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ORIGINAL RESEARCH

Comparative Evaluation of Cleaning Efficacy using Four Novel Nickel–titanium Rotary Instruments: An *in vitro* Scanning Electron Microscope Study

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ABSTRACT

Aim: The aim of the study was to compare the cleaning efficacy (debris and smear layer removal) of two multifile rotary systems (MTwo and Silk) and two single-file rotary systems (F6 Skytaper and NeoNiTi).

Materials and methods: Eighty mesial canals of mandibular first molars were cleaned and shaped using four nickel–titanium (NiTi) rotary instruments to size # 25 and 3% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA). Samples were randomly divided into four equal groups (n = 20) according to instrumentation: Group I, Mtwo; group II, Silk; group III, F6 Skytaper; group IV, NeoNiTi. Samples were split longitudinally and examined under scanning electron microscope (SEM) for debris and smear layer removal in coronal, middle, and apical thirds of each root canal.

Results: F6 skytaper and Mtwo groups showed significantly higher debris removal than Silk and NeoNiTi groups in apical third of root canal as well as when compared with NeoNiTi group in middle third. F6 Skytaper group showed significantly higher debris and smear layer removal than Silk group in coronal third. There was statistically significant difference among all thirds of root canal in terms of debris removal in Silk and NeoNiTi groups. There was statistically significant difference among all thirds of root canal in F6 Skytaper and NeoNiTi groups in terms of smear layer removal.

Conclusion: F6 Skytaper single-file rotary instrumentation showed the maximum cleaning efficacy followed by Mtwo multifile rotary instrumentation in all thirds of root canal.

Clinical significance: F6 Skytaper rotary instrument is most efficient followed by Mtwo rotary instrument among all rotary instruments.

Keywords: Debris, F6 Skytaper, Mtwo, NeoNiTi, Original research, Silk, Smear layer.

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INTRODUCTION

Contemporary methods of root canal instrumentation produce smear layer on the canal walls. Smear layer in endodontics may interfere with action of irrigants, intracanal medicaments, close adaptation of root filling materials to canal walls, adhesion, and penetration of root canal sealers.[1-4] Elimination of residual pulp tissue and removal of debris are of paramount importance to the success of root canal treatment.[5]

Rotary nickel–titanium (RNT) instruments represent a relatively new approach for rapid and simplified canal preparation to fulfill these objectives.[6] During the past few years, RNT instruments with advanced blade designs have been developed to improve cleaning efficiency during root canal preparation. Among them, Mtwo file is one of the widely recommended RNT systems.[7-9] The instrument has positive rake angles, S-shaped cross section, and two sharp cutting edges with minimal radial contact providing maximum space for debris removal.[10]

Silk files (Mani) are anatomy-based novel RNT file system with silky smooth tactile feel. Silk files are available in simple, standard, and complex packs, each

containing three instruments. It is unique cross-sectional tear drop design cuts exceptionally well and resists fracture, which eliminates the "screwing-in" effect common with many other systems, while removing debris effectively and reducing instrument stress. Groundbreaking proprietary heat treatment provides excellent flexibility without sacrificing efficiency and safety.[11]

Single-file rotary systems are gaining increasing popularity because of more efficient and less time-consuming biomechanical preparation. F6 Skytaper (Komet Brasseler GmbH and Co, Lemgo, Germany) file is a novel RNT single-file system with S-shaped cross section and two sharp cutting edges.[12] This file system is available in five different sizes (20, 25, 30, 35, and 40) with a constant taper of 0.06.

NeoNiTi file (Neolix, France) is another novel RNT single-file system, manufactured using Electric Discharge Machining technology, which claims to improve its fatigue resistance, variable changing profiles, progressive flexibility, and results in sharp cutting edges. It is an efficient file system to shape the root canal completely to a continuously tapering funnel shape. It has nonhomothetic rectangular cross section. This file system consists of two files: NeoNiTi C1 for coronal enlarging and NeoNiTi A1 for canal shaping upto the apex.[13]

So far very little information exists about the cleaning efficacy of F6 Skytaper. Also no studies had been conducted evaluating cleaning efficacy of Silk and NeoNiTi files. The purpose of this study was to compare the cleaning efficacy of two multifile RNT systems (MTwo and Silk) and two single-file RNT systems (F6 Skytaper and NeoNiTi) by evaluating the debris and smear layer removal after chemomechanical preparation using SEM.

MATERIALS AND METHODS

Forty extracted human mandibular first molars with root curvature (10–20°) were selected.[14] Only mesial canals were included in the study. Conventional access opening was done. After access opening, glide path preparation was done with # 15 K hand files. The instrumentation was carried out using a 16:1 gear reduction handpiece powered by a torque-controlled electric motor (X-Smart; Dentsply, Maillefer, California, USA). To standardize, all the canals were enlarged to size # 25. About 3% NaOCl was used as an intracanal irrigant in between each file size for the experimental samples. Final irrigation of the samples was done with 17% EDTA (1 mL) and 3% NaOCl (3 mL), followed by normal saline (3 mL).[15] The teeth were randomly divided into four groups based on RNT file system used for instrumentation, each containing 20 mesial canals:

1. *Group I*: Mtwo
2. *Group II*: Silk
3. *Group III*: F6 Skytaper
4. *Group IV*: NeoNiTi.

The instrumentation sequence, speed, and torque for each instrument group were followed according to the manufacturer's recommendation. This study design was based on previous published literature by Schäfer et al,[7] and Bidar et al,[8] where MTwo was used as a standard for comparison but included in the experimental group.

Group I

Canals were prepared by introducing each Mtwo file directly to working length (WL), maintaining speed of 280 rpm, and torque 1.2 Ncm using a gentle in and out movement in the following sequence:

- # 10, 0.04 taper
- # 15, 0.05 taper
- # 20, 0.06 taper
- # 25, 0.06 taper.

Group II

Silk file complex pack was used for instrumentation of moderately curved canals. Canals are prepared with crown-down technique, maintaining speed of 500 rpm and torque 3 Ncm using a gentle in and out movement in the following sequence:

- # 25, 0.08 taper instrument used at coronal third
- # 20, 0.04 taper instrument used at WL
- # 25, 0.04 taper instrument used at WL.

Group III

Canals are prepared with a single # 25, 0.06 taper F6 Skytaper file directly to WL, maintaining speed of 300 rpm and torque 2.2 Ncm using a gentle in and out movement.

Group IV

Canals are prepared with NeoNiTi C1 and NeoNiTi A1 files maintaining speed of 300 rpm and torque of 1.5 Ncm in the following sequence:

- # 25, 0.12 taper NeoNiTi C1 is used for coronal enlargement.
- # 25, 0.06 taper NeoNiTi A1 is used for shaping middle and apical thirds.

NeoNiTi A1 file is used till the middle thirds using three or four circumferential brushing actions and used till the WL using pecking motion.

Scanning Electron Microscope Preparation

Decoronation of samples was done at cementoenamel junction by using a diamond disk with water cooling leaving mesial root segments. Diamond disks were used to prepare grooves on buccal and lingual surface of

roots. At this time, a master cone of 25 size 6% taper was constantly placed within the canal to prevent accidental contamination of the canal with dentin debris. Chisel and mallet are used for splitting the roots into two halves. The samples were prepared for SEM. Photomicrographs at 2000×, 5000×, and 10,000× magnifications were taken at coronal, middle, and apical thirds of root canal for debris and smear layer evaluation. The cleanliness was evaluated by means of a numerical evaluation scale proposed by Hülsmann et al[16] and criteria for the scoring were the following:

Debris Score

- *Score* 1: Clean root canal wall, only few small debris particles.
- *Score* 2: Few small agglomerations of debris.
- *Score* 3: Many agglomerations of debris covering less than 50% of the root canal wall.
- *Score* 4: More than 50% of the root canal wall covered by debris.
- *Score* 5: Complete or nearly complete root canal wall covered by debris.

Smear Layer Score

- *Score* 1: No smear layer, dentinal tubules open.
- *Score* 2: Small amount of smear layer, some dentinal tubules open.
- *Score* 3: Homogeneous smear layer covering the root canal wall, only few dentinal tubules open.
- *Score* 4: Complete root canal wall covered by a homogeneous smear layer, no open dentinal tubules.
- *Score* 5: Heavy, nonhomogeneous smear layer covering the complete root canal wall.

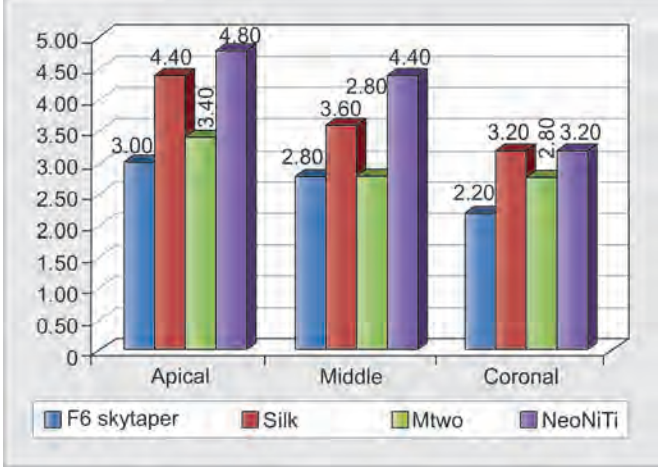
The data were statistically analyzed by using the Kruskal–Wallis test and the Mann–Whitney U test using Statistical Package for the Social Sciences version 20 software and the significance was set at p = 0.05.

RESULTS

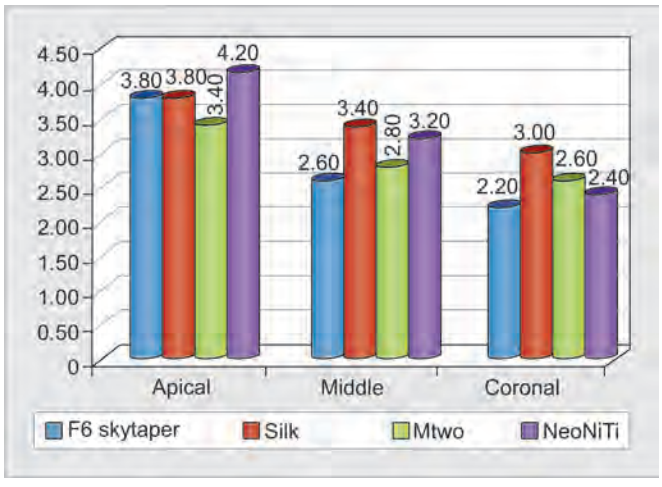
F6 Skytaper group showed lowest average debris and smear layer scores in all thirds of root canal. Mtwo group showed almost similar average debris and smear layer scores to that of F6 Skytaper group. NeoNiTi group showed highest debris scores in all thirds of root canal and highest smear layer scores in apical third. Silk group showed highest smear layer scores in middle and coronal thirds. Coronal third showed lowest debris and smear layer scores and apical third showed highest debris and smear layer scores in all groups (Graphs 1 and 2).

F6 Skytaper and MTwo groups showed significantly higher debris removal compared with Silk and NeoNiTi instrumentation groups in the apical third of the root canals. F6 Skytaper and MTwo groups resulted in significantly higher debris removal than NeoNiTi group in the middle third. F6 Skytaper group resulted in significantly higher debris and smear layer removal than Silk group in the coronal third. There was no statistically significant difference among F6 Skytaper and Mtwo groups (Tables 1 and 2). So F6 Skytaper group showed highest cleaning efficacy followed by Mtwo group among all groups in all thirds of root canal. Mtwo group showed almost similar cleaning efficacy to that of F6 Skytaper group (Figs 1 and 2). There was no statistically significant difference among Silk and NeoNiTi groups in terms of debris and smear layer removal, so both groups resulted in poor cleaning efficacy (Figs 3 and 4).

In F6 Skytaper group there was statistically significant difference in smear layer removal among apical and middle thirds ($p < 0.0005$) as well as apical and coronal thirds ($p < 0.0118$) of root canal. In NeoNiTi group, there



Graph 1: Comparison of four rotary instruments at three regions of root canal with respect to mean debris scores



Graph 2: Comparison of four rotary instruments at three regions of root canal with respect to mean smear layer scores

Table 1: Comparison of four rotary instruments at three regions with respect to debris scores by Kruskal–Wallis ANOVA and pairwise comparison by Mann–Whitney U-test

	Apical				*Middle*				*Coronal*			
Materials	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*
F6 Skytaper	3.00	0.94	3.00	11.10	2.80	0.92	2.50	14.80	2.20	0.63	2.00	14.10
Silk	4.40	0.70	4.50	25.25	3.60	1.26	4.00	22.20	3.20	1.03	3.00	24.40
Mtwo	3.40	1.17	3.00	15.35	2.80	1.40	2.50	15.40	2.80	1.32	2.00	19.40
NeoNiTi	4.80	0.42	5.00	30.30	4.40	0.84	5.00	29.60	3.20	1.14	3.00	24.10
H-value	18.7360				11.2260				5.7080			
p-value	0.0001*				0.0110*				0.1270			
Pair-wise comparisons by Mann–Whitney U-test												
F6 Skytaper *vs* Silk	p = 0.0052*				p = 0.1509				p = 0.0376*			
F6 Skytaper *vs* Mtwo	p = 0.3868				p = 0.9367				p = 0.3830			
F6 Skytaper *vs* NeoNiTi	p = 0.0003*				p = 0.0023*				p = 0.0348*			
Silk *vs* Mtwo	p = 0.0353*				p = 0.1846				p = 0.4046			
Silk *vs* NeoNiTi	p = 0.1483				p = 0.1276				p = 0.9372			
Mtwo *vs* NeoNiTi	p = 0.0032*				p = 0.0099*				p = 0.3857			

*p < 0.05; SD: Standard deviation; H: Planck constant; P: Probability; ANOVA: Analysis of variance

Table 2: Comparison of four rotary instruments at three regions with respect to smear layer scores by Kruskal–Wallis ANOVA and pairwise comparison by Mann–Whitney U-test

	Apical				*Middle*				*Coronal*			
Materials	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*
F6 Skytaper	3.80	0.79	4.00	20.00	2.60	0.97	2.50	16.10	2.20	0.63	2.00	16.30
Silk	3.80	0.63	4.00	20.20	3.40	1.07	3.00	24.30	3.00	0.82	3.00	26.60
Mtwo	3.40	0.97	3.50	15.80	2.80	1.03	3.00	18.60	2.60	0.84	2.00	20.80
NeoNiTi	4.20	0.63	4.00	26.00	3.20	0.79	3.00	23.00	2.40	0.70	2.00	18.30
H-value	4.5390				3.4880				5.4010			
p-value	0.2090				0.3220				0.1450			
Pair-wise comparisons by Mann–Whitney U-test												
F6 Skytaper *vs* Silk	p = 0.9397				p = 0.1306				p = 0.0494*			
F6 Skytaper *vs* Mtwo	p = 0.3784				p = 0.6355				p = 0.3431			
F6 Skytaper *vs* NeoNiTi	p = 0.2176				p = 0.1527				p = 0.6540			
Silk *vs* Mtwo	p = 0.3246				p = 0.2717				p = 0.2561			
Silk *vs* NeoNiTi	p = 0.1681				p = 0.7502				p = 0.0837			
Mtwo *vs* NeoNiTi	p = 0.0505				p = 0.3810				p = 0.5919			

*p < 0.05; SD: Standard deviation; H: Planck constant; P: Probability; ANOVA: Analysis of variance

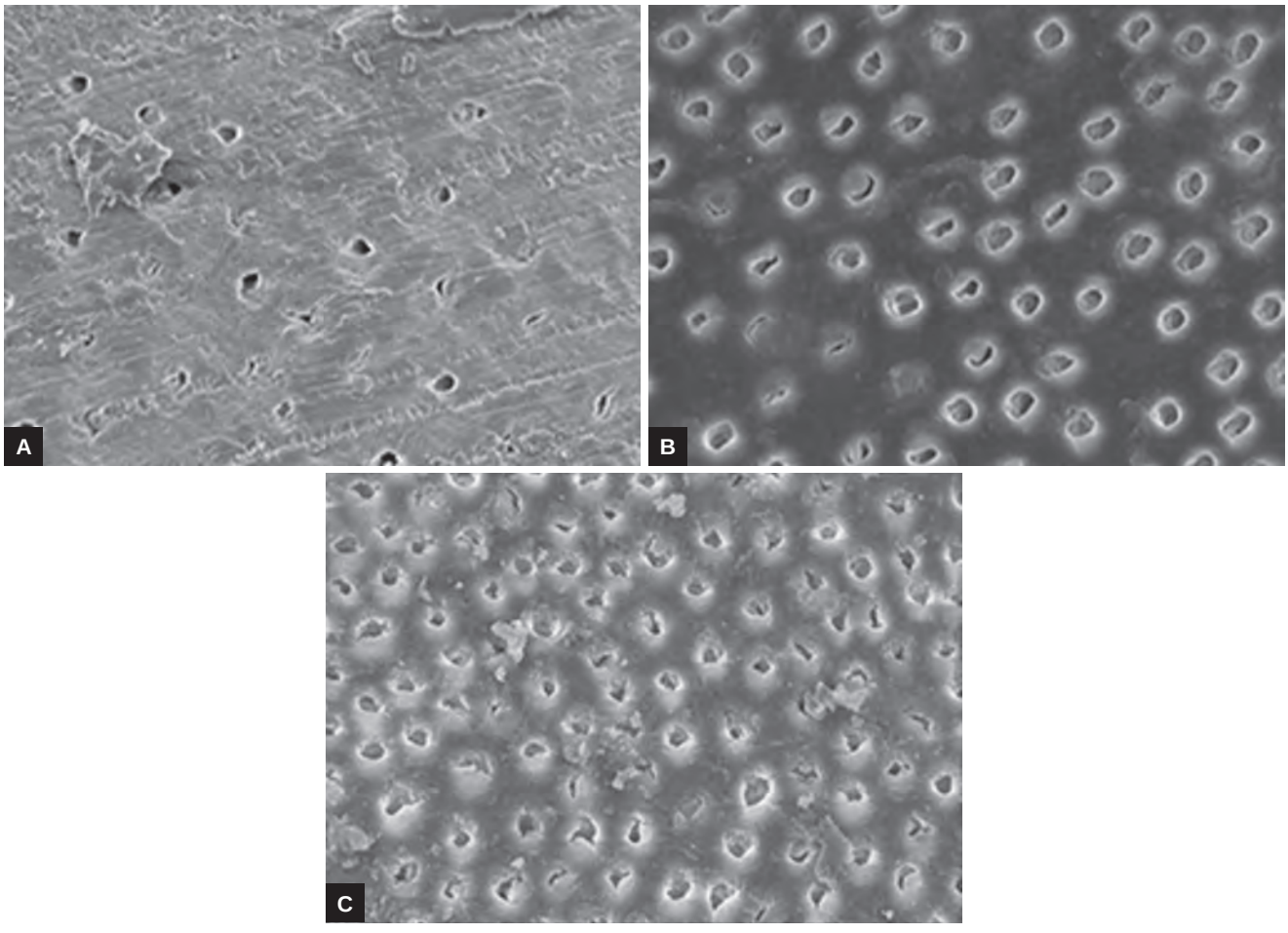
was statistically significant difference in smear layer removal among apical and coronal thirds (p = 0.0090), among apical and middle thirds (p = 0.0004), and among middle and coronal thirds (p = 0.0285). In NeoNiTi group, there was statistically significant difference in debris removal among apical and middle thirds (p = 0.0026) and middle and coronal thirds (p = 0.0212) of root canal. In Silk group, there was statistically significant difference in debris removal among apical and middle thirds (p = 0.0117) of root canal (Tables 3 and 4).

DISCUSSION

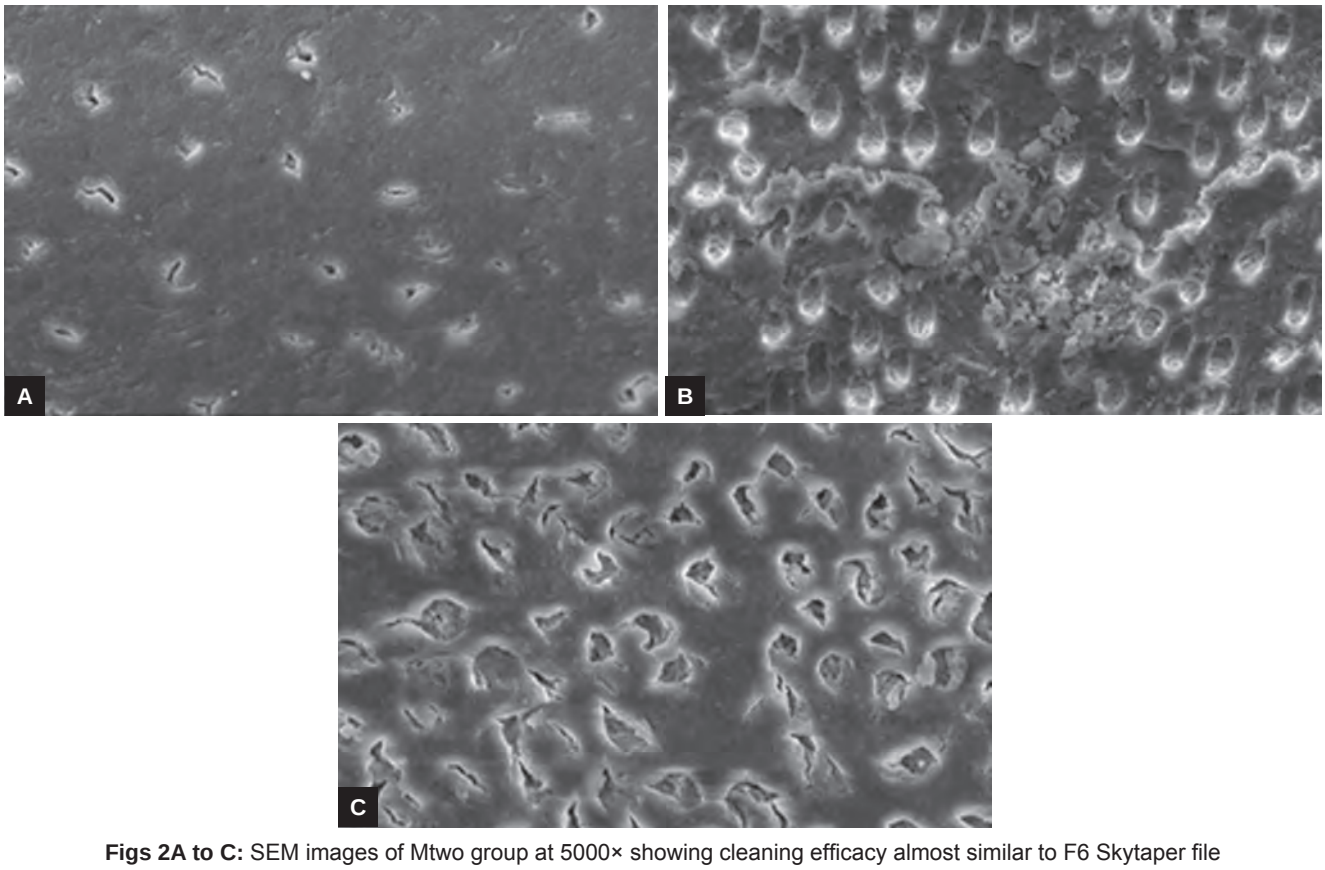
The ability to clean effectively the endodontic space is dependent on both instrumentation and irrigation. Endodontic instruments may vary in their debris and smear layer removal efficacy due to their specific flute design. Irrigation plays a key role in successful debridement and disinfection. Sodium hypochlorite is an antibacterial irrigant solution capable of dissolving organic tissue; however, it cannot remove inorganic smear layer.[16] Therefore, a combination of NaOCl and EDTA has been recommended to effectively remove both the organic tissues and inorganic smear layer.[17-19] All canals were prepared up to International Organization for Standardization # 25 which is in accordance with previous studies.[20]

It is desirable to remove both debris and smear layer due to its potential deleterious effects.[15,16,21]

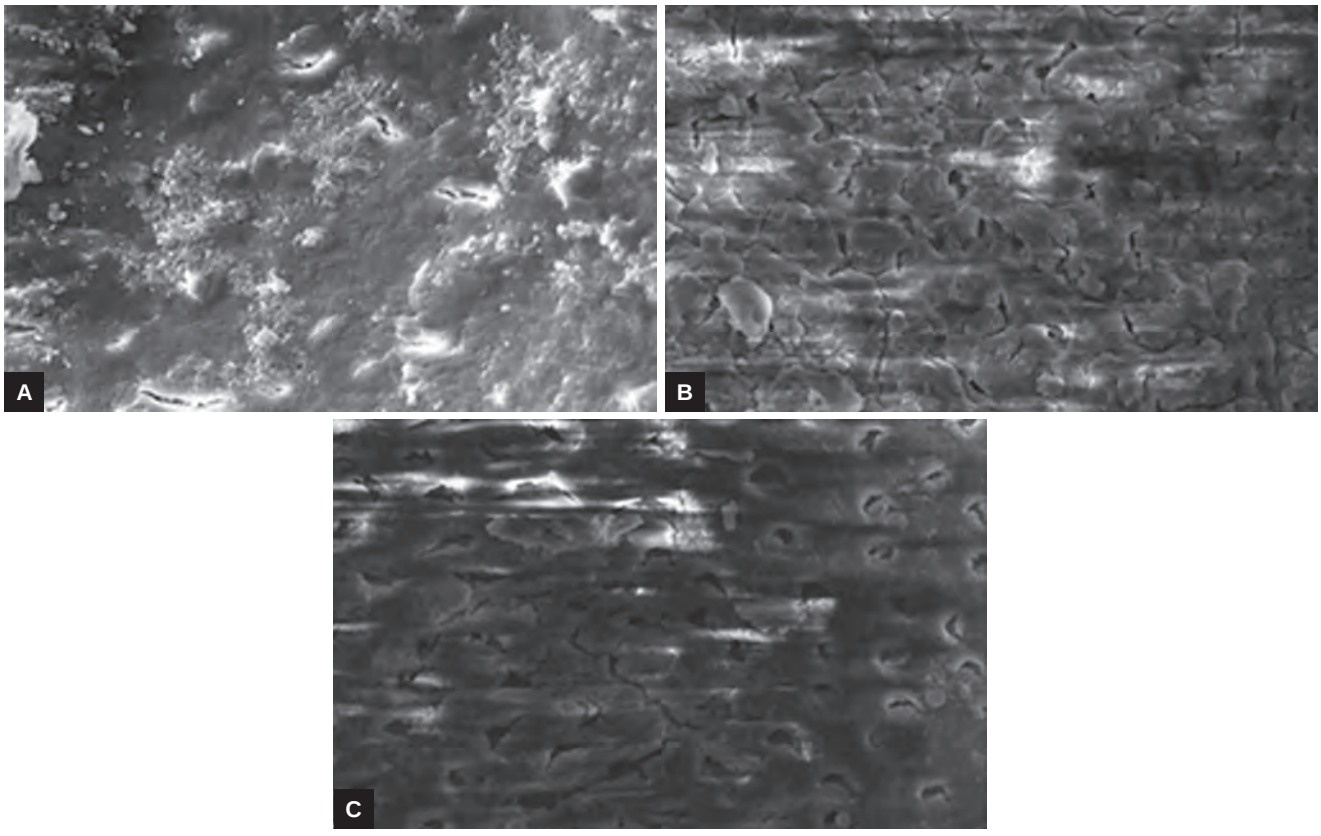
Mtwo system was chosen as a standard for comparison in this study due to their popularity and published research evaluating these systems.[7-9] NeoNiTi single file was used for comparison with F6 Skytaper single file



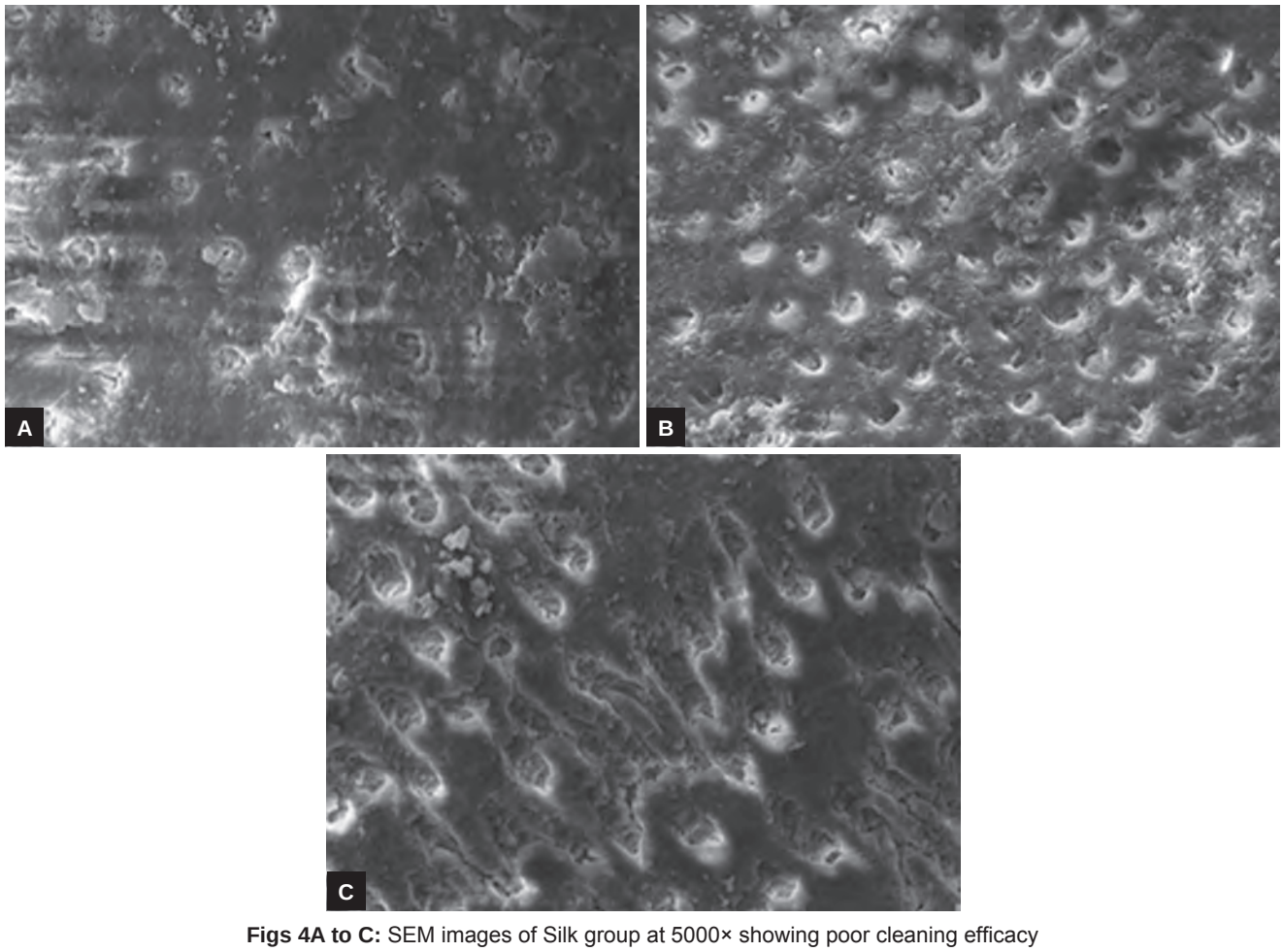
Figs 1A to C: SEM images of F6 Skytaper group at 5000× showing highest cleaning efficacy



Figs 2A to C: SEM images of Mtwo group at 5000× showing cleaning efficacy almost similar to F6 Skytaper file



Figs 3A to C: SEM images of NeoNiTi group at 5000× showing poor cleaning efficacy



Figs 4A to C: SEM images of Silk group at 5000× showing poor cleaning efficacy

Table 3: Comparison of three regions in four rotary instruments with respect to debris scores by Kruskal–Wallis ANOVA and pairwise comparison by Mann–Whitney U-test

	F6 sky taper				*Silk*				*Mtwo*				*NeoNiTi*			
Regions	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*
Apical	3.00	0.94	3.00	18.40	4.40	0.70	4.50	20.50	3.40	1.17	3.00	18.20	4.80	0.42	5.00	20.40
Middle	2.80	0.92	2.50	16.60	3.60	1.26	4.00	14.70	2.80	1.40	2.50	14.20	4.40	0.84	5.00	17.20
Coronal	2.20	0.63	2.00	11.50	3.20	1.03	3.00	11.30	2.80	1.32	2.00	14.10	3.20	1.14	3.00	8.90
H-value	3.8870				6.0410				1.4850				10.8800			
p-value	0.1430				0.0490*				0.4760				0.0040*			
Pair-wise comparisons by Mann–Whitney U-test																
Apical *vs* coronal	p = 0.6248				p = 0.1494				p = 0.3322				p = 0.2604			
Apical *vs* middle	p = 0.0598				p = 0.0117*				p = 0.2611				p = 0.0026*			
Middle *vs* coronal	p = 0.1550				p = 0.4337				p = 0.9683				p = 0.0212*			

*p < 0.05; ANOVA: Analysis of variance

Table 4: Comparison of three regions in four rotary instruments with respect to smear layer scores by Kruskal–Wallis ANOVA and pairwise comparison by Mann–Whitney U-test

	F6 sky taper				*Silk*				*Mtwo*				*NeoNiTi*			
Regions	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*	*Mean*	*SD*	*Median*	*Mean rank*
Apical	3.80	0.79	4.00	23.10	3.80	0.63	4.00	19.40	3.40	0.97	3.50	19.35	4.20	0.63	4.00	23.20
Middle	2.60	0.97	2.50	13.50	3.40	1.07	3.00	15.20	2.80	1.03	3.00	14.65	3.20	0.79	3.00	15.00
Coronal	2.20	0.63	2.00	9.90	3.00	0.82	3.00	11.90	2.60	0.84	2.00	12.50	2.40	0.70	2.00	8.30
H-value	13.0840				4.0660				3.4970				15.7750			
p-value	0.0010*				0.1310				0.1740				0.0001*			
Pair-wise comparisons by Mann–Whitney U-test																
Apical *vs* coronal	p = 0.0118*				p = 0.2978				p = 0.2210				p = 0.0090*			
Apical *vs* middle	p = 0.0005*				p = 0.0346				p = 0.0662				p = 0.0004*			
Middle *vs* coronal	p = 0.3246				p = 0.4271				p = 0.5726				p = 0.0285*			

*p < 0.05; ANOVA: Analysis of variance

because the latter has resulted in good debridement of canals in earlier study.[12]

The SEM was chosen as it has been proven to be more sensitive and specific in evaluating the cleaning efficiency.[7,8,10,12] First molars were used because mesial roots of these teeth have maximum evidence of curvature in literature.[15]

The purpose of this study was to compare the cleaning efficacy of two multifile nickel–titanium rotary systems (MTwo and Silk) and two single-file systems (F6 Skytaper and NeoNiTi) by evaluating the debris and smear layer removal after chemomechanical preparation using SEM.

In the present study, it was observed that none of the instrumentation groups had completely cleaned root canal, which is in accordance with previous studies.[7,8,16,22] In the present study, apical third of the canals was less clean than the middle and coronal thirds in all instrumentation groups, which is in accordance with previous studies.[10,20,23] This result might be due to less accessibility of irrigants to the most narrowest apical region when compared with middle and coronal regions. In F6 Skytaper group, there was statistically significant difference in smear layer removal among apical and middle thirds ($p < 0.0005$) as well as apical and coronal thirds ($p < 0.0118$) of root canal. In NeoNiTi group, there was statistically significant difference in smear layer removal among apical and coronal thirds ($p = 0.0090$), among apical and middle thirds ($p = 0.0004$), and among middle and coronal thirds ($p = 0.0285$). This result is in accordance to the study done by Gambarini and Laszkiewicz[17] in which there was a statistically significant difference between all thirds of root canal, especially between the coronal and apical thirds for GT rotary instrument in terms of smear layer removal.

In NeoNiTi instrumentation group, there was statistically significant difference in debris removal among apical and middle thirds ($p = 0.0026$) and middle and coronal thirds ($p = 0.0212$) of root canal. In Silk instrumentation

group, there was statistically significant difference in debris removal among apical and middle thirds (p = 0.0117) of root canal. This result is according to the study done by Foschi et al[10] in which there was statistically significant difference between the apical third and the middle and coronal thirds for both Mtwo and Protaper instrumentation groups in terms of debris removal.

Both F6 Skytaper and Mtwo groups showed significantly higher debris removal than other groups in apical third of root canal, which is according to the study done by Saeid Zamiran et al[9] where Mtwo files removed debris and smear layer better than BioRace. This result is also according to the study done by Schäfer et al[7] in which Mtwo file resulted in better cleaning than K3 and Race files. F6 Skytaper and Mtwo groups showed significantly higher debris removal compared with NeoNiTi group in the middle third, which is in accordance to the study done by Dagna et al[12] where F6 Skytaper cleaned middle third of the canals better than F360. This result is also according to the study done by Bidar et al[8] in which Mtwo files cleaned the middle third of canals significantly compared with Race and Medin instruments. F6 skytaper group showed significantly higher debris and smear layer removal than silk group in coronal third.

Overall F6 Skytaper instrumentation showed highest cleaning efficacy among all files followed by Mtwo instrumentation in all thirds of root canal; however, there was no statistically significant difference among F6 Skytaper and Mtwo groups in terms of debris and smear layer removal. So Mtwo instrumentation showed cleaning efficacy almost similar to F6 Skytaper instrumentation. This result may be attributed to the fact that both instruments share similar file design, i.e., S-shaped cross section with two sharp cutting edges, small core diameter, and greater chip space.[12] An increasing helical pitch from tip to the shaft in Mtwo files reduces the transportation and accumulation of debris toward the apex.[10,21]

NeoNiTi file is claimed to have sharp cutting edges as a result of electric discharge machining technology. On the contrary, in the present study, NeoNiTi instrumentation resulted in lowest debris removal in all thirds of root canal, reflecting its poor cutting efficiency.[13]

Silk file is claimed to have cross-sectional teardrop design and groundbreaking proprietary heat treatment, which results in good cutting efficiency. On the contrary, in the present study, Silk instrumentation resulted in lowest smear layer removal in middle and coronal thirds of root canal, reflecting its poor cutting efficiency. Although Silk instrumentation has shown better debris removal than NeoNiTi, there was no statistically significant difference among them in debris and smear layer removal in all thirds of root canal. In this study, both Silk and NeoNiTi instrumentation showed poor cleaning efficacy.

CONCLUSION

None of the instrumentation techniques cleaned the root canal completely. F6 Skytaper single-file instrumentation showed highest cleaning efficacy followed by Mtwo multifile instrumentation in all thirds of root canal. NeoNiTi single-file and Silk multifile instrumentation showed poor cleaning efficacy. Except NeoNiTi instrumentation, all other rotary instrumentation techniques are more comfortable to work with and consumed less time for biomechanical preparation, reflecting poor cutting efficiency of NeoNiTi compared with others. Further studies should be carried out to evaluate the cleaning efficacy of NiTi rotary files used in the study design.

CLINICAL SIGNIFICANCE

F6 Skytaper rotary instrumentation is most efficient followed by Mtwo rotary instrumentation among all rotary instruments.

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