Comparison and evaluation of surface deformation of Hyflex controlled memory and Hyflex electric discharge machining nickel titanium rotary files and cyclic fatigue resistance after instrumentation and heat sterilization – An in vitro study

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Abstract

Aims: The aim of this study is to evaluate and compare the surface deformation and cyclic fatigue resistance of Hyflex controlled memory (CM) and Hyflex electric discharge machining (EDM) files following instrumentation and heat sterilization.

Subjects and Methods: Thirty Hyflex CM and thirty Hyflex EDM files were selected and profilometric images taken. Sixty extracted molars were decoronated, cleaning and shaping done with files, and subjected to autoclaving. Profilometric images were taken after instrumentation and sterilization. Cyclic fatigue testing was done at 30° and 60° in a custom-made jig.

Statistical Analysis Used: The Mann–Whitney test was used to compare profilometer and cyclic fatigue values between Hyflex CM and Hyflex EDM groups, whereas Friedman’s and Wilcoxon signed-rank test were used for intragroup comparisons.

Results: Intact Hyflex EDM files showed higher surface roughness values compared to Hyflex CM. Hyflex CM showed an increase in surface roughness after instrumentation and sterilization that was statistically significant while Hyflex EDM showed no statistical significance both after instrumentation and sterilization. Hyflex EDM showed a significantly higher mean number of cycles to failure than Hyflex CM at both degrees.

Conclusions: Hyflex EDM files are able to maintain their surface topography and also have cyclic fatigue resistance better than Hyflex CM after both instrumentation and sterilization.

Keywords: Cyclic fatigue; Hyflex controlled memory; Hyflex electric discharge machining; optical profilometry; sterilization

INTRODUCTION

The introduction of nickel titanium (NiTi) rotary instruments (1988) for endodontic procedures has made root canal therapy simpler and faster.[1] Despite all the advantages, the possibility of unexpected fracture of NiTi rotary files within canals because of cyclic/flexural and torsional fatigue distresses clinicians.[2] To prevent this procedural complication, manufacturers have come up with various methods to improve the mechanical properties and development of newer alloys is one among them.[3]

A thermally treated controlled memory (CM) alloy has been introduced recently in which the austenite/martensite transition temperature has been shifted so that

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a stable martensite microstructure is obtained at body
temperature (B19' martensite + R-Phase + Austenite).[4,5] This
removes the super elasticity property of conventional
NiTi instruments.[6] Thus, the induced fracture due to
torsion or flexural fatigue is prevented.

Hyflex CM files were introduced (Coltene Whaledent Alstatten,
Switzerland) based on a special thermomechanical procedure. These
files claim improved flexibility, resistance to fatigue
compared to conventional rotary instruments with added
advantage of reversion achieved by heat sterilization. Clinically,
these CM rotary instruments have shown outstanding cyclic
fatigue resistance.[4,7]

Hyflex EDM (Coltene Whaledent, Alstatten, Switzerland)
instruments are manufactured through electrodischarge
machining process. This causes a superficially isotropic
surface on the material, which is said to increase the
cyclic fatigue and torsional stress resistance of the
instrument.[8] Due to the unique control memory mechanism
of this instrument, it is easier to negotiate complex canal
curvatures causing less iatrogenic complications and also
exhibits reversion on heat sterilization.[4,7] The manufacturer
also claims that the cyclic fatigue resistance of Hyflex CM is
300% compared to Hyflex EDM which is around 700% thus
reducing the risk of fatigue failure.[9]

Due to the various manufacturing process, the
incorporation of surface microcracks and cavities in the
grooves and cutting edges of the files are unavoidable
which, in turn, compromises the cyclic and torsional
fatigue resistance of the files.[10] In addition, the chances of
failure increase exponentially when the files are rotated
inside a severely curved canal.[11] In a study, it was reported
that 93% of instrument failures were due to this type of
induced fatigue.[12]

The surface characteristics of NiTi instruments
subjected to cyclic fatigue were determined mainly
using scanning electron microscopy (SEM) or atomic
force microscopy (AFM).[13,14] Recently, Ferreira et al.
suggested the use of optical profilometry in analyzing
the surface properties of endodontic files because this
method makes it possible to analyze wider surfaces with
reproducible measurements and superior qualitative and
quantitative information when compared with AFM and
SEM.[15]

On reviewing the literature, studies examining the preuse,
postuse, and postheat sterilization surface properties
and topographies of Hyflex CM and Hyflex EDM files
through three-dimensional (3D) optical profilometry
and cyclic fatigue resistance of these instruments after
instrumentation and subsequent heat sterilization were
not available. Hence, the present study was undertaken to
evaluate them.

SUBJECTS AND METHODS
Sixty intact extracted permanent molars with root curvature
of 30°–60° (Schneider method) and with complete root
formation were collected according to CDC guidelines. Thirty
new Hyflex CM and thirty new Hyflex EDM instruments were
tested for the biomechanical preparation of curved root
canals. The instruments selected were 21 mm and 0.25 mm
tip size (Hyflex CM 0.06 taper, and Hyflex EDM ~ taper).
Before the experiment, the files were inspected using a
stereomicroscope and any file with defect was discarded.

The instruments were grouped as follows (n = 30):

- Group A: Hyflex CM
- Group B: Hyflex EDM.

Teeth were decoronated 2 mm above the cemento-enamel
junction (CEJ) to provide straight line access and stable
reference plane. Working length was calculated 1 mm short
of the apical foramen.

Surface roughness and deformation
The intact files from both the groups were evaluated under
optical profilometer before instrumentation, and the images
were recorded 3 mm from the tip of each instrument. Coronal
preflaring was done with 25/0.08 file in the Hyflex CM group
and with 25/0.12 file for the Hyflex EDM group. Cleaning
and shaping were conducted with all the experimental files
in compliance with the manufacturer’s recommendation.
The canals were irrigated with 3% sodium hypochlorite and
17% ethylene diamine tetra acetic acid (EDTA).

After instrumentation, the experimental files were observed
under the optical profilometer for surface roughness,
deformations of the cutting blades and flutes, and the
values were recorded for both. Instruments of both the
experimental groups were cleaned and subjected to
autoclave sterilization at 121°C at 15 psi for 15 min and
observed again under the optical profilometer to assess the
change in surface roughness, reversion of the cutting blades
and flutes, and the values were recorded.

Cyclic fatigue testing
Group A and Group B files were further subdivided into two
groups of 15 each as A1 and B1 (30°) and A2 and B2 (60°). Files
were tested inside a custom-made stainless steel
artificial canal having a curvature of 30° or 60° with a 5
mm radius of curvature in the laboratory. The diameter (1.5
mm) of the simulated canals was greater than that of the
instruments tested, thus allowing free rotation.

All the instruments were rotated according to the
manufacturers recommended settings (speed: 500 rpm
Torque: 2.5 Ncm) using a 16:1 gear reduction hand
piece (X-smart, DENTSPLY) powered by a torque controlled
electric motor until failure occurred. To reduce friction on the files and prevent overheating while rotating inside the curved canals, lubricating oil (WD-40, Milton Keynes, UK) was used.

A stop clock was used to measure the time duration from initiation of the cycles to failure. The time to fracture in seconds was multiplied by rotations per minute to obtain the number of cycles to failure (NCF) for each instrument. The length of each fractured instrument was measured using a digital caliper.

RESULTS

The statistical analyses were performed using the SPSS software version 22.0, 2013 (IBM Corp., Armonk, NY, USA). The Mann–Whitney test was used to compare profilometer and cyclic fatigue values between Hyflex CM and Hyflex EDM groups. Friedman's Test and Wilcoxon Signed-rank tests were used to compare the values between different time intervals and different curvatures. The level of significance was set at $P < 0.05$.

The parameters evaluated are as follows:
- $S_a = \text{Mean of the surface roughness}$
- $S_q = \text{Square root of the mean of the surface roughness}$
- $S_z = \text{Average height between peaks and valleys in the optical measurement field}$

The mean and standard deviations of the $S_a$, $S_q$, and $S_z$ values are shown in Table 1. The $S_a$, $S_q$, and $S_z$ values of the HyFlex EDM group were significantly higher than those of the HyFlex CM group before use, after use and after sterilization ($P < 0.05$). In both groups, the tested amplitude parameters ($S_a$, $S_q$, and $S_z$) increased after root canal preparation. These parameters were statistically significantly increased in the HyFlex CM group after use and sterilization ($P < 0.05$), but there was no significant difference between the after use and post sterilization groups ($P > 0.05$). In contrast, the increase in the HyFlex EDM group was not statistically significant both after use and sterilization ($P > 0.05$).

Figures 1 and 2 show the optical profilometric images of Hyflex CM and Hyflex EDM files before use, after use, and after sterilization.

The mean NCF and the length of fractured instruments in the cyclic fatigue testing are in Table 2. The mean NCF was higher and the mean length of fractured segment was smaller for Hyflex EDM than Hyflex CM and this was statistically significant ($P < 0.05$).

DISCUSSION

Hyflex CM and Hyflex EDM files are manufactured from the same CM wire but using different processes. Hyflex CM is manufactured using thermomechanical process during which there are the formation of surface irregularities such as pits, fissures, and metal folds increasing the surface roughness. This may act as a starting point for crack initiation which might progress during clinical usage causing fracture of the files due to cyclic fatigue.$^{[16,17]}$ This can be a reason for the increase in postinstrumentation roughness ($S_a$) seen in this study.

The $S_z$ values of Hyflex CM increased significantly after use and when poststerilization files were compared with intact file there was statistically significant difference, implying that Hyflex CM was not able to completely revert back to its original preuse configuration after heat treatment. Otsuka and Ren also reported that the transformation temperatures of used CM wire required to revert back to its original configuration increases with usage when compared to unused wire due to progressive accumulation of mechanical stress.$^{[18]}$

According to the qualitative parameters, intact Hyflex EDM files were found to have a significantly rougher surface than intact Hyflex CM files owing to their manufacturing process (electrical discharge machining). However, they showed no significant increase in the parameters evaluated both after use and sterilization. EDM technology perhaps helped in the better preservation of its surface characteristics and surface roughness values.$^{[19]}$ It may also be attributed to the unique white layer (SEM) formed on its superficial surface during manufacturing, which has higher hardness and better properties compared to the bulk material.$^{[8]}$

In addition to the EDM manufacturing process, another reason for the better performance of Hyflex EDM could
Table 1: Mean and Standard Deviations of $S_a$, $S_q$, and $S_z$ parameters before use, after use, and after sterilization of HyFlex CM and Hyflex EDM NiTi Instruments (in $\mu$m)

|                | Cutting blade | Flute          | Cutting blade | Flute          | Cutting blade | Flute          | Cutting blade | Flute          |
|----------------|---------------|----------------|---------------|----------------|---------------|----------------|---------------|----------------|
|                | Mean±SD       | $P$            | Mean±SD       | $P$            | Mean±SD       | $P$            | Mean±SD       | $P$            |
| $S_a$          |               |                |               |                |               |                |               |                |
| Before use     | 21456.03±3336.96* | BU versus AU (<0.001*) | 4135.03±709.95* | BU versus AU (<0.001*) | 70985.03±12777.19* | BU versus AU (0.20) | 13568±2128.06* | BU versus AU (0.18) |
|                | 42897.03±6004.09* | BU versus AS (<0.001*) | 7988.03±940.85* | BU versus AS (<0.001*) | 77980.07±16260.27* | BU versus AS (0.20) | 14743.07±3638.36* | BU versus AS (0.18) |
|                | 41784.93±3841.22* | AU versus AS (0.22) | 7586.97±1015.08* | AU versus AS (0.13) | 72344.97±11188.90* | AU versus AS (0.20) | 14167.03±2025.18* | AU Versus AS (0.18) |
| $S_q$          |               |                |               |                |               |                |               |                |
| Before use     | 29878.9±4795.90* | BU Versus AU (<0.001*) | 4987±656.36* | BU versus AU (<0.001*) | 86349.03±16635.09* | BU versus AU (0.36) | 18776.07±3671.42* | BU versus AU (0.36) |
|                | 58097.97±6374.01* | BU versus AS (<0.001*) | 10896.97±925.66* | BU versus AS (<0.001*) | 92098.03±14177.78* | BU versus AS (0.36) | 19908.1±4790.40* | BU versus AS (0.36) |
|                | 54667.93±6427.33* | AU versus AS (0.05) | 10196±1525.67* | AU versus AS (0.05) | 88653.97±14221.23* | AU versus AS (0.36) | 19450.07±2366.97* | AU versus AS (0.36) |
| $S_z$          |               |                |               |                |               |                |               |                |
| Before use     | 154675.07±25568.79* | BU versus AU (<0.001*) | 45763.07±5686.22* | BU versus AU (<0.001*) | 446873.97±86468.36* | BU versus AU (0.88) | 123359.97±16797.78* | BU versus AU (0.50) |
|                | 272785.03±46805.70* | BU versus AS (<0.001*) | 115853.97±18968.44* | BU versus AS (<0.001*) | 460895±56461.79* | BU versus AS (0.88) | 125876.03±25218.54* | BU versus AS (0.50) |
|                | 264668.1±35896.17* | AU versus AS (0.35) | 112433±15741.00* | AU versus AS (1.63) | 44761.07±68543.50* | AU versus AS (0.88) | 125752.9±16333.23* | AU versus AS (0.50) |

*Statistically Significant, Different superscript letters (xy) indicate statistically significant differences at 5% level for intergroup comparison between Hyflex CM and Hyflex EDM. SD: Standard deviation, EDM: Electric discharge machining, CM: Control memory
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be the difference in usage instructions recommended by the manufacturer. The larger coronal preflaring with Hyflex EDM 25/0.12 compared with Hyflex CM may have resulted in better preservation of Hyflex EDM 25/0.08 files' surface properties.\[19\]

In parallel with the present study, Uslu et al. also compared the alterations in the surface topographies of Hyflex CM and Hyflex EDM files before and after root canal preparation using 3D optical profilometry, and the results were in accordance with the results obtained in our study.\[19\]

Lopes et al. reported that the grooves on the cutting edges of files have negative effect on the cyclic fatigue resistance and might be responsible for their lower cyclic fatigue resistance.\[20\] Hence, this study also assessed the cyclic fatigue fracture of these instruments after instrumentation and heat sterilization.

Pruett et al. showed that the instruments separate at the point of maximum flexure of the shaft, which corresponds to the midpoint of curvature.\[21\] In this study, Hyflex CM fractured at a range of 6.8–7.1 mm at 30° and 60° which was statistically significant implying that the point of flexure changes for the file when subjected to different curvatures. For Hyflex EDM, the fracture occurred at a range of 5.5–5.7 at 30° and 60°, and this was not statistically significant showing that the point of flexure remains the same for the file irrespective of the angle of curvature. This could be because the taper of Hyflex EDM decreases from 8% to 4%, 4 mm from the tip of the file where it is subjected to maximum flexural stress.\[12\]

The mean NCF was higher for Hyflex EDM than Hyflex CM at both angles, and this difference was statistically significant. This may be attributed to the better preservation of surface topography and better fatigue life of EDM files.

Under the conditions of this study, fracture and overall failure were more frequent in severely curved canals (60°) than in moderately curved canals (30°). This can be explained by the overloading induced on the instrument by an abrupt change in canal curvature which restrains the rotating instrument, giving rise to multidirectional loading (tension, bending and torsion) that lead to fracture of the instruments.\[22\] An increase in angle of curvature from 30° to 60° led to significant increase in fracture incidence for both file systems which was statistically significant.

**CONCLUSIONS**

Within the limitations of the present study, Hyflex CM files showed a significantly higher level of higher surface roughness and deformation compared with the Hyflex EDM files after the preparation of severely curved canals and sterilization. EDM technology provided better preservation of NiTi file surface after clinical usage in severely curved canals when compared with conventional grinding method. Hyflex EDM files have a better resistance to cyclic fatigue at both 300 and 600 curvatures than Hyflex CM.

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**Conflicts of interest**
There are no conflicts of interest.

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**Table 2: Mean number of cycles to failure and mean length of fractured fragment (in mm) between different curvatures in Hyflex CM and Hyflex EDM groups**

|                      | Mean ± SD | Length of fractured fragment (in mm) |
|----------------------|-----------|-------------------------------------|
|                      | NCF       |                                     |
| Hyflex CM            |           |                                     |
| 30°                  | 2228.07 ± 140.54*  | 6.87 ± 0.74*                     |
| 60°                  | 1406.4 ± 124.23*   | 7.06 ± 0.64*                     |
| Hyflex EDM           |           |                                     |
| 30°                  | 4603.27 ± 423.05*  | 5.58 ± 0.52*                     |
| 60°                  | 3373.47 ± 306.44*  | 5.73 ± 0.33*                     |

Different superscript letters indicate statistically significant differences at 5% level (ab, for intragroup comparison; xy for intergroup comparison). NCF: Number of cycles to failure, SD: Standard deviation, EDM: Electric discharge machining, CM: Control memory

**Figure 2:** Profilometric image of Hyflex electric discharge machining files: (a) Before use; (b) After use; (c) After sterilization
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