Original Research

Evaluation of Surface Characteristic Changes of WaveOne Gold and WaveOne Single Reciprocating Files Using Scanning Electron Microscopy: An in-vitro Study

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Received 12 September 2017 and Accepted 13 December 2017

Abstract

Introduction: The purpose of this study was to evaluate surface topography of WaveOne Gold (WOG) and WaveOne (WO) files using SEM before and after use. **Methods:** Twelve primary files from each system were scanned for surface defects before instrumentation at 100x and 750x. Each file was planned ti be used to instrument six root canals and then examined under SEM after preparing one, three and six canals at same magnifications. Data were scored and statistically analyzed using Mann Whitney and Friedman tests ($p \leq 0.05$). **Results:** Surface defects were detected in both study groups with higher values in WOG group before use. Surface defects significantly increased in both WO and WOG groups after use. WOG group showed significantly greater defects including metal strips, pitting, craters, micro-cracks and blunt edges ($p \leq 0.05$). **Conclusion:** WaveOne Gold file has a different metallurgy due to it's gold finish that does not enhance it's resistance to surface defects during clinical use.

Keywords: Surface changes; SEM; WaveOne; WaveOne Gold.

Menecy A.M, Mokhless N.A.S, Hanafy S.A. Evaluation of Surface Characteristic Changes of WaveOne Gold and WaveOne Single Reciprocating Files Using Scanning Electron Microscopy: An in-vitro Study. J Dent Mater Tech 2018; 7(1): 25-32.

Introduction

Despite the increasing popularity of Ni-Ti rotary instruments, there exists concern about unexpected separation during use. Increasing resistance to file separation has been the main goal of manufacturers in developing the latest Ni-Ti rotary instruments. Thermal treatment of Ni-Ti alloys has been used to optimize mechanical properties of these files (1).

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 which relieve internal stresses induced by cold work on the alloy such as twinning and atom dislocation of the crystalline structure which may, later on, act as a point of crack initiation and propagation and reduce cyclic fatigue resistance of instruments (2, 3).

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 it's relationship to incidence of fracture is still questionable (4, 5).

The aim of this in-vitro study was to evaluate surface characteristic changes of 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, DentsplyMaillefer, Ballaigues, Switzerland) made of the new gold alloy using scanning electron microscopy.

Materials and methods

Grouping: Twenty four primary files were used in this study and divided according to the type of file into two groups (n=12). The sample size was calculated for the study using stuG* Power 3.1.9.2 software for Windows (Universität Düsseldorf, Germany).

Pre-instrumentation scanning: The files from each group were observed under SEM at 100x and 750x magnifications in lateral views, with no cleaning treatment before use (JSM-5300, JEOL, USA) to detect any manufacturing defect present. Each file was scanned twice; one with the flat portion on the shank facing up and one with the flat portion facing down. Files were evaluated at three segments starting from the tip: 0-2mm, 2-4mm and 4-8mm.

Preparation of teeth: A total of 144 extracted mandibular molars were collected from the outpatient clinic of Oral Surgery Department, Faculty of Dentistry, Alexandria University, Egypt. The length of selected teeth were in the range of 19-21mm, type I Vertucci's classification (6) and 15º to 30º mesial root curvature (Schneider's technique) (7) starting at 6-8mm from the apex. 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 2.5% sodium hypochlorite. All specimens were standardized to 18 mm length by flattening of the cusps using a double-faced diamond disc (Komet, Brasseler GmbH& Co.KG, Germany) mounted on low-speed handpiece. To ensure apical patency, a # 10 K 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 acrylic resin blocks to facilitate handling.

Canal instrumentation: Mechanical glide path preparation was performed in all canals using ProGlider files (DentsplyMaillefer, Ballaigues, Switzerland) mounted on endodontic engine X-Smart plus (DentsplyMaillefer, Ballaigues, Switzerland) with 16:1 contra angle at 300 rpm and 3 N/cm as recommended by the manufacturer. In both study groups, each file was used to prepare six root canals using X-Smart Plus 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 2.5% 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 each canal preparation, the files were cleaned thoroughly with a soft toothbrush under running water and then placed in an ultrasonic cleaner for 5 minutes to remove dentin debris. Each instrument was properly dried and stored in closed Eppendorf tube before next SEM analysis.

Post- instrumentation scanning: All instruments were observed under SEM in lateral views at 100x and 750x magnifications after preparing one, 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 superficial defects present in both groups were observed after instrumenting one, three and six root canals by two reliable operators and scored according to Tripi*et al.* score(8) including the following:

(a) Micro-cracks: microscopic cracks in the blades without complete instrument separation.

(b) Complete fracture: instrument separation during study.

(c) Metal strips: visible strips of metal on the surface of the instrument.

(d) Pitting:presence of several small pits.

(e) Disruption of cutting edge: loss of the regular continuous shape of the blades.

(f) Fretting: observable notches and incisions on the surface.

(g) Plastic deformation: loss of regular geometry of the instrument.

(h) Craters: presence of large pits in the surface.

(i) Dentin debris: presence of materials removed from canal walls.

(j) Blunt edges: loss of sharpness of cutting edges.

(k) Scraping: visible scraped areas on the surface.

After data was collected, it was revised and fed to statistical software SPSS IBM version 20 (SPSS, Inc., Chicago, IL). Descriptive statistics in the form of mean and standard deviation were used to describe numeric data. Friedman test was used to calculate variability within every single group, while variability among the two study groups was calculated using Mann Whitney test at $p \leq 0.05$.

Results

The descriptive and analytic statistics were illustrated in tables (1-6).

Before use, micro-cracks were detected in WOG group only; in addition, WOG group presented significantly more metal strips and pitting than WO group, while no significant difference was found between both groups concerning debris (*$p<0.05$*) (Fig 1 and Fig 2).

After use, WO group showed significantly more debris than WOG group, while WOG group showed significantly more metal strips, pitting, craters, micro-cracks and blunt edges. Both groups showed a significant decrease in metal strips in the apical part compared to the coronal part; both groups showed significantly more debris in the coronal segment after one canal preparation but the amount of debris was significantly greater in the apical segment after preparing three and six canals *($p<0.05$)* (Fig 3- 5).

Craters and micro-cracks significantly increased with use in WOG after preparing one canal while in WO group craters were not shown except after preparing six canals. The apical part of WO files showed significantly more pitting and blunt edges coincident with more debris than the coronal part *($p<0.05$).*

Table 1. Comparison between the two study groups according to metal strips

Metal Strips	**Before using scoring (n = 12)**	**After use in canal scoring** 1 (n = 12)	3 (n = 12)	6 (n = 12)	**P**
Wave one					
0 – 2 mm	1.75 ± 1.71	0.58 ± 0.51	1.3 ± 1.2	0.0 ± 0.0	0.003*
2 – 4 mm	2.92 ± 2.19	2.17 ± 1.47	2.5 ± 2.20	2.5 ± 2.30	0.298
4 – 8 mm	6.25 ± 2.60	4.42 ± 2.31	3.17 ± 1.64	1.92 ± 1.62	0.003*
p_0	0.004*	0.006*	0.013*	0.005*	
Wave one Gold					
0 – 2 mm	4.83 ± 1.53	4.42 ± 3.99	1.75 ± 1.36	1.6 ± 1.2	<0.001*
2 – 4 mm	9.33 ± 3.08	7.92 ± 2.54	3.33 ± 1.87	3.33 ± 1.50	<0.001*
4 – 8 mm	12.83 ± 2.48	9.92 ± 2.64	8.25 ± 2.49	6.58 ± 1.62	<0.001*
p_0	<0.001*	0.007*	<0.001*	<0.001*	

P: p values for Friedman test for comparing between the four studied periods

p_0: p values for Friedman test for comparing between the three file segments

*: Statistically significant at $p \leq 0.05$

Table 2. Comparison between the two study groups according to debris

Debris	**Before using scoring (n = 12)**	**After use in canal scoring** 1 (n = 12)	3 (n = 12)	6 (n = 12)	P
Wave one					
0 – 2 mm	6.92±2.81	18.58±8.43	35.17±6.97	22.67±4.68	<0.001*
2 – 4 mm	7.75±5.94	22.17±8.93	34.17±12.13	21.17±7.85	<0.001*
4 – 8 mm	12.0±2.66	28.92±9.02	33.08±5.52	16.83±4.06	<0.001*
p_0	0.008*	0.006*	0.739	0.016*	
Wave one Gold					
0 – 2 mm	6.58±1.68	8.58±5.63	25.17±15.70	23.17±6.12	<0.001*
2 – 4 mm	7.42±2.15	10.58±5.74	13.42±7.55	17.0±7.64	0.023*
4 – 8 mm	11.67 ± 2.19	14.08±5.18	21.0±7.32	13.75±4.81	0.002*
p_0	<0.001*	0.249	0.001*	0.007*	

P: p values for Friedman test for comparing between the four studied periods

p_0: p values for Friedman test for comparing between the three file segments

*: Statistically significant at $p \leq 0.05$

Table 3. Comparison between the two study groups according to pitting

Pitting	Before using scoring (n = 12)	After use in canal scoring 1 (n = 12)	3 (n = 12)	6 (n = 12)	P
Wave one					
0 – 2 mm	0.17 ± 0.58	0.50 ± 1.17	0.50 ± 0.90	1.0 ± 1.13	0.059
2 – 4 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.42 ± 1.0	0.112
4 – 8 mm	0.25 ± 0.87	0.0 ± 0.0	0.0 ± 0.0	0.33 ± 0.78	0.300
p_0	0.368	0.050*	0.049*	0.096	
Wave one Gold					
0 – 2 mm	1.0 ± 1.35	1.17 ± 1.64	0.58 ± 1.08	2.75 ± 1.48	0.017*
2 – 4 mm	0.75 ± 0.97	0.75 ± 1.22	1.42 ± 2.15	3.75 ± 1.48	0.001*
4 – 8 mm	0.83 ± 1.53	1.08 ± 1.38	2.0 ±1.35	3.08 ± 1.51	0.005*
p_0	0.704	0.670	0.095	0.161	

P: p values for Friedman test for comparing between the four studied periods
p_0: p values for Friedman test for comparing between the three file segments
*: Statistically significant at $p \leq 0.05$

Table 4. Comparison between the study groups according to craters

Craters	Before using scoring(n = 12)	After use in canal scoring 1 (n = 12)	3 (n = 12)	6 (n = 12)	P
Wave one					
0 – 2 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	-
2 – 4 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	-
4 – 8 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.50 ± 0.90	0.029*
p_0	-	-	-	0.049*	
Wave one Gold					
0 – 2 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	-
2 – 4 mm	0.0 ± 0.0	0.08 ± 0.29	0.33 ± 0.49	0.33 ± 0.49	0.045*
4 – 8 mm	0.0 ± 0.0	0.08 ±0.29	0.58 ± 0.90	0.58 ± 0.90	0.066
p_0	-	0.607	0.074	0.047*	

P: p values for Friedman test for comparing between the four studied periods
p_0: p values for Friedman test for comparing between the three file segments
*: Statistically significant at $p \leq 0.05$

Table 5. Comparison between the study groups according to micro-cracks

Micro-Cracks	Before using scoring (n = 12)	After use in canal scoring 1 (n = 12)	3 (n = 12)	6 (n = 12)	P
Wave one					
0 – 2 mm	0.0 ± 0.0	0.17 ± 0.58	0.0 ± 0.0	0.08 ± 0.29	0.572
2 – 4 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.25 ± 0.45	0.029*
4 – 8 mm	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.75 ± 1.14	0.007*
p_0	-	0.368	-	0.268	
Wave one Gold					
0 – 2 mm	0.0 ± 0.0	1.50 ± 1.45	2.0 ± 1.54	2.08 ± 1.0	0.001*
2 – 4 mm	0.42 ± 0.90	0.83 ± 1.53	1.83 ± 1.90	2.42 ± 1.93	0.056
4 – 8 mm	0.33 ± 0.49	0.33 ± 0.65	2.50 ± 0.90	2.33 ± 0.49	<0.001*
p_0	0.115	0.490	0.911	0.598	

P: p values for Friedman test for comparing between the four studied periods
p_0: p values for Friedman test for comparing between the three file segments
*: Statistically significant at $p \leq 0.05$

Table 6. Comparison between the study groups according to blunt edges

Blunt edges	Before using scoring (n = 12)	After use in canal scoring			P
		1 (n = 12)	3 (n = 12)	6 (n = 12)	
Wave one					
0 – 2 mm	0.0 ± 0.0	0.58 ± 0.90	1.33±1.37	3.0 ± 0.95	<0.001*
2 – 4 mm	0.0 ± 0.0	0.0 ± 0.0	0.50 ± 1.17	0.75 ± 1.36	0.032*
4 – 8 mm	0.0 ± 0.0	0.0 ± 0.0	0.25 ± 0.62	0.25 ± 0.62	0.112
p_0	-	0.018*	0.038*	<0.001*	
Wave one Gold					
0 – 2 mm	0.0 ± 0.0	1.58 ± 1.83	1.75±1.91	2.75 ±0.97	<0.001*
2 – 4 mm	0.0 ± 0.0	0.67 ± 1.72	1.17 ± 2.29	2.33 ± 1.37	<0.001*
4 – 8 mm	0.0 ± 0.0	0.92 ± 1.44	1.0±2.34	2.58 ± 1.38	<0.001*
p_0	-	0.337	0.459	0.353	

P: p values for Friedman test for comparing between the four studied periods
p_0: p values for Friedman test for comparing between the three file segments
*: Statistically significant at $p \le 0.05$

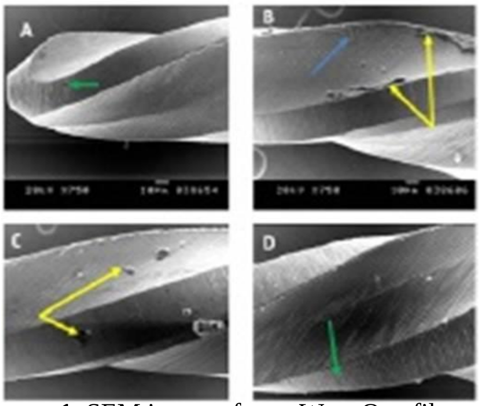

Figure 1. SEM image of new WaveOne file at 750X magnification.

(A) ;(0-2mm) segment showing pitting (green arrow)
(B); (2-4mm) segment showing debris (yellow arrows) and metal strips (blue arrow)
(C); (4-8mm) segment showing debris (yellow arrows)
(D); (4-8mm) segment showing pitting (green arrow)

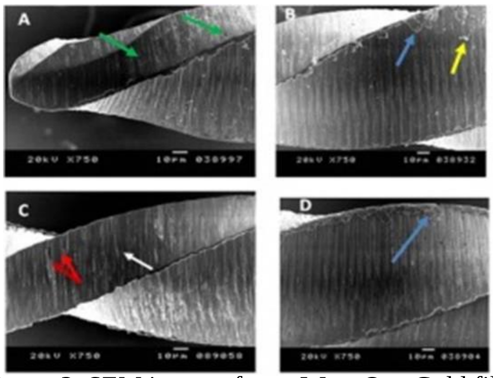

Figure 2. SEM image of new WaveOne Gold file at 750X magnification

(A); (0-2mm) segment showing pitting (green rrows)
(B) ;(2-4mm) segment showing debris (yellow arrow) and metal strips (blue arrow)
(C) ;(4-8mm) segment showing micro-cracks (red arrows) parallel to the machining marks (white arrow)
(D) ;(4-8mm) segment showing metal strips (blue arrow)

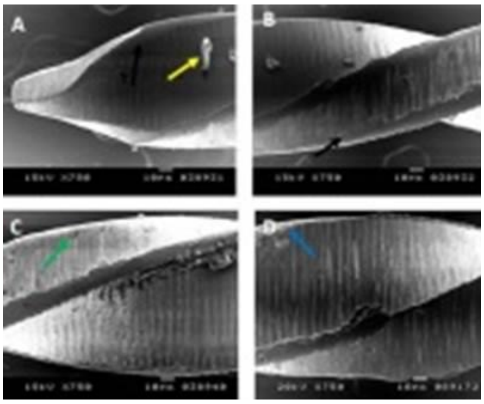

Figure 3.SEM image of WaveOne Gold file after use in six canals at 750X magnification.

(A); (0-2mm) segment showing debris (yellow arrow) and blunt edge (black arrow)
(B) ;(2-4mm) segment showing blunt edge (black arrow)
(C); (4-8mm) segment showing pitting (green arrow)
(D) (4-8mm) segment showing crater (blue arrow)

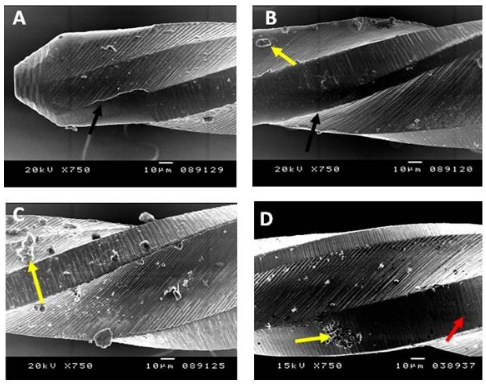

Figure 4.SEM image of WaveOne file after use in six canals at 750X magnification

(A); (0-2mm) segment showing blunt edge (black arrow)
(B); (2-4mm) segment showing debris (yellow arrow) and blunt edge (black arrow)
(C) ;(4-8mm) segment showing debris (yellow arrow)
(D);(4-8mm) segment showing debris (yellow arrow) and micro-crack (red arrow).

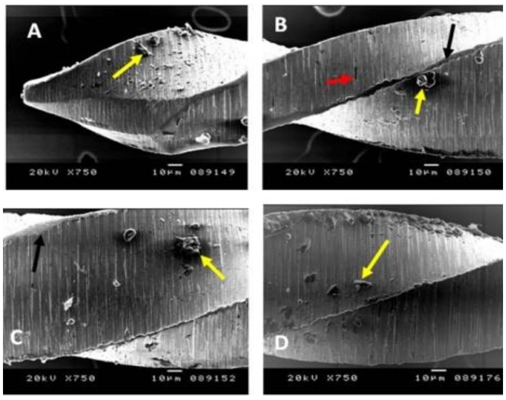

Figure 5.SEM image of WaveOne Gold file after use in three canals at 750X magnification

(A); (0-2mm) segment showing debris (yellow arrow)

(B); (2-4mm) segment showing blunt edge (black arrow), micro-crack (red arrow) and debris (yellow arrow)

(C); (4-8mm) segment showing debris (yellow arrow) and blunt edge (black arrow)

(D); (4-8mm) segment showing debris (yellow arrow)

Discussion

In the present research, two recent brands of rotary Ni-Ti files, WaveOne and WaveOne Gold were examined with SEM for surface changes before and after use. WaveOne Gold displayed significantly more surface defects before use than expected and earlier surface defects after use were obviously recognized than WaveOne.

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 (4). 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 (5, 9). This research was established to investigate such claims.

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 (9). The manufacturer recommends single use of WO and WOG files to prevent cross infection and prevent unexpected separation; each file in this study was used for preparation of 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 (10, 11).

Manufacturing Ni-Ti endodontic instruments is more complex than that of stainless steel instruments, as the files have to be machined rather than twisted which results in surface imperfections. (12) Bhagabati*et al.* (13) reported that these defects can reduce cutting efficiency of the file and increase liability to fracture. In the current study, both files showed surface defects and machining marks under SEM before use. Fatma and Ozgur (14) reported the difficulty of machining defect-free Ni-Ti instruments in WaveOne primary files, and Hanan*et al.* (15) observed a larger number of surface defects in WaveOne files compared with the Reciproc instruments. Micro-cracks were detected only in WOG group, while WOG files showed significantly more pitting and metal strips than WO files. This might be due to the different heat treatment processes performed on WOG file after machining which obviously could not eliminate surface defects (3).

In the present research, both studied files showed a significant increase in surface defects including micro-cracks, debris, blunt edges, pitting and craters after being used. WOG files displayed significant micro-cracks after being used in one canal; on the other hand, these defects were detected after preparing six canals in WO group. This early appearance of micro-cracks in WOG group might be due to the presence of significantly greater surface defects in this group before use. According to Tsujimoto*et al* (16), micro-cracks occur on the surface of a heat-treated file when stress concentration is coincident with machining marks or defects.

Despite the cleaning process performed after using instruments, dentin debris was still detected in both groups; this could be due to surface imperfections and roughness resulting from manufacturing process. WO group showed significantly more debris than WOG group after use which might be due to the modified convex triangular cross-section of WO file that touches canal walls at three points compared to the alternating offset parallelogram-shaped cross section of WOG file that touches canal walls at two or one point only (17). This is in accordance with the study by Ha *et al* (18). who found a relationship between instruments' cross-sectional designs and contact area with canal walls that causes more digging into dentinal walls and engage more debris.

Both files showed significantly more debris at their coronal part after one canal preparation than the apical part. On the other hand, when using the files for preparation of more canals, the debris significantly increased in the apical part rather than the coronal part. WO and WOG files were designed in a manner that auger debris coronally by unequal bi-directional reciprocating motion and regressive taper coronally, but increasing file taper and contact with canal walls at the apical part of the files leads to clogging of this part with debris during further instrumentation (17).

In this study, both files showed a significant increase in blunt edges after being use. Caballero *et al*. (19). reported that blunt edges are produced by friction of the instruments against root canal walls. WOG showed significantly more blunt edges than WO despite less friction with canal walls which might be due to their different metallurgy such as greater austenitic phase in WOG that increase liability to wear and permanent deformation (3, 18). In addition, WO files showed significantly more blunt edges and fewer metal strips at the tip compared with the coronal part due to greater friction with canal walls because of the greater taper at this area in addition to convex triangular cross-sectional design with three contact points with canal walls (17).

In the current study, craters were detected in both study groups after use in addition to significant increase in pitting. Formation of craters and pitting on the surface of Ni-Ti files after use was explained by Cai*et al.* (20) as a result of corrosion and deterioration of NiTi instruments during instrumentation in the presence of NaOCl and EDTA. Also, a study by Cabarello*et al* (19). Reported that NaOCl was associated with deterioration of the surface of the instrument as a result of a chemical reaction creating roughness, pitting and large craters.

By tracking back the thermo-mechanical manufacturing process and the metallurgy of both Ni-Ti files, Wave One Gold file was subjected to heat treatment after milling. 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 permanents deformation and surface changes which might support our findings. This was in agreement with Shen *et al* (3). Who found that K3XF files subjected to heat treatment similar to WOG had a different phase transformation behavior which may be attributed to heat treatment history of the instruments.

Although WO file showed fewer surface defects after use in our study, the apical part of this file constitutes a weakness point showing significantly more pitting and blunt edges coincident with more accumulation of debris as a result of it's cross-sectional design and regressive taper.

An important finding of this study is that no complete fracture was detected in both study groups which means that WaveOne and WaveOne Gold primary files are safe for use in up to six root canals, as was explained by Generali *et al* (21). As the ciprocating movement appears to prevent or delay exceeding the elastic limit of the alloy and subsequent plastic deformation and fracture. In addition, Tsujimoto*et al.* (16). Reported that heat-treated files are less likely to display sudden fracture because of the short micro-cracks pattern developed on their surface after use in comparison with longer cracks found on other types of Ni-Ti files. This is in agreement with the findings of Pirani *et al* (22). And Cunha *et al* (23). but contradict the study by Shen *et al*. (24) who reported fracture of Wave One files after clinical use; this difference might be attributed to random collection of discarded files from four different specialists of different skills.

Conclusion

The thermo-mechanical process used for manufacturing either WaveOne or WaveOne Gold files could not completely eliminate machining surface defects, however, both files are safe to prepare up to six canals although root canals with severely curved or narrow apical part may pose a challenge for both files. Further investigations concerning metallurgy of Gold Ni-Ti alloy is required using other methods as X-ray diffraction and Differential Scanning Calorimetry

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