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Evaluation of Surface Characteristic Changes of Reciproc, waveOne and WaveOne Gold Single Reciprocating Files Using Scanning Electron Microscopy before and after use: An in-vitro Study.

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ABSTRACT

Background: The purpose of this study was to evaluate surface characteristics of Reciproc (R25) WaveOne (WO) &WaveOne Gold (WOG) files using SEM before and after use. **Methods:** fifteen primary files from each system were scanned for surface defects before instrumentation at 10x-1000x. Each file was planned to be used to instrument six root canals and then examined under SEM after preparing three and six canals at same magnifications. Data were scored and statistically analysed using CHI –SQ and Anova tests (p≤ 0.05). **Results:** Surface defects were detected in all study groups with higher values in WO & WOG group before use. Surface defects significantly increased in both WO and WOG groups after use as compared to R25. WO & WOG group showed significantly greater defects including metal strips, pitting, craters, micro-cracks and blunt edges (p≤ 0.05). **Conclusions:** Wave One Gold file has a different metallurgy due to its gold finish that does not enhance its resistance to surface defects during clinical use. Wave One and Wave One Gold showed significant increase in surface defects after six canal use which limits their usage in more than one teeth in single patient.

Keywords: Surface changes; SEM, Reciproc, Wave One; Wave One Gold.

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INTRODUCTION

The introduction of nickel-titanium (NiTi) endodontic files has offered immense flexibility when instrumenting curved canals while reducing the potential for file separation and canal transportation compared to their stainless-steel predecessors.[1,2] Review of literature reveals that, in spite of their greater flexibility and more resistance they tend to unexpectedly break because of cyclic fatigue (CF) which is a serious problem jeopardizing outcome of the root canal treatment.[3,4] Increasing resistance to file separation has been a driving goal for advancements in metallurgy and innovation in endodontic instrument design and use.[5] M-wire Ni-Ti alloy invented in 2007 by DENTSPLY, Tulsa, USA, is manufactured by a method of preparing Ni-Ti with metallurgic modification induced by multiple thermal treatment cycles during milling.[6] Recently, a special thermal process was introduced to M-wire alloy after grinding process is completed to produce a new Gold alloy. The main advantage of such heat treatment, according to the manufacturer claims, is to improve flexibility and strength of the file. On the other side, the effect of thermal processing techniques including gold finish on file's microscopic surface characteristics and its relationship to incidence of fracture is still questionable.[7,8]

The aim of this in-vitro study was to evaluate surface characteristic changes of Reciproc 25/.8 (R25,VDW, Munich, Germany) Wave One primary file 25/.08 (WO,Dentsply Maillefer, Ballaigues, Switzerland) made of M-wire Ni-Ti alloy and WaveOne Gold primary file 25/.07 (WOG, Dentsply Maillefer, Ballaigues, Switzerland) made of the new gold alloy using scanning electron microscopy before and after use, contributing to further the knowledge of the characteristics and performance of these instruments.

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MATERIALS & METHODS

The present study was carried out in the Postgraduate Department of Conservative Dentistry and Endodontics, Government Dental College and Hospital Srinagar. The study protocol was approved by the Ethics Committee of Govt. Dental College Srinagar.

Grouping: forty-five primary files were used in this study and divided according to the type of file into three groups (n=15 in each group). Group 1 [Reciproc file (R25, tip size = 25, apical taper = 0.08], Group 2 [WaveOne (WO) Primary file, tip size 25, 0.08 taper from d1-d3], Group 3 [Wave One Gold(WOG) Primary tip size 25, 0.07 taper from d0-d3]. Determination of sample size was obtained with an α-error of 5% and power of 80%.

Pre-instrumentation scanning: All instruments were observed under a scanning electron microscope (HITACHI S-3600N) before use at 10X to 1000X magnification. These instruments were mounted on a specific stub that held the instruments, in a standardized position. Files were evaluated at three segments starting from the tip 0-3mm, 3-6mm and 6-9 mm so that 9 mm of its shaft could be scanned to observe the surface changes and compare them between instruments. None of the instruments were autoclaved before or after use.

Preparation of teeth: A total of 270 mesial canals of mandibular molars were selected from the pool of teeth extracted for periodontal reasons collected from the Department of Oral and Maxillofacial Surgery, GDC Srinagar. Teeth with completely formed apices, narrow canals with a single, slight curve (angle between 15° and 30° and a 4–5 mm radius) were chosen. The radius and the angle of the curve was determined using the technique of Pruett et al.[9] Teeth were disinfected by immersion in 2.5% sodium hypochlorite for 30 minutes and cleaned from soft tissues and calculus. Endodontic access cavities were prepared using #4 round end diamond bur for the initial entry followed by Endo-Z bur (Komet, Brasseler GmbH& Co.KG, Germany) for lateral extension and finishing of the cavity walls. Access cavities were then irrigated with 3ml of 5% sodium hypochlorite. All specimens were standardized to 18 mm length by flattening of the cusps using a double-faced diamond disc mounted on low-speed handpiece. To ensure apical patency, a # 10K file (Dentsply Maillefer, Ballaigues, Switzerland) file was introduced until just visible at the apical foramen and 1mm was subtracted from this measurement to establish working length. Only canals that could be negotiated by # 10 or # 15 K file but resisted passage of # 20 K file were selected. The apical foramen of each root was sealed with a ball of wax and the teeth were placed in sample collection tubes secured with addition silicone impression material to facilitate handling.

Canal instrumentation: The canal orifices were located and the canals irrigated with 5% NaOCl solution and negotiated using a size 10 K-file. Subsequently, coronal flaring was done using a Gates Glidden number 2 drill. Size 15 K-file was used to verify a reproducible glide path. In all study groups, each file was used to prepare six root canals using X-Smart Plus (DENTSPLY Maillefer) electronic motor in reciprocal motion according to the pre-saved program on the motor by the manufacturer. Shaping procedures were performed until the file met resistance or reached the full working length. After three pecking motions, the instrument was removed from the canal and cleaned with sterile gauze and the canal was irrigated with 3 ml of 5% NaOCl using a 30-gauge needle with lateral opening. EDTA gel was used to aid in preparation of the root canals. This procedure was repeated until the file reached the original working length. After three canal preparations, the files were cleaned thoroughly with a soft toothbrush under running water and then placed in an ultrasonic cleaner (MACH9 MOCOM S.R.L ITALY) for 5 minutes to remove dentin debris. Each instrument was properly dried and stored in closed blood sample collection tube before next SEM analysis. This procedure continued until 6 canals were prepared using each file.

Post- instrumentation scanning:

All instruments were observed under SEM after preparing three and six root canals in a same manner as in pre-instrumentation scanning. Repositioning and photographing the files in the same position in the SEM chamber is important to observe and compare the changes between the sessions. The following images were obtained for all of the samples:x10/x150 for macroscopic defects., x260/x670 for the blades of the instruments., x260/x800 for the geometry of the edges and the tip of the instruments., x1000/ x1200 for the surface of the instrument. All the electron-micrographs of each of the 15 instruments of every group were analyzed, coded and stored digitally. All the images obtained by the analysis of the instruments after a number of uses were displayed at the same time and scored. The criteria used for assessing the instruments included the observation of presence or absence of superficial defects as per caballero et al[10]. Defects observed included Plastic deformation, Microcracks, Complete fractures, Large crater, Disruption of the cutting edges & Blunt edges

Scoring

The presence of superficial defects of each instrument from each group on use was scored according to caballero et al.[10]

Score	Criteria
1	No Fracture, no plastic deformation, no Microcracks, no large craters, no disruption of the cutting edges or blunt edges along the shaft examined
2	Plastic deformation, Microcracks, large craters, disruption of the cutting edges or blunt edges along the shaft examined of which one spiral along the shaft examined
3	Plastic deformation, Microcracks, large craters, disruption of the cutting edges or blunt edges along the shaft examined of two spirals along the shaft examined
4	Plastic deformation, Microcracks, large craters, disruption of the cutting edges or blunt edges along the shaft examined of more than two spiral along the shaft examined
5	Fracture

Statistical Analysis

Stastical software (SPSS ver.20.0) and GRAPH PAD (prism 5.00) was used to carry stastical analysis of data. Defects were noted as present /absent and percentage was calculated. Superficial defects were submitted through CHI –SQ. test to analyse difference between number of usages in all the three groups individually. Superficial defect score was summarized by mean and standard deviation and Compared using Anova to analyse difference between groups. P Value < 0.05 was considered significant

RESULTS

The descriptive and analytic statistics are illustrated in [Tables 1-3 & graphs 1-2].

None of the files in any group showed plastic deformation, Microcracks, Craters, blunt edges and disruption of cutting edges before use [Table 1, Graph 1]. Machining defects (irregular edges, grooves, burs, metal flash, metal strips) were present in all the three groups before use with significantly higher number in WO & WOG [Figure 1]. In terms of surface defects such as Microcracks, craters, blunt edges and disruption of cutting edges There is a significant difference between group 1(Reciproc) vs group 2 (WO) & group 1(Reciproc) vs group 3 (WOG) with significant increase in the surface defects after use in six canals in group 2 & group 3 [Table 2]. There is no significant difference between group 2(Wave One) and group 3 (Wave One Gold) after use in six canals. After preparing six canals significant difference is observed in terms scoring of superficial defects between Group 1 vs group 2 and group 1 vs group 3, however there is insignificant difference for group 2 vs group 3 [Table 3, Graph 2]

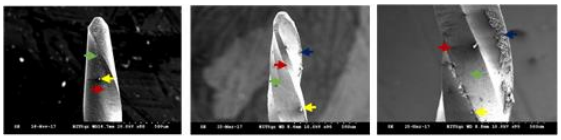


Figure 1: SEM image of new Reciproc(a) ,WaveOne (b) & wave one gold(c) files at 100X magnification before use,note surface defects in all files such as pitting (green arrow) debris (yellow arrows) ,metal flash(blue arrows) , grooves (red arrows)

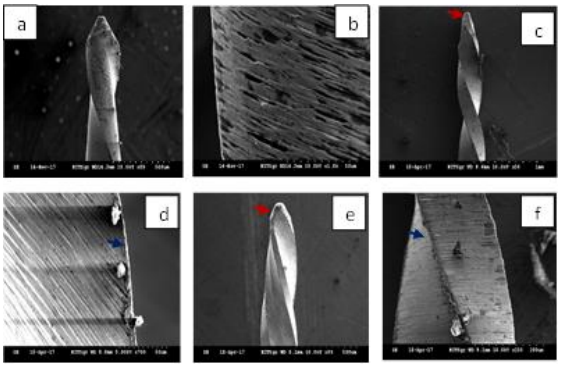


Figure 2: SEM image of Reciproc ,WaveOne & waveOneGold files at 100X -1000x magnification after 3 canal use, note there is no significant appearance of surface defects in Reciproc (a,b) ,however there is slight blunting of edges(blue arrow) & tip(red arrow) in wave one(c,d) and wave one gold (e,f)

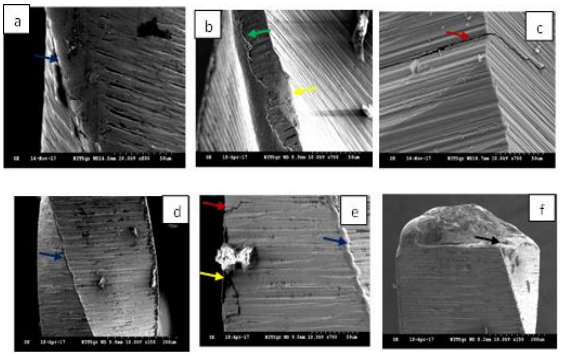


Figure 3: SEM image Of Reciproc ,Wave One & Wave One Gold files at 250X -1000x magnification after 6 canal use, note appearance of some surface defect such as blunting of edges in Reciproc (a,) however there is significant blunting of edges(blue arrow) , craters(green arrow),disruption of cutting edges (yellow arrow) & microfractures (red arrow) in Wave One(b,c) and Wave One Gold (d,e). note shearing type of fracture (black arrow) in Wave One Gold on 6th canal use(f)

Table 1: Number and percentage of RECIPROC(R25), WAVE ONE, WAVE ONE GOLD instruments showing specific defects before and after use in three and six root canals

		Reciproc (group 1)			Wave One (group 2)			Wave One Gold (group 3)		
		before use	after 3 canals	after 6 canals	before use	after 3 canals	after 6 canals	before use	after 3 canals	after 6 canals
plastic deformation	n	0	0	0	0	0	0	0	0	0
	%age	0%	0%	0%	0%	0%	0%	0%	0%	0%

	P-value	-	NV	NV	NV	NV	NV	NV	NV	NV
complete fracture	n	0	0	0	0	0	0	0	0	1
	%age	0%	0%	0%	0%	0%	0%	0%	0%	6%
	P-value	-	NV	NV	NV	NV	NV	NV	NV	1.000
microcracks	n	0	0	1	0	1	9	0	0	7
	%age	0%	0%	6%	0%	6%	60%	0%	0%	46%
	P-value	-	NV	1.000	NV	1.000	<0.001*	NV	NV	<0.001*
craters	n	0	0	2	0	0	12	0	0	8
	%age	0%	0%	13.30%	0%	0%	80%	0%	0%	53.30%
	P-value	-	NV	0.483	NV	NV	<0.001*	NV	NV	<0.001*
blunt edges	n	0	0	3	0	3	13	0	2	11
	%age	0%	0%	20%	0%	20%	86.60%	0%	13%	73.30%
	P-value	-	NV	0.224	NV	0.224	<0.001*	NV	0.483	<0.001*
disruption of cutting edges	n	0	0	2	0	0	13	0	0	9
	%age	0%	0%	13.30%	0%	0%	86.60%	0%	0%	60.00%
	P-value	-	NV	0.483	NV	NV	<0.001*	NV	NV	<0.001*
debris	n	15	15	15	15	15	15	15	15	15
	%age	100%	100%	100%	100%	100%	100%	100%	100%	100%

NV: No value; *Statistically Significant Difference (P-value<0.05)

Table 2: Inter-group comparison

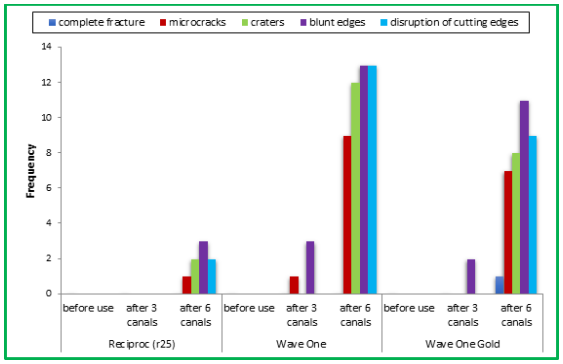
	Reciproc vs Wave one			Reciproc vs Wave One Gold			Wave One vs Wave One Gold		
	before use	after 3 canals	after 6 canals	before use	after 3 canals	after 6 canals	before use	after 3 canals	after 6 canals
plastic deformation	NV	NV	NV	NV	NV	NV	NV	NV	NV
complete fracture	NV	NV	NV	NV	NV	NV	NV	NV	1.000
microcracks	NV	1.000	0.005*	NV	NV	0.035*	NV	1.000	0.464
craters	NV	NV	<0.001*	NV	NV	0.020*	NV	NV	0.245
blunt edges	NV	0.224	0.001*	NV	0.483	0.009*	NV	1.000	0.651
disruption of cutting edges	NV	NV	<0.001*	NV	NV	0.020*	NV	NV	0.215
debris	NV	NV	NV	NV	NV	NV	NV	NV	NV

NV: No value; *Statistically Significant Difference (P-value<0.05)

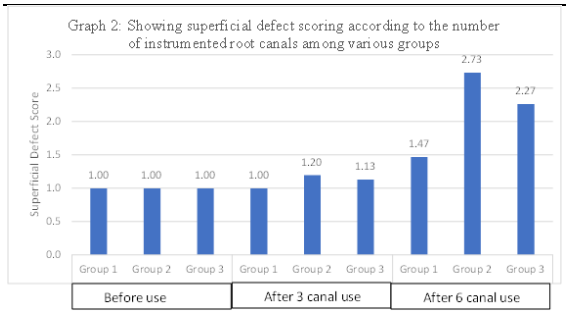
Table 3: Showing superficial defect scoring according to the number of instrumented root canals among various groups

		N	Mean	SD	95% CI for Mean		Comparison	P-value
0 Canals	Group 1	15	1.00	0.00	1.00	1.00	1 vs 2	-
	Group 2	15	1.00	0.00	1.00	1.00	2 vs 3	-
	Group 3	15	1.00	0.00	1.00	1.00	1 vs 3	-
3 Canals	Group 1	15	1.00	0.00	1.00	1.00	1 vs 2	0.088
	Group 2	15	1.20	0.41	.97	1.43	2 vs 3	0.564
	Group 3	15	1.13	0.35	.94	1.33	1 vs 3	0.251
6 Canals	Group 1	15	1.47	0.64	1.11	1.82	1 vs 2	0.001*
	Group 2	15	2.73	0.96	2.20	3.27	2 vs 3	0.184
	Group 3	15	2.27	1.16	1.62	2.91	1 vs 3	0.021*

*Statistically Significant Difference (P-value<0.05)



Graph 1: Graphical representation of development of different surface defects in Group 1, Group 2 and Group 3 before use and after use in three and six canals.



DISCUSSION

Success of root canal treatment is fundamentally dependent on root canal preparation. The introduction of a nickel–titanium alloy (NiTi) opened a new perspective in endodontics because of their superelasticity. Endodontic instruments made of Superelastic NiTi allows instruments to remain centralized inside the root canal which results in satisfactory root canal preparations even for curved root canals respecting the anatomy and contributing to a better prognosis.[11,12] The crystallographic phase transformations in Superelastic NiTi instruments weakens the instrument leading to an unexpected breakage(flexural fracture) caused by a defect in the internal structure of the metal alloy and not accompanied by deformation of its external structure.[13] A series of proprietary thermomechanical processing has led to the development of the next-generation endodontic instruments. Reciproc, WaveOne and WaveOne Gold files are reciprocating single file systems requiring less time than full-sequence rotary systems; and stress on the instrument is relieved through bi-directional reciprocating motion, thereby extending their durability and resistance to cyclic fatigue in comparison with systems that use continuous rotation motion.[8] On the other hand, the manufacturer claimed that the section, size and geometry of WOG have been modified compared to WO and the metallurgy of this file has been changed from M-wire to a Gold alloy by heat treatment after milling to provide enhanced mechanical properties than conventional Ni-Ti and M-wire files.[7,14] However, According to studies the effect of thermal processing techniques including gold finish on file's microscopic surface characteristics and its relationship to incidence of fracture is still questionable and extensive literature search shows lack of data on comparative evaluation of surface changes of these single file systems before and after use.[7,8] This research was established to investigate such claims & to evaluate the surface characteristic changes of Reciproc (VDW, Munich, Germany), Wave One primary file (WO, Dentsply Maillefer, Ballaigues, Switzerland) made of M-wire Ni-Ti alloy and WaveOne Gold primary file (WOG, Dentsply Maillefer, Ballaigues, Switzerland) made of the new gold alloy using scanning electron microscopy, before use and after use in 3 and 6 canals.

For standardization in the current study, the primary file of each brand was used to prepare the canals to full working length after establishing glide path according to the recommended protocol by the manufacturer.[14] The manufacturer recommends single use of Reciproc, WO and WOG files to prevent cross infection and prevent unexpected separation; each file in this study was used for preparation of total six root canals to resemble the clinical situation where more than one molar for one same patient can be prepared or for one molar with six canals as has been reported in the literature.[15,16] Machining of Ni-Ti endodontic instruments produces surface imperfections.[17] Bhagabatiet al.[18] reported that these defects can reduce cutting efficiency of the file and increase liability to fracture. In this study unused WaveOne and WaveOneGold showed more machining defects like irregular edges, grooves, burs, metal flash, metal strips than unused Reciproc file , while WOG files showed significantly more pitting and metal strips than WO files (fig. 1), same results were observed by Fatma and Ozgur [20] and Hanan et al.[21] This might be due to the different heat treatment processes performed on WOG file after machining which obviously could not eliminate surface defects.[6]

In the present study, Wave One & Wave One Gold files showed a significant increase in surface defects including micro-cracks, debris, blunt edges, pitting and craters after being used in six canals as compared to Reciproc files. This early appearance of micro-cracks in WO & WOG group might be due to the presence of significantly greater surface defects in this group before use. According to Tsujimotoet al,[21] micro-cracks occur on the surface of a heat-treated file when stress concentration is coincident with machining marks or defects.

Caballero et al,[10] reported that blunt edges are produced by friction of the instruments against root canal walls. In this study, there was no significant appearance of blunt edges in Reciproc group after use in three canals [Figure 2] and when usage increased from three to six canals. This in part can be attributed to the cross-sectional S-shaped design of Reciproc in which active part of the blade touches canal walls at two or one point only minimizing the frictional contact with the dentinal wall. However, both WO and WOG files showed a significant increase in appearance of blunt edges [Figure 2 & 3] and fewer metal strips after the use increased from three to six canals which could be due to greater friction with canal walls because of the greater taper (.08) in addition to convex triangular cross-sectional design with three contact points with canal walls further increasing the friction. In WaveOneGold improved metallurgy (Gold alloy), New parallelogram cross-sectional design with 2 cutting edges and decreased taper (.07), it was expected will perform better than Wave One in terms of blunting of edges, however, in this study there was no difference between WO and WOG as both showed significant increase in appearance of blunt edges when usage increased from three to six canals, which might be due to their different metallurgy. As reported earlier by Gambarini et al (2008),[22] that thermomechanical processing is frequently used to optimize the microstructure and transformation behaviour of NiTi alloys, which in turn has greater influence on the mechanical properties of NiTi files. Gustavo De-Deus et al (2016),[23] reported that the

proprietary thermomechanical treatment produces a NiTi alloy that is softer and more ductile than the traditional one demonstrating improved flexibility and fatigue resistance, and reduced micro hardness while maintaining similar characteristics of the surface. In view of the above studies it can be concluded that the manufacturer has tried to strike a balance by changing the cross-sectional design and decreasing the taper to negate the effects of decrease in microhardness of NiTi alloy by proprietary thermomechanical treatment and optimize the function of new file system.

In this study, craters and disruption of cutting edges were detected in both WO and WOG [Figure 3] after use & significantly increased when instrumentation was increased from three to six root canals. Cai et al,[24] has reported the deterioration of NiTi instruments as a result of corrosion during instrumentation in the presence of NaOCl and EDTA. Also, Bonaccorso et al,[25] and Caballero et al,[10] stated that NaOCl treatment affected the chemical composition of the surface causing significant increase in iron deposits as a result of galvanic corrosion of the shaft and, in particular of the bulk exposed through machining marks and fabrication microcracks.In view of the facts stated by Cai et al and Bonaccorosa et al the significant increase in craters and disruption of cutting edges in WO and WOG group as compared to Reciproc group can be explained. WO and WOG have more surface defects as compared to Reciproc, which provide a microenvironment in presence of NaOCl for galvanic corrosion to occur decreasing the structural integrity of the surface of file and on subsequent use resulting in formation of craters and disruption of cutting edges. Since corrosion and deterioration of NiTi instruments during disinfection and instrumentation in presence of NaOCl has been a concern, but there is no consensus regarding this issue in literature further studies should be conducted to determine the effect of NaOCl in corrosion of thermally treated NiTi files.

Except one file in WOG group, an important finding of this study is that no complete fracture was detected in any study group when instrumented up to six root canals which is in agreement with the studies of Hanan et al,[20] Pirani et al,[26] and Hee-Chul Kim et al.[27] The results from these studies & this study again makes a case for these file systems to be used preferably as single use tool to prevent fracture in the root canal.

Alapati et al,[28] hypothesized that the clinical fracture of NiTi rotary files is usually caused by a single overload incident during instrumentation. In view of this finding the fracture of single WOG file can be explained which was subsequently proved by the fractographic SEM analysis of fractured fragment which revealed a shear type of fracture which has occurred [Figure 3].

In this study, no macroscopic signs of plastic deformation or spiral distortion were observed even when the number of uses increased from three to six uses. This confirmed that the number of canals treated was not too high and suggested a safe use in multi-rooted teeth. These results are consistent with the results of Kim et al,[27] and pirani et al.[26]

In the intergroup comparison between Reciproc, WO and WOG after usage in six canals Reciproc has significantly lesser development of Microcracks, craters, disruption of cutting edges and blunt edges than both WO and WOG. Cheung et al,[29] reported that machining scratches on the instrument surface could act as local stress raisers or even crack-like features that might become the origin of a fatigue crack. As in our study Reciproc instruments before use has significantly lesser machining defects before use as compared to both WO and WOG instruments which could explain the presence of significantly less defects in Reciproc after use in six canals. Also, by tracking back, the thermo-mechanical manufacturing process and the metallurgy of Ni-Ti files, Wave One Gold file was subjected to heat treatment after milling. The metallurgical characteristics of these heat-treated files had not only a 2-stage specific transformation behaviour (A-R-M) but also had high austenite finish (Af) temperatures.[7] This led to increase in austenitic finish temperature of the file, which means that the austenitic phase is greater than martensitic during canal preparation rendering the file more subjected to deformation and surface changes which might support our findings. This is in agreement with Shen et al [6] who found that K3XF files subjected to heat treatment similar to WOG had a different phase transformation behaviour which may be attributed to heat treatment history of the instruments.

CONCLUSION

Within the limitations of this study following conclusion can be drawn

- Manufacturing of files by machining method leaves surface defects which can be seen in all file systems before use
- All single file systems (Reciproc, WaveOne, WaveOneGold) performed significantly better with insignificant appearance of surface defects when used up to three canals.
- Wave One and Wave One Gold showed significant increase in surface defects after six canal use which limits their usage in more than one teeth in single patient.
- Reciproc performed significantly better than both Wave One and Wave One Gold Suggesting it can be used to prepare more than one teeth in single patient

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