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COMPARATIVE STUDY OF DYNAMIC CYCLIC FATIGUE RESISTANCE OF TWO FILES WITH DIFFERENT KINEMATICS.

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Objectives: The aim of the study was to determine the dynamic cyclic fatigue resistance (DCFR) of R-motion file and Protaper Next file (PTN) by differential scanning calorimetry (DSC) and scanning electron microscopy (SEM).

Methods: R-motion file (25/.06), PTN file (25/.06) were used and divided into 2 groups (n = 28) according to the file type. DCFR was performed using an artificial canal. Files were allowed to work until separation. The numbers of cycles to failure (NCF) and the time to fracture (TTF) were calculated. The files were subjected to DSC and SEM.

Results: R-motion files had higher NCF and TTF compared to PTN files. SEM examination showed that all files showed ductile fracture.
DSC of the R-motion file displayed Austenitic phase at body temperature) 37 ˚C) while PTN file failed to demonstrate any peaks within the applied heat range.

Conclusions: R-motion files had higher CFR and TTF than PTN files.

Key words: dynamic cyclic fatigue, R-motion file, PTN file

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Conflicts of interest:
The authors declare no conflicts of interest.

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ETUDE COMPARATIVE DE LA RÉSISTANCE À LA FATIGUE CYCLIQUE ENTRE 2 LIMES ENDODONTIQUES

Objectifs : Le but de l'étude était de déterminer la résistance à la fatigue cyclique dynamique (DCFR) du fichier R-motion et du fichier Protaper Next (PTN) par calorimétrie différentielle à balayage (DSC) et microscopie électronique à balayage (MEB).

Méthodes: Le fichier R-motion (25/.06), le fichier PTN (25/.06) ont été utilisés et divisés en 2 groupes (n = 28) selon le type de fichier. Le DCFR a été réalisé à l'aide d'un canal artificiel. Les dossiers ont été autorisés à fonctionner jusqu'à la séparation. Le nombre de cycles jusqu'à l'échec (NCF) et le temps jusqu'à fracture (TTF) ont été calculés. Les fichiers ont été soumis au DSC et au SEM.

Résultats: les fichiers R-motion avaient un NCF et un TTF plus élevés que les fichiers PTN. L'examen SEM a montré que tous les dossiers présentaient une fracture ductile. Le DSC du fichier R-motion affichait la phase austénitique à la température corporelle (37 ˚C), tandis que le fichier PTN n'a pas réussi à démontrer de pics dans la plage de chaleur appliquée.

Conclusions: les fichiers R-motion avaient un CFR et un TTF plus élevés que les fichiers PTN.

Mots clés: fatigue cyclique dynamique, fichier R-motion, fichier PT

Introduction

Proper cleaning and shaping of the root canal are considered as an essential goal to control infection in the root canal system. During this process file separation represents a serious problem which is reported to occur by 0.09% to 5% [1]. This separation occurs due to either cyclic failure or torsional failure [2]. Cyclic fatigue occurs when the file rotates freely inside a curved canal, leading to tension and compression in the region of maximum flexure and finally leads to file separation [3]. As cyclic fatigue represents a high percent of mechanical failures [4], this motivated both the researchers and manufacturers to conduct further studies about cyclic fatigue testing.

Also, a lot of changes can occur to the file surface topography after mechanical use i.e. micro pitting. These pits can give rise to microcracks and finally lead to file separation[5]. Therefore, the impact of this study was to assess the NCF, TTF and surface characterizations of the files by SEM. Also, to determine the phase transformation using DSC. The null hypotheses tested were that there wouldn't be significant differences among the instruments regarding their cyclic fatigue resistance (CFR).

Materials and Methods

Sample size calculation: A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference would be found between different tested groups regarding cyclic fatigue. By adopting an alpha level of (0.05), a beta of (0.2) (i.e., power=80%) and an effect size (f) of (0.595). Sample size calculation was performed using A G*Power program version 3.1.9.7 [1] based on a previous study [7]. The predicted sample size (n) was a minimum total of 48 (i.e., 24 per group).

Sample grouping: 28 files of each file system were selected for the study.

In this study we used two file systems size 25 taper 6% and 25mm in length: R-motion file (FKG, Dentaire, la chaux de fonds, Switzerland) and PTN (Dentsply, Maillefer, Ballaigues, Switzerland) file. R-motion file is a newly launched heat-treated, electropolished reciprocating file with a constant taper and a round triangular cross section [8-11]. The reciprocating angle is (170° counterclockwise and 50° clockwise rotation modes)[12]. PTN file is an M Wire file system with an increasing and decreasing percentage of taper [13]. A new custom-made device (Egyptian patent number 265/2021) following the international standards [14, 6] was manufactured to perform dynamic cyclic fatigue testing. The device contains a custom-made frame to hold both the contra angle and the SS artificial canal. The simulated canal had a 5 mm radius with 60˚ curvature. The file tip was 6 mm away from the center of the curvature [14, 6]. The simulated canal was sealed with a glass cover [6, 14-16].

Dynamic cyclic fatigue testing: VDW Silver Reciproc endodontic rotary motor (Munich, Germany) with a 6:1 reduction hand piece (Sirona, Bensheim, Germany) at speed 300 rpm was used with R-motion file. While ZX J. Morita endodontic rotary motor (Corp, Tokyo, Japan) with a contra angle (16:1 reduction) at speed 300 rpm and torque 2 Ncm was used with PTN file. The tested files were mounted in its position in the SS canal and immersed in a water bath at 37℃. The rotating files were covered by lubricant oil. All the files were allowed to continuously work until separation. The TTF was recored using a stopwatch[6, 11, 17] and the NCF was recorded using the following equation: NCF= Time spent until fracture(s) ×300rpm/60S [18-22].

The separated segment was collected and placed in a pouch. Then the sample was subjected to SEM and DSC.

SEM: Three samples of the fractured surfaces of the files were subjected to SEM (ZEISS Supra 35VP; GmBH, Oberkochen, Germany) to assess the topographic features of the fractured files using a high magnification of (180x, 500x and 1000x [7, 23].

DSC: Three fragments of the fractured 5mm of the tip from each group were subjected to DSC[24]. The Specimens weighed from 2.5mg to 8.5mg. The DSC was conducted over temperature range from 0 °C to 50 °C. The liquid nitrogen was used to cool the specimen from 50°C to 0 °C. while Heating was obtained through heating from 0 °C to 50 °C. The linear heating cooling rate was 10 °C/min [6, 25]. A CALISTO data processing software V.149 was used to analyze the obtained graphs.

Statistical analysis: Numerical data were presented as mean and standard deviation (SD) values. Shapiro-Wilk's test was used to check their normality. Data was found to be normally distributed and was analyzed using one way analysis followed by Tukey post hoc test. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.3.1 for Windows[2].

Results

Mean and SD values of the NCF and TTF (minutes) for different file types were presented in tables 1 and

1- Faul, Franz, et al. "G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences." *Behavior research methods* 39.2 (2007): 175-191.

2- R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

2. SEM Oof the tested files showed that all tested files had the ideal morphological appearance of ductile fracture with many voids and fatigue striations (Figures 1 and 2). At 1000x the outer surface of PTN file showed machining grooves which were absent on the outer surface of R-motion file (Figure 3). The phase transformation of PTN file showed no peaks (Figure 4). While the R-motion file showed the Austenite start (As), Austenite finish (Af), Martensite start (Ms) and Martensite finish (Mf) at 29, 34.2, 25.8, 30.5 (Figure 5).

Table 1. mean and standard deviation (SD) values of number of cycles to failure (NCF)

File type	Number of cycles to failure (NCF) (mean±SD)
R-Motion	944.57±221.81^{A}
PTN	345.43±76.98^{B}
p-value	**<0.001***

** statistically significant (p<0.05). Means with different superscript letters within the same columns are significantly different*.

Table 2. mean and standard deviation (SD) values of TTF (minutes).

File type	Time to failure (TTF) (mean±SD)
R Motion	3.15±0.7^{A}
PTN	1.15±0.26^{B}
P- value	**<0.001***

** statistically significant (p<0.05). Means with different superscript letters within the same columns are significantly different.*

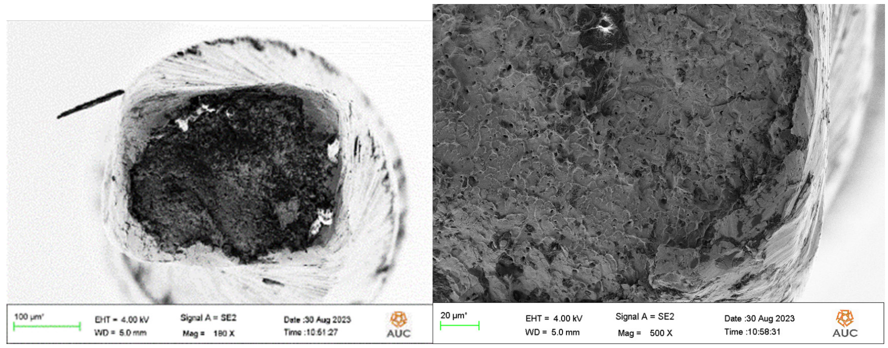

Figure 1. SEM the tip of PTN file. Figure (A) is at magnification of 180x, showing the ideal morphological appearance of ductile fracture with a multiple crack surrounding a centrally located overload zone (red arrows). Figure (B) is at a higher magnification of 500x, showing large micro voids (yellow arrows) and fatigue striations (blue arrows).

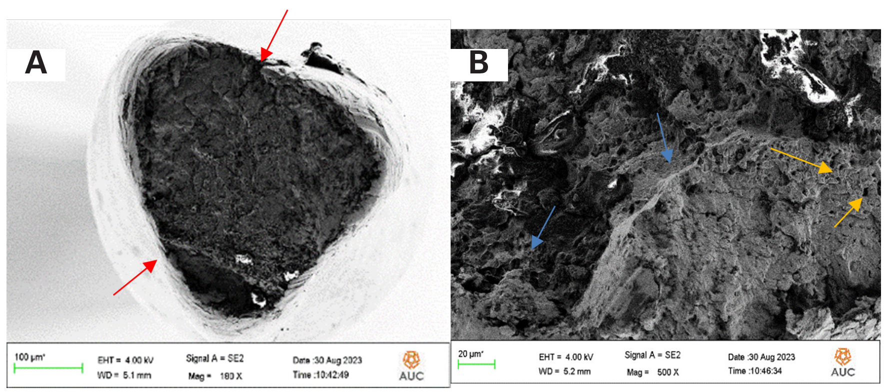

Figure 2. SEM of the tip of the R Motion file. Figure (A) is at magnification of 180x. showing ideal morphological appearance of ductile fracture with a multiple crack surrounding a centrally located overload zone (red arrows). Figure (B) is at magnification of 500x. High magnification showing a large micro void (yellow arrows) and fatigue striations (blue arrows).

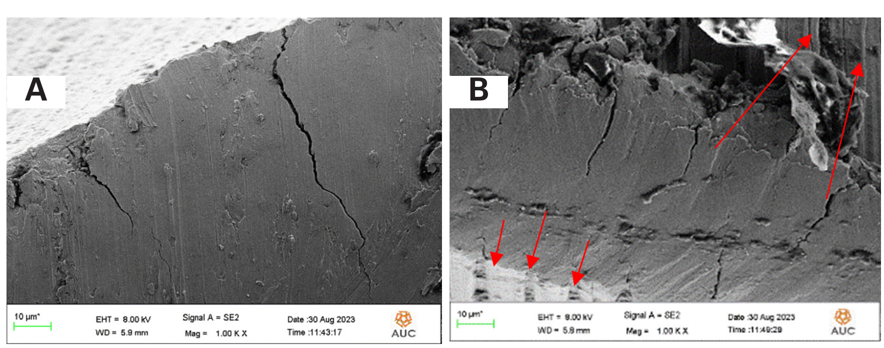

Figure 3. SEM at 1000x. of the outer surface of R-motion file (A) showing the smooth outer surface. And for PTN file (B) showing the machining grooves (red arrows) on the outer surface.

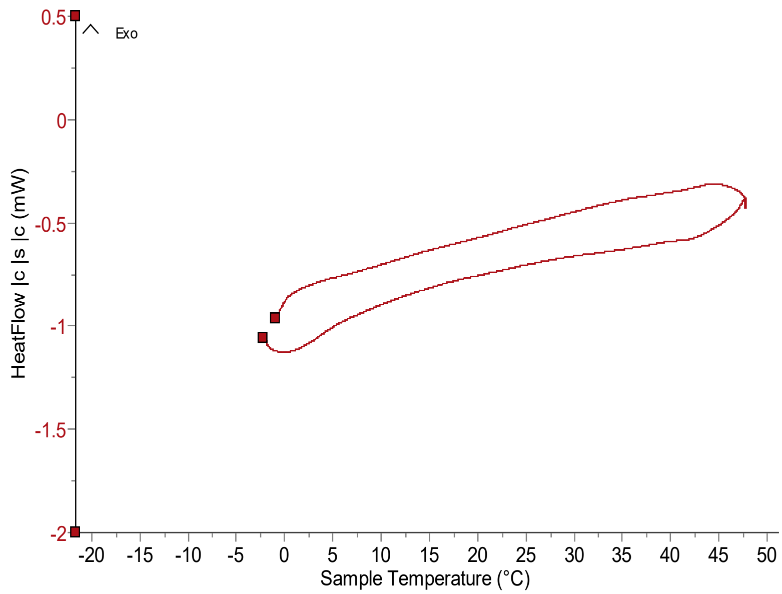

Figure 4. DSC plot for PTN file. The red arrow indicates the direction of heating, and the blue arrow indicates the direction of cooling.

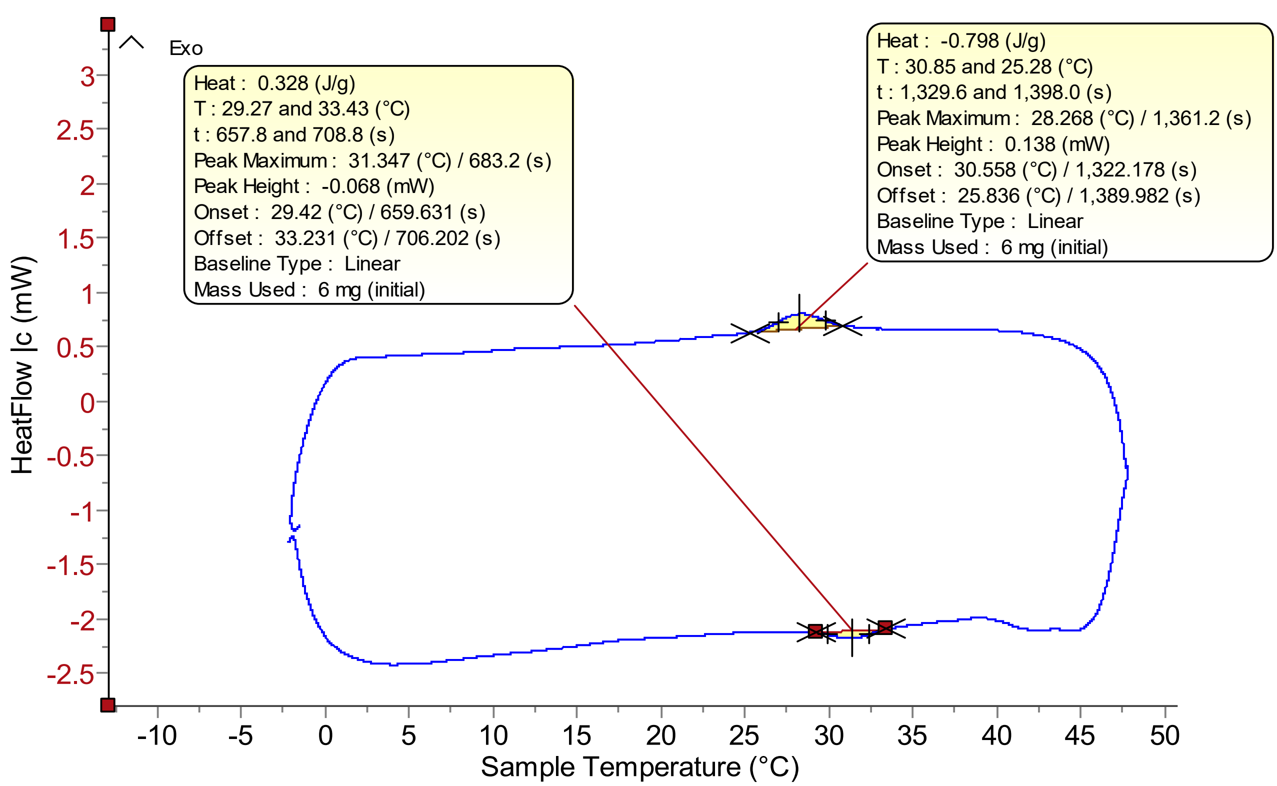

Figure 5. DSC plot for R Motion file showing cooling and heating curve with phase transformation temperatures. The red arrow indicates the direction of heating, and the blue arrow indicates the direction of cooling.

Discussion

Our study assessed the dynamic CFR of PTN files and R-motion files using SEM and DSC. Both file systems had the same tip size (25) and taper (6%) for better standardization. Many studies had imitated the clinical situation during dynamic cyclic fatigue testing [26-33].

The results showed that the NCF and TTF of R-motion files were higher than PTN files. This may be related to the results of Gouédard *et al* [34], Plotino *et al* [35] and Elnaghy *et al* [36] when used electropolished files compared to other files. Their results were explained by the electropolishing process that forms a more homogeneous oxide layer that protects the surface and reduces surface irregularities that may act as a point for stress concentration and crack initiation.

The low cyclic fatigue resistance of PTN file may be related to its composition. It mainly contains the austenite phase and maintains its pseudo-elastic state. In addition, according to Pedullà E *et al* [37] the decreasing and increasing percentage tapered design over the active portion of PTN file gives the file larger diameter at the maximum stress point and instruments of large diameter has a lower CFR.

The cross section of the file also influences CFR and TTF [38]apical preparation and step-back procedures. Maximum torque, apically directed force and the numbers of revolutions were recorded at a resolution of 100 samples s-1. Load causing separation as required by the ISO 3630-1 test and cyclic fatigue was also recorded. Mean maximum scores were calculated and statistically tested using one- and two-way analyses of variance. Results: Highest and lowest torque scores were recorded, respectively, in straight canals in plastic blocks at 25 Nmm and in natural canals at 14 Nmm. Significant differences were recorded for canal type and preparation phase ($P < 0.0001$. The PTN has a rectangular cross section [13] while R motion file has a rounded triangular cross-section. This was the case in a study conducted by Faus-Llácer V *et al* [39] found that the CFR of T Pro E2 files and T Pro E4 files with triangular cross section had high CFR compared to T Pro E1 files with rectangular cross section and their results may be attributed to the core mass when it increases, the contact points between the walls of the root canal and the file surface increases and so, the CFR of the Ni-Ti files decreases.

Also, these results may be related to the different kinematics of the used files. These results agreeing with Keskin *et al* [40] and Dias *et al* [21]that found the files used in reciprocation motion had higher CFR compared to other files used in continuous rotation motion. And their explanation was that the reciprocation motion prevents the file taper lock by clockwise and counterclockwise motion which releases the applied stresses on the file.

In the present study SEM of the outer surface of PTN file showed several vertical machining grooves, while R-motion file showed a smooth surface due to electropolishing process. Similarly to Lopes *et al* [42] found electropolished files had smoother surface compared to non-electropolished files and their result attributed to the effect of electropolishing in reducing surface irregularities.

DSC analysis, in the present study the DSC analysis of PTN file did not show any peaks on heating or cooling. This suggests that PTN files maintain the original phase of M Wire. While DSC analysis of R-motion file showed the (As, Af, Mf, and Ms) was (30.5, 34.6, 31.1, 25.05. This suggests that this file is at Austenitic state at body temperature (37ºC) and Martensitic state at room temperature (25ºC)

Conclusion

Under the circumstances of this study, it was concluded that:

The dynamic cyclic fatigue resistance of electropolished R-motion files was statistically significantly higher than PTN files. R Motion files and PTN files show ductile type of fracture when exposed to dynamic cyclic fatigue. R Motion files are in a Martensitic state at room temperature 25ºC. And in an Austenitic state at body temperature 37ºC.

Acknowledgments

None.

Recommendations

Conduct DSC below 0ºC and above 50ºC.

The TTF should be calculated electronically to avoid any bias.

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