# Effects of 6 Single-File Systems on Dentinal Crack Formation

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## Abstract

**Introduction:** The purpose of this study was to compare the formation of microcracks after canal preparation performed with different single-file systems as One Shape (Micro-Mega, Besancon, Cedex, France), F6 SkyTaper (Komet Italia Srl, Milan, Italy), HyFlex EDM (Coltene/Whaledent AG, Altstatten, Switzerland), WaveOne (Dentsply Maillefer, Ballaigues, Switzerland), Reciproc (VDW, Munich, Germany), and WaveOne Gold (Dentsply Maillefer). **Methods:** Eighty-four human extracted mandibular central incisors (40–60 y) were selected and divided into 6 experimental groups ($n$ = 12 teeth) and a control group (unprepared teeth): One Shape (group 1), F6 SkyTaper (group 2), HyFlex EDM (group 3), WaveOne (group 4), Reciproc (group 5), and WaveOne Gold (group 6). Roots were then sectioned at 3, 6, and 9 mm from the apex, and the surface was observed under a stereomicroscope. Data were analyzed using logistic regression ($P < .05$). **Results:** No cracks were observed in the control group. All the systems tested caused cracks, mainly in the apical section (3 mm). HyFlex EDM (33.3%) and WaveOne Gold (58.3%) showed fewer microcracks than other experimental groups ($P < .01$); however, no significant difference was found between them in crack formation ($P > .05$). There was no difference among the other experimental groups ($P > .05$). **Conclusions:** All the instruments tested created dentinal cracks. Within the limitations of this study, the flexibility of nickel-titanium instruments because of heat treatment seems to have a significant influence on dentinal crack formation. HyFlex EDM and WaveOne Gold caused less microcracks than the other instruments tested. *(J Endod 2017;43:456–461)*

## Key Words

F6 SkyTaper, HyFlex EDM, microcracks, single-file system, Wave One Gold

**Significance**

Shaping procedures can induce dentinal microcracks. New nickel-titanium single files such as HyFlex EDM, WaveOne Gold, and F6 SkyTaper were marketed to shape root canals. Multiple factors (eg, flexibility) influence microcrack formation, especially in the apical third of roots.

Vertical root fracture (VRF) in endodontically treated teeth is 1 of the most frustrating complications of root canal therapy (1). Several factors including dentin thickness, obturation strains, and post placements such as dentinal microcracks have been investigated as major causes of VRF (2–5). Root canal shaping procedures and rotary instrumentation have the potential to induce crack formation (6–8), which can extend to complete fractures under functional load (9).

Several factors of nickel-titanium (NiTi) files such as different heat treatments, designs, cross-sectional shape, and kinematics may influence the generation of cracks (8, 10). Advances in NiTi instruments and their kinematics allowed the possibility to shape root canals with single-file systems activated in rotary or reciprocating motion (11, 12).

Reciproc (Rec) (VDW, Munich, Germany), WaveOne (WO) (Dentsply Maillefer, Ballaigues, Switzerland), and the recently marketed WaveOne Gold (WOG) (Dentsply Maillefer) are the main examples of commercially available single-file reciprocating systems (13). One Shape (Micro-Mega, Besancon, Cedex, France), F6 SkyTaper (F6ST) (Komet Italia Srl, Milan, Italy), and HyFlex EDM OneFile (HEDM) (Coltene/Whaledent AG, Altstatten, Switzerland) are instruments designed and marketed to shape root canals using the single-file technique with or without the use of a glide path file in continuous clockwise rotation.

HEDM is manufactured using electrical discharge machining. These files are produced with the well-known controlled memory treatment also used in HyFlex CM (Coltene/Whaledent AG) (14). F6ST is made with traditional NiTi and manufactured using the traditional grinding method; only 1 instrument, which is available in 5 different sizes and an S-shaped cross section with a constant taper of 0.06, is needed for root canal shaping (15). One Shape is another single-file system made with traditional NiTi and manufactured using the traditional grinding method. Its design has 3 different cross-sectional areas over the entire length of the working part and a variable pitch (16). Rec and WO have different cross section and design characteristics, but both are made with M-Wire (17, 18)

WOG uses the same reciprocating kinematics ("WaveOne ALL") as WO. According to the manufacturer, the instrument is repeatedly heat treated and cooled, giving the file a distinctive gold color and providing increased flexibility and cyclic fatigue resistance.

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Only 1 instrument, which is available in 4 different dimensions with an off-centered parallelogram design cross section and variable taper, is needed for root canal shaping (19).

To date, there are few studies in the literature regarding the occurrence of microcracks when using these single-file systems. Thus, the purpose of this study was to investigate the formation of microcracks after canal preparation performed with these different single-file systems.

## Materials and Methods

Human mandibular central incisors with mature apices from 40- to 60-year-old patients extracted for periodontal reasons were selected and kept in distilled water. Proximal radiographs of the teeth were taken, and only single-rooted teeth with a single straight canal (<5°) were included in the study.

The coronal portions of all teeth were removed using an Isomet low-speed saw (Isomet 1000; Buehler, Lake Bluff, IL) under water cooling, leaving roots approximately 13 mm in length. All the roots were inspected with a stereomicroscope (Optika szr 10; Optika Srl, Ponteranica [BG], Italy) with 45× magnification to detect any preexisting external defects or cracks. Teeth with such defects were excluded from the study and replaced by similar teeth.

Sample size estimation was calculated *a priori* with G*Power 3.1.9.2 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), and 7 groups (1 control and 6 experimental) of 12 teeth each were finally formed in order to have 80% power and an alpha error probability of 0.05.

In all teeth, the canal width near the apex was compatible with a size 10 K-file (Dentsply Maillefer). The buccolingual and mesiodistal widths of the canals were measured at 9 mm from the apex on radiographs. The homogeneity of the 7 groups with respect to the canal width at the 9-mm level was assessed by using analysis of variance ($P = 1.000$). Twelve teeth were left unprepared as the control group.

The working length was established by subtracting 1 mm from the length of a size 10 K-file inserted into the canal until the tip of the file became visible at the apical foramen. The periodontal ligament was simulated as in previous reports (11, 20).

## Root Canal Preparation

Root canal shaping procedures were performed with 6 different single-file techniques (One Shape, F6ST, HEDM, WO, Rec, and WOG) according to the manufacturers' instructions of each system with slow pecking motion and light apical pressure. If some resistance was felt that would have required more apical pressure, the instrument was removed, and the flutes were cleaned. This was repeated for each file until the working length was reached. A new file was used to shape each canal.

One Shape and F6ST files (groups 1 and 2, respectively), both size 25 with a taper of .06, and HEDM files (group 3), size 25 with a variable taper from .08 at the tip up to .04 in the coronal part, were used in continuous rotation as suggested by the manufacturers; WO Primary (Dentsply Maillefer) and Rec R25 files (groups 4 and 5, respectively), size 25 with a variable taper from .08 at the tip up to .04 in the coronal part, and WOG Primary (Dentsply Maillefer) (group 6), size 25 with a variable taper from .07 at the tip up to .03 in the coronal part, were used with the appropriate reciprocating motion.

All instruments were activated using a 6:1 reduction ratio contra-angle handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc, VDW) using continuous rotation or the preset reciprocating programs "Reciproc ALL" or "WaveOne ALL" depending on the instrument tested.

After each instrument insertion, the teeth were irrigated with 2 mL 3% sodium hypochlorite (Coltene/Whaledent AG) using a syringe and a 30-G Endo Irrigation Needle single side vent (Transcodent, Kesselort, Germany) placed 1 mm from the working length. After completion of the procedure, canals were rinsed with 2 mL distilled water. To avoid any artifact by dehydration, all roots were kept moist in distilled water throughout all the experimental procedures (5).

The mean preparation time (in seconds) was recorded for each file using a digital stopwatch. The same expert operator performed all root canal preparations, and 2 blinded operators checked the presence of dentinal defects or no defects. Whenever there was a disagreement, a consensus had been reached (5).

## Microscopic Examination

All the roots were horizontally sectioned 3, 6, and 9 mm from the apex with a low-speed saw under water cooling. The slices were then viewed through a stereomicroscope. The samples were photographed with a reflex camera (Nikon D90; Nikon Tokyo, Japan) attached to the stereomicroscope at a magnification of 24× and 80× to determine the presence of microcracks. Light-emitting diode (LED) transillumination was used to evaluate root surfaces. The LED transillumination was performed with the aid of a probe (Microlux Transilluminator; AdDent, Danbury, CT) used as suggested in a previous report (21).

## Definition of Defects

A *crack* was defined as only defects originating from the inner root canal space. All other defects that did not originate from the canal wall as craze lines were not considered cracks (Fig. 1 and 2). Roots were classified as cracked if at least 1 of the 3 sections obtained from each root showed even 1 crack (22, 23).

## Statistical Analysis

Logistic regression within the generalized linear model option of IBM SPSS (version 23; IBM, Armonk, NY) was used to ascertain the effects of canal preparation by 6 different file systems on the likelihood of crack formation. Pair-wise comparison (Tukey least significant difference) was conducted if a significant difference was found. Moreover, the number and percentage of defected roots in each group were evaluated. The level of significance was set at .05.

## Results

The distribution of microcracks per group and section level as well as the total cracked roots and their relative percentage per group are shown in Table 1. No cracks were observed in the control group. All the single files tested caused dentinal cracks. The logistic regression model was statistically significant ($P < .001$). Pair-wise comparison revealed a significant difference between the control group and all the experimental groups ($P < .05$). Logistic regression analysis revealed no significantly different roots with microcracks between HEDM and WOG ($P > .05$). However, HEDM showed statistically fewer roots with microcracks compared with the other experimental groups ($P < .05$). Furthermore, WOG showed less roots with microcracks than WO ($P < .01$), but no significant difference was found in comparison with One Shape, F6ST, and Rec ($P > .05$). No difference was observed among the other experimental groups (One Shape, F6ST, WO, and Rec) ($P > .05$).

The apical section (3 mm) showed the major number of microcracks for all of the tested instruments. Regarding the different sections, HEDM and WOG produced a similar amount of microcracks ($P > .05$), which was significantly less than the other experimental

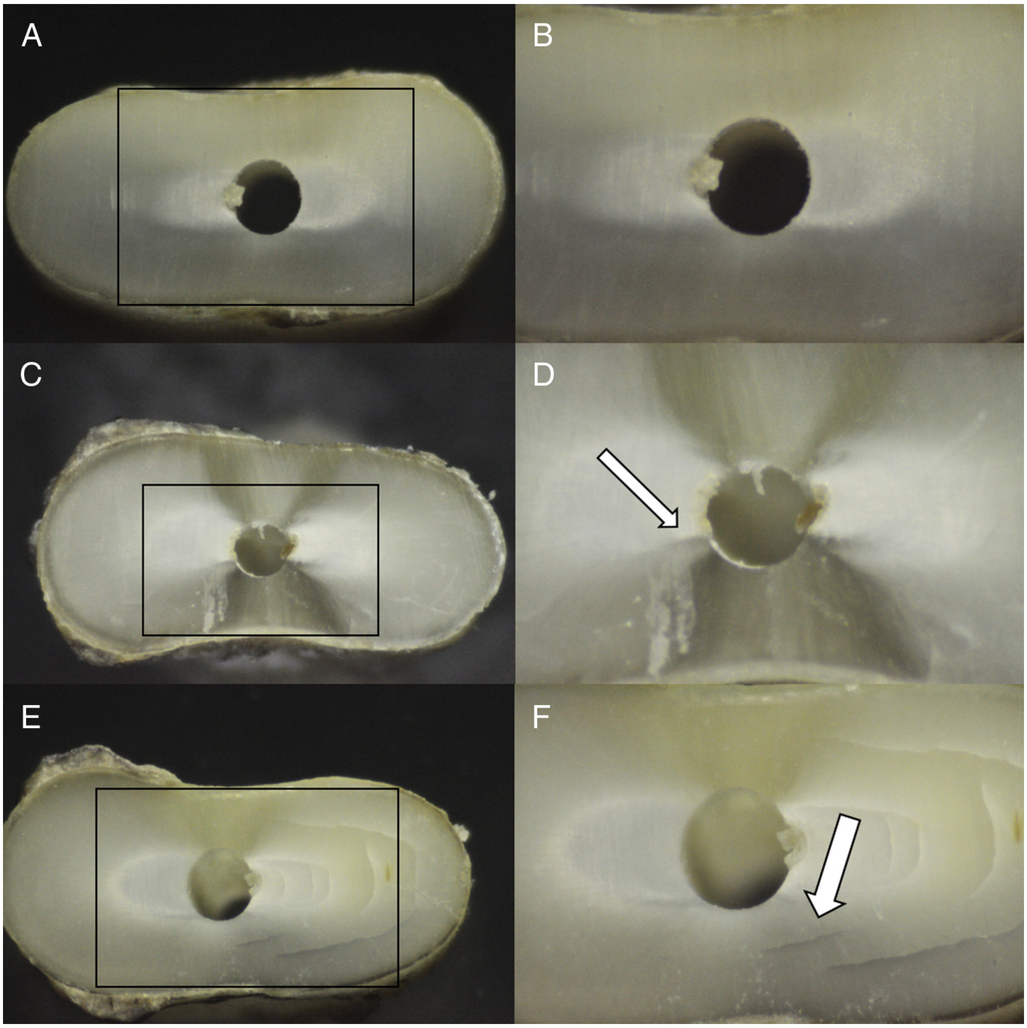


**Figure 1.** Cross sections at the 6-mm level. (*A*, *C*, and *E*) 24× and (*B*, *D*, and *F*) 80× magnifications. (*A* and *B*) No microcracks were observed in the control group. (*C* and *D*) A visible microcrack after NiTi instrumentation *(thin white arrow)*. (*E* and *F*) Craze lines *(thick white arrow)* after NiTi instrumentation were not classified as microcracks.

groups at 3, 6, and 9 mm ($P < .01$). No significant difference was observed between the other experimental groups (One Shape, F6ST, WO, and Rec) at each section level ($P > .05$). There was no statistically significant difference in preparation time for all of the tested instruments ($P > .05$).

## Discussion

The effect of 6 single-file systems regarding the incidence of microcracks after root canal preparation was evaluated (5, 20, 24). Studies on dentinal crack formation present some limitations. The patient age may play an important role in the presence of dentinal cracks (25); consequently, we selected teeth from a limited age group (40–60 y). In addition, acrylic blocks and a silicone impression material were used to simulate bone and periodontal ligament, respectively, as reported in previous studies (5, 25). Periodontal ligament simulation is important because it acts as a major stress absorber and should influence the outcome of such studies (5). In this study, the roots were distributed among the groups equally according to their root canal diameter at the 9-mm level (5). Standardization was achieved in the groups by including only teeth with a canal width near the apex compatible with a size 10 K-file and leaving all the roots approximately 13 mm in length (24). Moreover, illumination conditions may affect the ability to identify microcracks. In the present study, LED transillumination was used to enhance the visualization of dentinal defects (21). Preparation time could influence the results obtained. However, in this study, no difference in preparation time was observed for all of the tested instruments. These results are probably because of the easy canal configurations (mandibular central incisors) of the tested teeth as well as the use of only single-file techniques (no sequences of files) to shape root canals. In this study, as in previous reports, teeth were sectioned at different levels, looking for microcracks using a stereomicroscope (5, 24, 25). The sectioning method has a significant disadvantage related to its destructive nature and possible microcracks induced by the sectioning (26, 27). However, in our study, we speculated that it did not happen because no microcrack defects were found in the control group (5, 24).

Another nondestructive system such as micro–computed tomography (micro-CT) imaging was proposed to investigate the microcracks induced by rotary instrumentation (26, 27). A study on microcracks using micro-CT analysis reported no new microcracks caused by instrumentation (26).

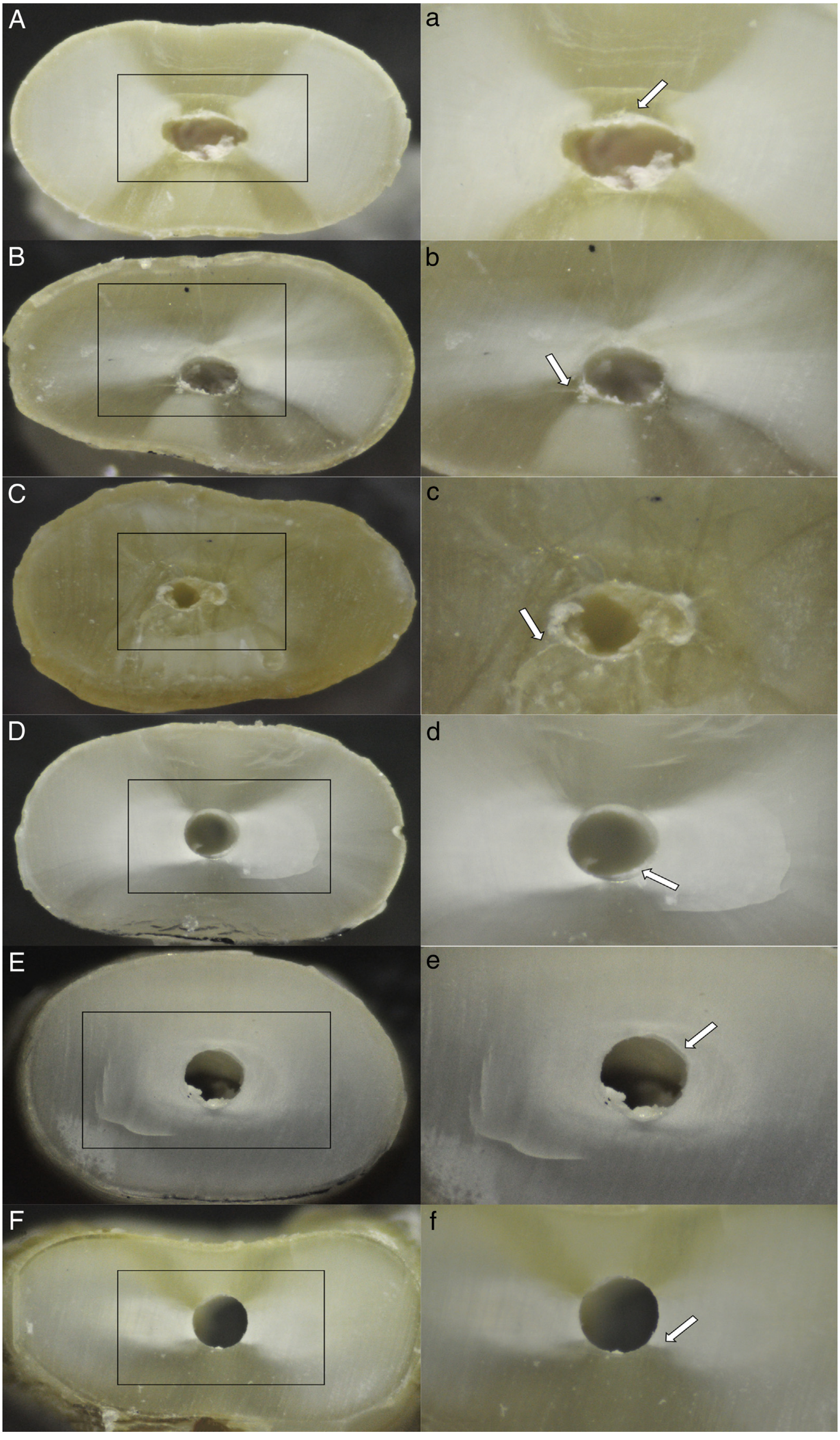


**Figure 2.** Representative microscopic cross sections from each experimental group at the 6-mm level at (*A–F*) 24× and (*a–f*) 80× magnifications. *White arrows* indicate dentinal defects. (*A* and *a*) One Shape, (*B* and *b*) F6ST, (*C* and *c*) WO Primary, (*D* and *d*) Rec, (*E* and *e*) HEDM, and (*F* and *f*) WOG.

**TABLE 1.** Number of Microcracks at Different Levels and the Number and Percentage of Roots with Microcracks per Group

| Group | Number of microcracks 3 mm | 6 mm | 9 mm | Roots with microcracks per group (%) |
|---|---|---|---|---|
| Control | $0^a$ | $0^a$ | $0^a$ | $0^a$ |
| One Shape | $12^c$ | $6^b$ | $6^b$ | $9\ (75)^{c,d}$ |
| F6 SkyTaper | $10^c$ | $5^b$ | $6^b$ | $9\ (75)^{c,d}$ |
| HyFlex EDM | $4^b$ | $1^a$ | $2^a$ | $4\ (33.3)^b$ |
| WaveOne | $12^c$ | $6^b$ | $8^b$ | $11\ (91.6)^d$ |
| Reciproc | $10^c$ | $6^b$ | $6^b$ | $9\ (75)^{c,d}$ |
| WaveOne Gold | $6^b$ | $1^a$ | $3^a$ | $7\ (58.3)^{b,c}$ |
| *P* value | .01 | .01 | .01 | .001 |

Similar lowercase letters in the same column indicate no statistically significant differences ($P > .05$).

In contrast, Jamleh et al (28) found new microcracks after instrumentation using micro-CT imaging. These contrasting findings could be caused by some methodological differences used in this study such as the exclusion of teeth that presented with microcracks before canal shaping, the use of high-resolution micro-CT scans, and the use of $BaSO_4$ staining to enhance microcrack detection (28).

Moreover, it was reported that the use of X-ray and computed tomographic imaging produces variable heating depending on the X-ray dose (resolution) and exposure time (29). Even if further research is necessary, it is reasonable to think that an increased temperature from the use of high-resolution micro-CT scans can induce dehydration of the samples and consequently the augmentation of already existing cracks, affecting the outcome of microcrack research, especially if teeth that presented with microcracks before canal shaping are not excluded (26, 27).

All 6 single-file systems used in this study created microcracks. This finding is in agreement with previous reports (5, 20, 24, 30).

The tip design of rotary instruments, cross-sectional geometry, constant or variable pitch and taper, and flute form could be related to crack formation (10). Although all instruments used in this study have different geometric features, this parameter seems to not affect the incidence of microcracks significantly. In fact, in many cases comparing instruments with different geometric features, no significant differences were observed (HEDM and WOG; WOG and One Shape, F6ST, or Rec; One Shape, F6ST, WO, and Rec). For this reason, the incidence of microcracks could be influenced by other features such as NiTi alloy and kinematic.

Previous studies reported higher flexibility of Controlled Memory files than those made from conventional NiTi wire or M-Wire (14, 31, 32). The high flexibility of WOG and HEDM files (this last file manufactured by Controlled Memory wire NiTi as HyFlex CM) may have contributed to the small number of cracks in this study, which is in agreement with previous reports (19, 20). HEDM produces fewer, but not significantly different, cracks compared with WOG. This result is probably caused by the less taper of WOG compared with HEDM and the high flexibility of HEDM caused by the synergistic effect of the Controlled Memory wire and the electrical discharge machining manufacturing process (33). Regarding kinematics, some studies suggested that the motion of a shaping technique could influence microcracks (5, 24, 30).

In this study, no statistical difference was observed among One Shape, F6ST (both made for continuous rotation), WO, and Rec (both made for reciprocation) or between HEDM (made for continuous rotation) and WOG (made for reciprocation). Instead, WOG produced less microcracks than WO even if the same reciprocating movement was used to activate both of these instruments. Therefore, these results suggest that shaping motion has no or at least a limited and unpredictable role on microcrack formation. Moreover, it is reasonable that the synergistic effect of kinematic and other factors such as NiTi alloy and geometric features influence microcracks.

Some studies showed less dentinal damage in reciprocating motion than continuous rotation (11) and vice versa (30) and no influence of kinematics on microcracks (34). The differences between these previous studies could be related to different methodologies such as the use of Gates-Glidden instruments (11), different sectioning levels (11), periodontal ligament simulation (11, 30), and different types and sizes of instruments (11, 30).

The major number of microcracks was observed in the apical section (3 mm) for all tested instruments, which is in agreement with previous studies (24, 35). For HEDM, Rec, WO, and WOG, the variable taper may explain the reduced number of microcracks in the middle and coronal teeth sections. Regarding F6ST and One Shape, these results are probably influenced from their cross section.

Within the limitations of this study, it could be concluded that multiple factors cause dentinal cracks, but the flexibility of NiTi instruments because of heat treatment seems to influence the incidence of microcracks more than other factors. In particular, HEDM caused less microcracks than other instruments, except WGO, which, in turn, produced less cracks than WO.

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