ORIGINAL ARTICLE

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A topographic analysis of the surface changes in reciprocating and rotary Ni-Ti instruments after multiple uses

Gülsen Kiraz, Arzu Kaya Mumcu, Safa Kurnaz

Department of Endodontics, Faculty of Dentistry, Kutahya Health Sciences University, Kütahya, Türkiye

Purpose: This study aims to investigate the impact of repeated use within curved root canals on the surface characteristics of both reciprocating and rotary instruments, using Field Emission Scanning Electron Microscopy (FESEM) for detailed analysis.

Methods: Curved acrylic blocks were randomly divided into two groups and were prepared using WaveOne Gold (WOG) and One Curve (OC) files. Both WOG and OC groups were further divided into subgroups: control, 1st use, 2nd use, 3rd use, and separated files. Following each use, the instruments underwent ultrasonic cleaning and sterilization procedures. These procedures continued until fracture occurred and changes in the surface characteristics of files were examined under FESEM. Descriptive data were reported for each group.

Results: With increasing use within each group, the instruments exhibited a rise in the frequency of surface damage, including cracks, flattening, deterioration of cutting edges, microcavities, and debris accumulation. A fracture occurred in the OC file after the 8th use, while the WOG file fractured after the 6th use.

Conclusion: Repeated use increased defects and deformations in both files. Based on the surface characteristics of both files, single-use applications of WOG and OC files are considered safer.

Keywords: Field emission scanning electron microscopy; One Curve; separated file; topographic change; WaveOne Gold.

Introduction

Nickel-titanium (Ni-Ti) instruments have revolutionized endodontics due to their high flexibility, enhanced cyclic fatigue resistance, and superior torsional strength (1). These properties facilitate efficient root canal preparation, reduce operator fatigue, shorten procedure times, and enable the safe preparation of curved anatomies (1). However, despite their widespread adoption, Ni-Ti files are not without limitations. The most concerning complication associated with their use is instrument separation within the root canal. This separation can arise from flexural fatigue, torsional fatigue, or a combination of these mechanisms (2).

Although instrument fractures within the root canal system do not invariably compromise treatment success, their presence undeniably impedes effective microbial control and introduces complexities into the endodontic treatment process (3). Moreover, retrieving a separated file may lead to excessive dentin removal, compromised root

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Correspondence: Gülsen Kiraz. Kutahya Health Sciences University, Kütahya, Türkiye
Tel: +90 275 – 260 00 43 e-mail: gulsen.kiraz@ksbu.edu.tr
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strength, and perforation. These frustrating complications can occur even in skilled hands (4).

Novel production strategies that leverage diversified thermomechanical processes are emerging to enhance Ni-Ti instrument mechanics, minimize fracture risk, and prolong lifespan. Thermomechanical processes induce phase transformations within the Ni-Ti alloy (5). Ni-Ti files exhibit three distinct microstructural phases: austenite (rigid), martensite (flexible), and R-phase (intermediate). The amount of alloy in each phase affects the mechanical properties of the file (6). Conventional Ni-Ti files have an austenite structure, and depending on the austenite finish (Af) temperature, direct phase transformation from austenite to martensite can occur in a single stage (7). Manipulating Af temperatures via post-heat treatment is conducted with the aim of altering the alloy's phase ratios and thereby enhancing flexibility and cyclic fatigue resistance to obtain safer, more durable instruments (8).

These new production strategies have led to the emergence of alloys such as M-wire, gold-wire, and C-wire (9). The WaveOne Gold system (WOG; Dentsply Sirona, Ballaigues, Switzerland) is a reciprocal system that is manufactured from a gold-wire and exhibits high flexibility, resistance to cyclic fatigue, and effective cutting. Gold heat treatment is carried out by heating the instrument and then slowly cooling it (10). This system consists of four file pieces: #20.07 (small), #25.07 (primary), #35.06 (medium), and #45.05 (large) (10). The unique parallelogram shape and two cutting edges of these files help minimize contact with canal walls while effectively clearing debris (10).

Micro-Mega has developed the One Curve (OC; Micro Mega, Besancon, France) rotational single-file system from C-Wire using a new heat treatment process. This special heat treatment imbues the files with remarkable pre-bending flexibility and controlled memory properties, ensuring the faithful preservation of the original root canal shape (11). This system consists of four file pieces (#20.04, #25.06, #35.04, and #45.04) with a variable cross-section design (triple helical cross-section at the tip and S-shaped cross-section close to the handle). In addition, the electropolishing process ensures that its resistance to cyclic fatigue is high, and the C-wire technology reduces the attachment of the instrument to inclined root canal walls, which facilitates root canal preparation (12).

There is no consensus in the literature about how many times a Ni-Ti instrument can be used safely in root canals and whether there is a difference in the amount of topographic change that occurs in the files when rotational and reciprocal file systems are used, especially in curved root canals. Therefore, the aim of this study was to examine the topographic changes that occur on file surfaces before and after single and multiple uses of single-file systems operating with reciprocal and rotational movements in curved root canals, using field emission scanning electron microscopy (FESEM).

The following null hypotheses were tested in this study:

1. There will be no differences in the topographic changes exhibited by WOG and OC files before preparation and after multiple uses.

2. There will be no difference in instrument separation between WOG and OC files based on the number of uses.

Materials and Methods

Sample Selection and Groups

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines.

As this study involved in vitro experiments, ethical committee approval was not required. A total of 14 simulated single root canals (EduDent, EndoPrep, İstanbul, Turkey), with a length of 16 mm, curvature radius of 3 mm, and curvature of 30°, were used for root canal preparation. Acrylic blocks were randomly divided into two groups—one group was prepared using WOG instruments and the other with OC instruments. Both WOG and OC files were divided into five subgroups: control, first use, second use, third use, and separated files.

Preparation of Root Canals

WOG Group (n = 5): WOG Glider (#15.02) and WOG Primary (#25.07) files were used with an X-Smart Plus motor (Dentsply Maillefer) in the WaveOne ALL mode, following the manufacturer's instructions and applying light apical pressure. Up-and-down movements of 3 mm were performed three times, followed by file removal, cleaning, and irrigation with 2 mL of 2.5% NaOCl. This cycle was repeated until the working length (WL) was reached. After each use, the files were removed, ultrasonic bath and sterilization procedures were applied, and then FESEM examinations were performed. On the second simulated tooth, the same WOG files and processes were used again. The same procedures were repeated on the third simulated tooth until a separated file occurred. To evaluate the metallurgical changes, the separated file piece was taken and observed via FESEM (Fig. 1).

OC Group (n = 5): One G (Micro Mega, Besancon, France) and OC 25.06 files (Micro Mega, Besancon, France) were used with the same motor, a light apical pressure, and a continuous rotational movement at 300 rpm speed and 2.5 N/cm torque, in accordance with the manu-

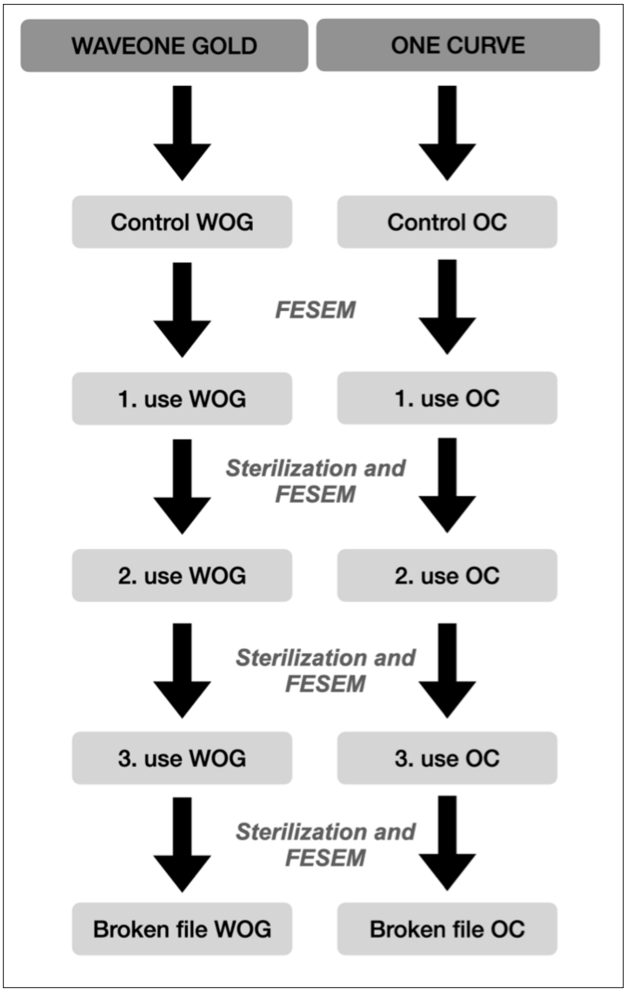

Fig. 1. Group distribution.

facturer's instructions. After every three strokes, the files were withdrawn and cleaned, followed by thorough irrigation with 2 mL of 2.5% NaOCl. After each use of the files, ultrasonic bath and sterilization procedures were applied, and then FESEM examinations were performed. On the second simulated tooth, the same OC files and processes were applied again. These procedures were repeated on the third simulated tooth until a fracture occurred. To evaluate the metallurgical changes, the separated file piece was observed via FESEM (Fig. 1).

Sterilization Procedures

The files were placed in an ultrasonic bath (Mercury, İstanbul, Türkiye) containing a precleaning enzymatic solution (Clenesafe PRO-ENZYM, Ruson Chemistry, İstanbul, Turkey) for 15 minutes. The instruments were then placed on sterilization papers that included information about the group and number of uses and were sterilized in an autoclave (Sümer, Ankara, Türkiye) for 30 minutes at 121°C and 210 KPa. This sterilization procedure was repeated after the files were used in each root canal.

FESEM Observations

Ni-Ti instruments were mounted and fixed in a standard position, and the surface properties of the files were analyzed using FESEM (Hitachi Regulus 8230, Co., Tokyo, Japan) at x100, x500, x2000, and x10000 magnifications. Photomicrographs of the 3 mm apical parts of the control files and the used files (WOG1, WOG2, WOG3, WOG separated file, OC1, OC2, OC3, and OC separated file) were compared and evaluated according to the following criteria: microcracks, debris, flattening of the file surface, deterioration of the cutting edge/blunting, and microcavity and burr amounts. During the evaluations, Troian et al.'s (12) three-point scoring system for spiral deterioration and four-point scoring system for surface wear were used (Table 1). All resulting micrographs were analyzed blindly using two precalibrated observers (0.89 kappa test). Descriptive data were reported for each group.

Results

The topographic changes of the files in the groups were examined, and the following results were obtained.

WOG Group

First Use: Examination of the file surfaces revealed no evidence of cracking or flattening. However, deterioration/blunting of the cutting edges, microcavities, and the presence of debris and burrs were observed (Fig. 2).

Second and Third Uses: Similar topographic changes were observed after the second and third uses of the WOG files,

Table 1. Scores for the spiral deterioration and surface wear of the files

Score	Spiral deterioration	Surface wear
1	No unraveling or reverse spiraling of the spirals	No deterioration along the surface
2	Unraveling and reverse spiraling observed in only one spiral	Minor deterioration present: 1-3 areas of defects along the surface
3	Unraveling and reverse spiraling observed in more than one spiral	Moderate amount of deterioration: 4-5 defective areas along the surface
4	–	Severe deterioration: more than 5 defective areas

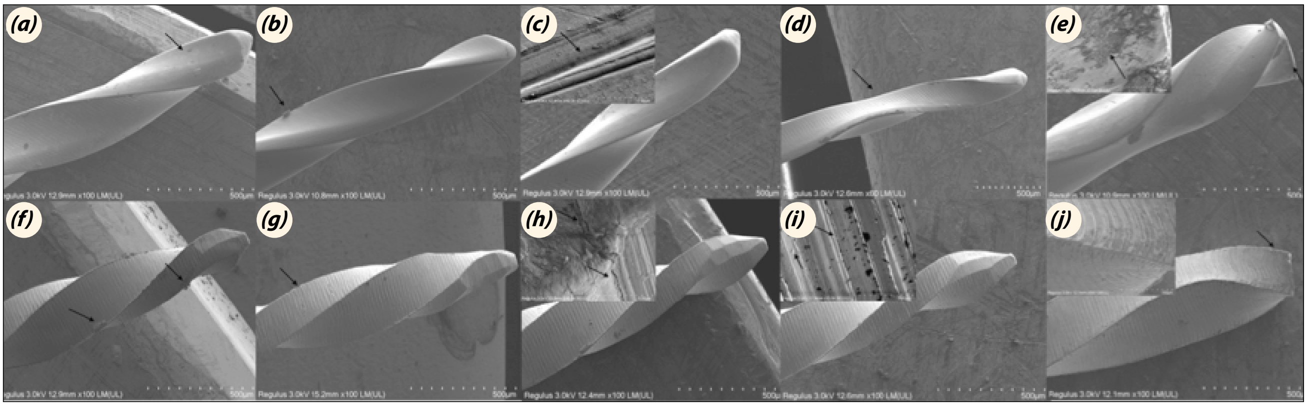

Fig. 2. Representative FESEM micrographs of the OC file surfaces **(a)** The arrow showing the presence of microcavities on the surface of the OC control file **(b)** The arrow showing the presence of burs on the surface of the OC first use file **(c)** The arrow showing the presence of microcrack on the surface of the OC second use file **(d)** The arrow showing the presence of flattening the surface of the OC third use file. **(e)** The arrows showing the presence of pitting corrosion the surface of the OC separated file. Representative FESEM micrographs of the WOG file surfaces **(f)** The arrows showing the presence of burs on the surface of the WOG control file **(g)** The arrow showing the presence of deterioration on the cutting edge of the WOG first use file **(h)** The arrow showing the presence of microcrack on the surface of the WOG second use file **(i)** The arrow showing the presence of debris and microcrack the surface of the WOG third use file **(j)** The arrows showing the presence of deterioration of the cutting edge of the WOG separated file.

with an increase in the number of cracks and debris on the file surfaces and deterioration/blunting of the cutting edge. However, there was no change in the microcavity and burr amount compared to the first use (Fig. 2).

Sixth Use and Fracture: It was found that by the sixth use, the cracks had spread over a large area, causing the files to break. Morphological examinations of the separated parts revealed the presence of pitting corrosion in significant areas. An increased amount of file flattening was observed, and deterioration/blunting on the cutting edge increased in proportion to the number of uses (Fig. 2).

OC Group

First Use: Examination of the file surfaces revealed no evidence of cracking, flattening, or deterioration/blunting of the cutting edges. However, microcavities, debris, and burrs were observed (Fig. 2).

Second Use: An increase in the number of cracks and debris on the file surfaces and deterioration and blunting of the cutting edge were observed. However, there was no change in the microcavity and burr amount compared to the first use (Fig. 2).

Third Use: An increased number of cracks on the file surfaces and further deterioration of the cutting edge were observed. Additionally, file flattening was observed for the first time after the third use. A difference in the amount of debris, microcavities, and burrs was observed compared to the second use (Fig. 2).

Eighth Use and Fracture: An examination of the separated file surfaces showed that the cracks had spread over a large area, causing the files to break. Morphological examinations of the separated parts revealed pitting corrosion in large areas. An increased amount of file flattening was observed. The deterioration/blunting of the cutting edge increased in proportion to the number of uses (Fig. 2).

The FESEM images revealed a greater accumulation of debris on the files that ultimately fractured in both groups, as compared to their less-used counterparts. The OC files fractured within the acrylic blocks on their eighth use, while the WOG files fractured upon their sixth use.

Discussion

The changes in the surface characteristics of reciprocal and rotary instruments following their repeated use in curved root canals, as well as the topographic changes in separated instruments, were investigated in this study. The results revealed that as the number of uses increased in both groups, cracks, flattening, deterioration of cutting edges, and microcavities on the file surfaces, debris, and smearing increased in frequency. Additionally, morphological examinations of the cross-sections of the separated pieces revealed pitting corrosion in wide areas. Therefore, the null hypotheses were rejected.

Ledesma-Montes et al. (13) reported the frequency of root dilaceration as 54.4% in the maxillary teeth and 45.6% in the mandibular teeth. Curved root canals, in particular, have so far created many difficulties for dentists and endodontists during root canal treatment. In curved root canals, the incidence of procedural errors such as apical transportations, root perforations, deterioration/blunting of files, and instrument separation are higher during root canal preparation compared to straight root canals (14,15). This study adopted a similar methodology to previous investigations (16-18) by employing moderately curved (30°) simulated acrylic root canals based on the Schneider method (19) for curvature calculation.

Several studies that have used scanning electron microscopy (SEM) to evaluate changes in the morphological characteristics of metallic materials have reported that SEM is a suitable method for accurately evaluating the deformation of files (12,20,21). FESEM is similar to traditional SEM but uses electrons instead of photons. In addition, unlike conventional SEM, FESEM does not require the sample to be metalized and enables detailed examination of the topography of the sample surface. Therefore, in this study, FESEM was used to evaluate the deformations and changes in the morphological characteristics of the instrument's surface.

The presence of a separated endodontic instrument within a root canal system has a negative prognostic effect on orthograde endodontic treatment, as it prevents the cleaning and shaping of the apical root canal (3). Instrument fracture, a complication of cyclic fatigue and torsional stress, especially in severely curved root canals, persists despite advancements in design, alloys, manufacturing, and techniques. This fracture can occur abruptly and unpredictably (22). The incidence of instrument fracture varies between 0.4% and 23% (3). It has been reported that 66–78% of these occurrences are due to cyclic fatigue, and 91% are due to torsional fatigue (23). In the present study, two instruments with different cross-sectional designs, heat treatments, and kinematics were compared. A WOG file is a reciprocating single file system with a parallelogram cross-section, two cutting edges, and an off-center design. Additionally, this file system has a gold heat treatment that occurs by heating and cooling slowly before manufacturing, thus increasing the elasticity of the file (24). An OC file is also a single rotation file system with a heat-treated C-wire, a triple helical cross-section in the apical part, and an S-shaped cross-section in the middle and coronal parts. Therefore, instruments with the same tip diameter (#25) and similar tapers were selected to minimize the study variables, as it is challenging to compare different instruments that vary in their heat treatments, kinematics, and design features. Previous studies have reported that the single-file technique results in significantly short preparation times compared to other full-sequence systems (25). Additionally, the experience levels of clinicians may also impact the deformation and fracture of the instruments used (26). Therefore, in this study, a single-file system was preferred, and an experienced endodontist performed the instrumentation.

Some topographic changes were observed on the surfaces of the files when they were evaluated after each use. Before use, there were some debris, burrs, and microcavities on the surfaces of the OC files, whereas there were no debris or microcavities on the surfaces of the WOG files. Karamifar et al. (20) and Saghiri et al. (27) reported the presence of pre-existing debris on the instruments utilized in their investigations. The authors stated that this could have been due to pre-use contamination and the manufacturing stages of the files. However, Pirani et al. (21) did not observe any such debris accumulation before use. The literature lacks a definitive consensus regarding pre-existing debris on instruments. The reported discrepancies might be attributable to variations within the manufacturing processes employed by different companies. As the number of uses increases, small surface deformations on the files can lead to further surface deformation and increased debris accumulation in these areas. Previous studies have reported that this situation may be caused by a reaction between the file surface and the irrigation solution (NaOCl), the electrostatic bond between the metal and the debris, or debris settling into microcracks (28), which may explain the topographic changes seen in our study.

Manufacturing processes of Ni-Ti files may result in uneven surfaces characterized by irregular edges, grooves, burrs, and microcavities. Hannan et al. (29) reported that microcavities on file surfaces distribute stress and may cause deterioration or flattening of cutting edges where stress is concentrated. In this study, crack formation and flattening of the file surfaces were not observed after the first use. However, deterioration/blunting of the cutting edges was observed after the second use of the OC files and after the first use of the WOG files. This finding confirms that microcavities on the file surfaces during the production phase affect the deterioration or blunting of the cutting edge, which increases with the number of uses.

Ni-Ti files may break during clinical use as a result of cyclic or torsional fatigue (30). Torsional fatigue failure occurs when the tip of the instrument gets stuck at any point in the canal and the stress caused by the continued rotation of the shaft exceeds the elasticity limit of the instrument. Cyclic fatigue fracture is caused by the accumulation of repetitive tensile and compressive stresses on a file subjected to curved canals. Cyclic fatigue has been reported as the main cause of instrument fractures during clinical use (30). In this study, fracture was observed on the eighth use of the OC files and the sixth use of the WOG files. Cyclic fatigue is affected by an instrument's kinematics, alloy, and metallurgical properties (31). Studies have reported that continuous rotational movement causes both tensile and compressive stresses in the inclined area and thus results in more cyclic fractures than reciprocation movement (32,33). However, in this study, the cyclic fracture resistance of the OC files, which involved continuous rotary motions, was found to be higher than that of the WOG files. Previous studies have suggested that reducing the core area may increase the fracture resistance of an instrument (34). Compared to tools with parallelogram cross-sections, tools with S-shaped cross-sections have lower core areas and thus exhibit better resistance to cyclic fatigue (34). The S-shaped cross-section of OC files may be a reason for their high resistance to cyclic fatigue. Compared to the WOG files, the OC files in this study separated more with use, which may have been due to the aforementioned reason.

The cyclic fatigue resistance of the OC files in this study may be partially attributed to the martensitic phase at room and intracanal temperatures. Previous studies have shown that modifying Ni-Ti instrument phases by adjusting the austenite start (As) and Af temperatures influences fatigue resistance (6,35). Stafoli et al. (35) reported that OC files' Af is between 40°C and 50°C, and they remain martensitic throughout their use, potentially contributing to superior fatigue performance compared to austenitic files, which are known for their relatively low flexibility and fatigue resistance (36).

Manufacturers recommend that Ni-Ti files should be used only once due to the wear and deformations caused on their surfaces by root canal preparation, irrigation solutions, and sterilization–disinfection processes (37). Pirani et al. (21) demonstrated through an energy dispersive X-ray spectroscopy (EDS) analysis that dentin residues accumulate in the grooves of these files, and they recommended the use of single-use endodontic instruments to reduce the possibility of cross-contamination. However, in clinical conditions, files may be used more than once for up to 3–4 root canals in the same molar or the same patient (21). Therefore, the cleaning, disinfection, and sterilization process is very important for minimizing and preventing the risk of cross-infection (21). In this study, the files underwent ultrasonic cleaning to eliminate any biological debris before autoclave sterilization.

A limitation of this study is that it was conducted using simulated root canals. Acrylic blocks simulate canals with highly standardized shapes, sizes, tapers, and curvatures. This provides a standard in vitro condition for comparing instrumentation techniques and devices (38). Acrylic blocks were used in this study to standardize and fix these factors; however, the mechanical properties of acrylic blocks differ from those of human dentin. The heat produced during instrumentation may soften acrylic, causing it to grip the cutting blades of the instruments, and due to the circular cross-section of the simulated canals, the findings obtained cannot be directly applied to clinical practice (38). However, the findings provide information on the fracture resistance of the instruments and the changes in surface properties that occur depending on the number of uses. Another limitation of our study is that only one type of rotary file and one type of reciprocating file were selected. Therefore, the results of this study cannot be generalized to all rotary and reciprocating systems.

Conclusion

In the present study, the OC files showed better fracture resistance than the WOG files. The results of this study showed that defects and deformations increased in both file types as the number of uses increased. The fracture resistance of Ni-Ti instruments is affected by their cross-sectional design, alloy properties, and heat treatments. Therefore, considering the evaluation of the surface properties of these files, a single use of WOG and OC files is safer than repeated use. Increasing the number of uses causes changes in the file surfaces, which increases the risk of fractures and negatively affects the prognosis of the treatment.

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