups ($P<0.05$).

Conclusions: The single-file systems, Neoniti and EdgeFile X1, demonstrated superior cleaning efficacy compared to the sequential EDMax system in the apical third, whereas the efficacy of all systems was equivalent in other root areas. Single-file systems may be more effective for root canal cleaning, especially in areas that are more difficult to access.

Keywords: Debridement, Root canal preparation, Rotary file, Scanning electron microscope, Single file system, Smear layer

Introduction

Optimal root canal cleaning and adequate shaping are integral to successful endodontic treatment. The ultimate aim is to sufficiently clean and shape the root canal system while maintaining its original configuration (1). The smear layer, consisting of dentin, remnants of odontoblastic processes, pulp tissue, and bacteria, develops after instrumentation. The presence of the smear layer may reduce dentin permeability to disinfecting agents and jeopardize the seal of the canals (2). Despite various advancements in Nickel Titanium rotary system manufacturing, the cleaning performance and debridement quality of different rotary systems still require further research. Evaluating the cleaning efficacy of instruments is critical, as inadequate cleaning can allow microorganism colonization, leading to endodontic failure (3).

The flexibility of NiTi-based endodontic files is enhanced by heat treatment, reducing the risk of failure, ledges, and canal transportation during the preparation of curved root canals (4). Single file systems with reciprocating motion were first introduced by Yared (5) and have gained popularity in endodontics (6). The EdgeFile X1 (EdgeEndo, Albuquerque, NM, USA) is a constant tapered (6%), single file with a triangular cross-

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section and reciprocating motion. It is made of an annealed heat-treated nickel-titanium alloy with the brand name Fire-Wire™, which increases flexural strength and enhances the file's durability and flexibility. The reciprocating motion with 150° (counterclockwise) cutting action and 30° (clockwise) release may increase the fatigue resistance (7) and minimize stress and the risk of fracture (8).

The NeoNiTi file (Neolix sas, Evron, France) is a heat-treated single file rotary system with a non-homothetic rectangular cross section and continuous rotation movement. It is manufactured by a wire-cut electrical discharge machining process, resulting in sharp cutting edges and improved fatigue resistance and flexibility (9, 10).

The EDMax file (Neolix sas, Evron, France) is a rotary system with a convex triangular and modified convex cross-section in shaping and finishing files, respectively. This file has an advanced flute design that combines multiple tapers along the shaft (11).

Although previous studies have evaluated the cleaning efficacy of various heat-treated rotary systems, comprehensive comparisons among EdgeFile X1, NeoNiTi, and EDMax files are limited. The purpose of this study was to compare the cleaning efficacy of these three file systems (EdgeFile X1, NeoNiTi, and EDMax) by evaluating debris and smear layer removal after chemo-mechanical preparation, using a scanning electron microscope (SEM) analysis.

Materials and methods

This in vitro study included forty-five extracted human mandibular molars with intact distal roots of similar length. The sample size was calculated based on previous data provided by Williamson et al. (12) . The minimum sample size was established at 15 specimens per group.

The selected teeth had a root canal curvature of 0-20° as determined by Schneider's method (13). Teeth with open apices, internal or external resorption, fractures, cracks, calcification, or previous endodontic treatment were excluded. After removing calculus, debris, and soft tissue residues, the teeth were immersed in 1.5% sodium hypochlorite solution for an hour and then kept in normal saline.

Sample preparation

Access cavity preparation was accomplished using a fissure diamond bur #008 (Tizkavan, Tehran, Iran) in a water-cooled high-speed handpiece. The distal canals were initially negotiated with a #10 stainless steel K-file. The canal diameter was standardized by selecting the roots fitting a #15 K-file at the apex. The working length was determined 1 mm short of the anatomical apex.

The samples were randomly divided into three groups (n=15) based on the rotary system employed. In all groups, the rotary systems were attached to the VDW Silver Reciproc endodontic motor (VDW GmbH, Munich, Germany), and the distal canals of mandibular molars were prepared according to the manufacturer's protocol. The study groups were as follows:

Group 1: Instrumentation was accomplished using the sequential EDMax rotary system (Neolix sas, Evron, France) with two orifice shaper files (yellow (#20, taper 6%) and red (#25, taper 6%)) set at 500 rpm and 150 N.cm according to the manufacturer's instructions.

Group 2: Samples were instrumented using the EdgeFile X1 reciprocating single-file system (EdgeEndo, Albuquerque, NM, USA) (#25, taper 6%) with reciprocating and in-and-out pecking motion, according to the manufacturer's instructions.

Group 3: The preparation was performed using the Neoniti single-file system (Neolix sas, Evron, France) (#25, taper 6%) set at 300 rpm and 2 N.cm according to the manufacturer's instructions.

The irrigation protocol consisted of 3 ml of 5.25% NaOCl after each instrument used, and 5 ml of normal saline as the final rinse. The apical patency was maintained using a #10 K file.

The samples were decoronated with a water-cooled diamond disc (D&Z, Berlin, Germany). Then, the disc was used to make a groove on the buccal and lingual surfaces of the tooth. These grooves were parallel to the long axis of the tooth and the diamond disc did not penetrate the root canal, to avoid creating artificial debris. The teeth were cracked longitudinally along the grooves.

Subsequently, samples were immersed in 2% glutaraldehyde (0.1 M) for 24 hours. Fixed samples were rinsed three times with sodium cacodylate buffer solution (PH=7.2) and incubated in osmium tetroxide for an hour. Subsequently, the samples were dehydrated by a series of incremental concentrations of ethanol solutions (30%-100%) and were placed in a desiccator for at least 24 hours. After assembly on coded stubs using a silver point, the samples were sputter-coated (KYKY SBC-12, Beijing, China) with a 200 Å gold-palladium layer. Figure 1 shows a sectioned sample.

SEM evaluation

The dentinal walls of the coronal, middle and apical thirds of each prepared sample were examined under an SEM (KYKY EM3200, China) at ×200 and ×2000

Figure 1. A sample of the sectioned tooth before filling and preparation

magnifications to detect the presence of debris and smear layer, respectively. Each SEM image was independently evaluated by three endodontists (MN, YS and BZ) and scored in terms of the amount of residual debris and smear layer using the five-score index provided by Hulsmann et al. (14), as described in Tables 1 and 2, respectively. Evaluators were blind to the group allocation so the type of utilized rotary system could not be identified. Inter-examiner reliability was assessed using the kappa coefficient.

Statistical analysis

Data were analyzed using IBM SPSS version 25 software (IBM Inc., NY, USA). The frequency of debris and smear layer scores in different groups was compared using the Kruskal-Wallis test. In case of a statistically significant difference, pair-wise comparisons were performed using Mann-Whitney U test. The debris and smear layer scores in the coronal, middle and apical areas of different groups were compared using the Friedman test followed by the Wilcoxon Signed Ranks test. P-value less than 0.05 was considered statistically significant.

Results

Kappa values revealed a strong agreement (85-92%) between evaluators regarding debris and smear layer scores.

Comparison of debris scores between different groups and root sections

Table 3 presents the distribution of debris scores obtained in the coronal, middle, and apical thirds after root canal instrumentation by different rotary systems. The Kruskal-Wallis test revealed a statistically significant difference in debris scores between different rotary

Table 1. Hulsmann scores for residual debris

Smear layer score	Definition
Score 1	Clean root canal wall and only a few small debris particles
Score 2	A few small agglomerations of debris
Score 3	Many agglomerations of debris covering <50% of the root canal wall
Score 4	More than 50% of the root canal walls were covered with debris
Score 5	Complete or nearly complete root canal wall coverage with debris

Table 2. Hulsmann scores for remained smear layer

Smear layer score	Definition
Score 1	No smear layer and all dentinal tubules were open
Score 2	A small amount of smear layer, and some dentinal tubules were open
Score 3	Homogeneous smear layer covering the root canal wall, and only a few dentinal tubules open
Score 4	Complete root canal wall covered by a homogeneous smear layer and no open dentinal tubules were observed
Score 5	Heavy, homogeneous smear layer covering the complete root canal wall.

Table 3. Mean ± standard deviation (SD), median, minimum and maximum values of debris layer scores among the groups

Rotary systems	Location						P value^
	Coronal		Middle		Apical		
	Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	
EDMax	1.93 ± 0.91[a]	2 (1-3)	1.86 ± 0.66[a]	2 (1-3)	2.64 ± 1[Ab]	2 (1-4)	<0.001
EdgeFileX	1.87 ± 0.74	2 (1-3)	1.93 ± 0.79	2 (1-3)	1.8 ± 0.77[B]	2 (1-3)	0.22
Neoniti	1.73 ± 0.88	1 (1-3)	1.93 ± 0.7	2 (1-3)	1.67 ± 0.48[B]	1 (1-2)	0.19
P-value*	0.14		0.34		0.003		

*Friedman Test
^Kruskal-Wallis test
Different letters indicated statistically significant difference between groups at P<0.05.

systems at the apical third (P=0.003). The differences in the middle (P=0.34) and coronal thirds (P=0.14) were statistically insignificant. Pair-wise comparisons between groups revealed significant differences in the apical debris between the EDMax and EdgeFile X1 (P=0.046) and also between EDMax and Neoniti (P=0.025) groups, whereas no significant difference was found between the EdgeFile X1 and Neoniti (P=1.00) groups.

Intragroup comparisons of debris scores indicated a statistically significant difference between the apical with coronal and middle thirds in the EDMax group (P<0.05). However, no significant differences in debris scores were observed between different root sections in the EdgeFile X1 (P=0.22) and Neoniti (P=0.19) groups.

Comparison of smear layer scores between different groups and root sections

Table 4 presents the distribution of debris scores obtained in the coronal, middle, and apical thirds after root canal instrumentation by different rotary systems. There was no statistically significant difference between the three groups in terms of smear layer scores in the apical, middle and coronal thirds (>0.05; Table 4).

Intragroup comparisons of smear layer scores using the Friedman test revealed a significant difference between root sections in all groups (P<0.05). Pairwise comparisons revealed that the smear layer score was significantly greater in the apical than the other root sections in all study groups (P<0.05, Table 4).

Figure 2 displays SEM micrographs of the canals prepared with different rotary systems.

Discussion

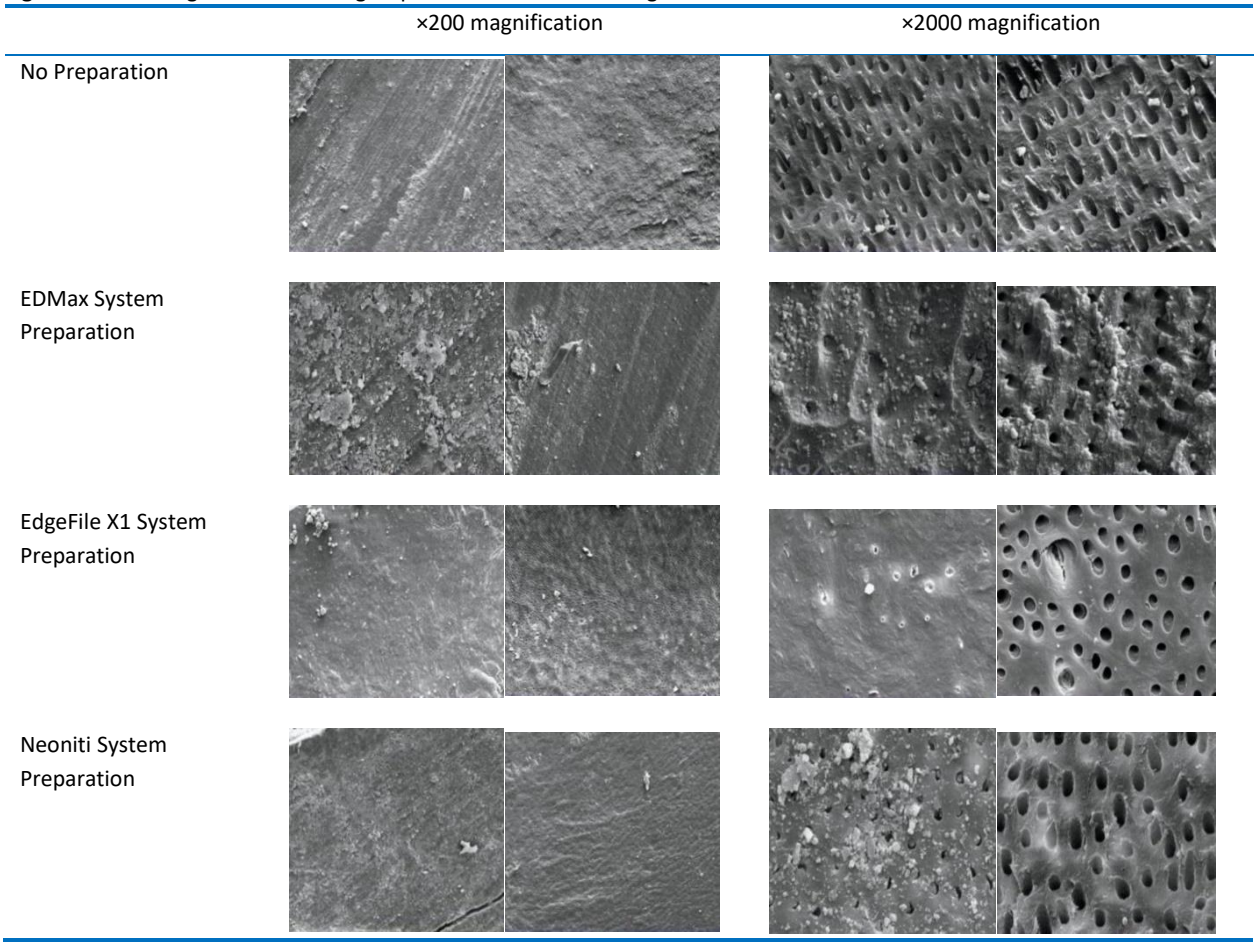
This in vitro study compared the cleaning efficacy of three different heat-treated rotary systems by evaluating the amount of smear layer and debris removed using SEM analysis. The rotary systems evaluated in this study were a sequential rotary EDMax, a single Neoniti file with rotary motion, and a single EdgeFile X1 with reciprocating motion. To evaluate the precise effect of these systems, only the distal canals of mandibular molars were instrumented in this study. The scanning electron microscope method was used in the present study because it provides excellent details of the surface of the root canal walls. However, the ability of

Table 4. Mean ± standard deviation (SD), median, minimum and maximum values of smear layer scores among the groups

Rotary systems	Location						P value*
	Coronal		Middle		Apical		
	Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	Mean ± SD	Median (Min-Max)	
EDMax	1.68 ± 0.84[a]	1 (1-3)	2.14 ± 0.86[b]	2 (1-3)	2.93 ± 0.91[c]	3 (2-5)	<0.001
EdgeFileX	1.8 ± 0.86[a]	2 (1-3)	1.93 ± 0.79[a]	2 (1-3)	2.4 ± 0.91[b]	3 (1-4)	0.001
Neoniti	1.87 ± 0.83[a]	2 (1-3)	1.93 ± 0.7[a]	2 (1-3)	2.47 ± 0.99[b]	3 (1-4)	0.001
P-value^	0.22		0.06		0.29		

*Friedman Test
^Kruskal-Wallis test
Different letters indicated statistically significant difference between groups at P<0.05.

Figure 2. SEM images of the tested groups at 200X and 2000X magnification



SEM analysis to reveal the penetration of debris into the dentinal tubules is limited (15). There is some controversy regarding the preservation or removal of smear layer. However, most authors believe that the success of root canal treatment in infected root canals depends on the elimination of smear layer, because the smear layer may contain infected tissues and interfere with medicament penetration and sealer adhesion (16, 17) .

In the present study, none of the rotary systems surveyed were able to clear the canals completely. This finding is consistent with the results of several studies (2, 10) and emphasizes the indispensable role of irrigants in the complete debridement of root canals (18).

The three systems showed comparable efficacy in cleaning debris in the coronal and middle thirds. This finding can be attributed to the larger diameter of dentinal tubules in coronal regions exposed to increased volume of irrigants, and the same size and taper of final files used in different groups (#25, taper 6%). In the apical third, however, debris accumulation was significantly greater in the EDMax rotary system compared to EdgeFile X1 and Neoniti systems. This finding highlights the better performance of single-file systems in apical root areas. The lower efficacy of sequential EDMax files in debris removal in the apical root third may be due to variable tapers and triangular convex cross-sections of files which may increase debris accumulation in apical root thirds. No significant differences were observed between the two single file systems (EdgeFile X1 and Neoniti) concerning the debris removal scores.

The intragroup assessment of the debris index revealed a significantly greater debris score in the apical third of the EDMax sequence group as compared to the middle and apical third areas. The EdgeFile X1 or Neoniti groups showed no significant difference in debris score between different root sections.

The outcomes of this study are contrary to the results of De-Deus et al. (19), who reported that a single F2 Protaper file in reciprocation exhibited poor quality of debris removal in the apical third compared to full sequence Protaper files. Saraf et al. (20) found that the Protaper full sequence system in rotary motion resulted in the cleanest canal in the apical third. In contrast, a single F2 file in reciprocating motion showed the greatest amount of debris at the coronal and apical

thirds. The better cleaning efficacy observed in these studies may be attributed to the final taper of 8% in the Protaper system, which allows deeper irrigation penetration (21), whereas, in the present study, the shaping file of the EDMax system was used (#25, taper 6%). Therefore, in the apical third, the EDMax system was less flexible. On the other hand, the advanced flute design of this system with multiple tapers along the shaft may cause more debris removal in the first two-thirds of the canal, resulting in more debris accumulation in the apical third.

No significant difference in smear layer scores was observed between groups at root sections. A significant difference in smear layer scores was observed between the middle and apical thirds in all three groups, with the apical area showing significantly greater smear layer scores than the middle and coronal root thirds. Therefore, irrespective of the rotary system, a greater smear layer is present in the apical root areas.

Previous studies have investigated debris and smear layer removal of different rotary systems and reported different results. Ashraf et al. (22) compared three rotary Instruments Neo NiTi, 2Shape and Revo_S. They concluded that residual debris of the 2Shape system in the apical region was significantly higher than the other two systems. They also found that the amount of smear layer in the coronal third was significantly higher than in the other two areas, contrary to this study's results. Chatterjee et al. (23) evaluated the debris and smear layer formation after canal preparation using the ProTaper Universal rotary file, twisted file, and XP Endo file. They concluded that the greatest and least amount of debris and smear layer was formed by the ProTaper Universal rotary and XP Endo file, respectively. Alobaidy et al. (24) compared the debris removal of 2Shape, HyFlex EDM, and Protaper Gold rotary systems. They found that the 2Shape system was significantly less effective than the HyFlex EDM and Protaper Gold systems at all root canal levels. The differences in the results may be attributed to using different rotary systems, different root canals with various degrees of curvature, and the applied irrigation protocol.

The *in vitro* design of this study may not fully replicate clinical conditions. The limited sample size and the focus on mandibular molars' distal canals may affect the findings' generalizability. The SEM method, while detailed, cannot show the full extent of debris penetration into dentinal tubules. Future studies should include a larger sample size and various tooth types to compare the cleaning efficacy of various rotary systems. Investigating the impact of different irrigation protocols in conjunction with various rotary files could provide a more comprehensive understanding of the cleaning efficacy of the instrumentation protocol. Additionally, in vivo studies would be valuable in confirming the clinical relevance of these findings.

Conclusions

Based on the results of this study

1- None of the tested rotary systems were able to completely clean the canals.
2- The sequential EDMax rotary system indicated a greater debris score in the apical third compared to EdgeFile X1 and Neoniti systems. Furthermore, the debris index was significantly greater in the apical than in the coronal and middle thirds in the EDMax group.
3- In all rotary systems, the smear layer score was significantly greater in the apical than in the other root sections.
4- Overall, the cleaning efficacy of both reciprocating and continuous rotation single-file systems was comparable to or even better than the sequential EDMax system.

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None

Conflict of interest

The authors declare no conflict of interest.

Authors' contributions

MN, YSH, and BZ conducted the study conception and design. MN edited and reviewed the study. AN conducted the experimental procedures and literature review. SS conducted experimental procedures. LE prepared the manuscript and reviewed the literature.

Ethical approval

The study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1398.199).

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