INFLUENCE OF INSTRUMENT DESIGN ON THE ABRASION WEAR RESISTANCE OF THREE DIFFERENT ROTARY NICKEL-TITANIUM ENDODONTIC INSTRUMENTS

Part one: Evaluation of wear in nickel-titanium instruments

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الملخص

تهدف هذه الدراسة المعملية إلى تقييم ومقارنة مقاومة التآكل (Abrasion wear) الذي سجل على ثلاثة أنظمة مختلفة لمبارد الأسنان آلية الحركة من سبيكة النيكل التيتانيوم بعد الاستخدام المتكرر. أستخدمت ثلاثون سنا مخلوعه ذات جذر واحد من الفكين العلوي والسفلي(السن الناجذ مع قناة واحدة)، وقسمت هذه الاسنان عشوائيا إلى ثلاث مجموعات تحتوي كل مجموعة على عشرة أسنان، حيث تم تحفير قناة الجذر بالحك بإستخدام المبرد في تسلسل تاجي سفلي أو تاجي إلى أسفل.

أستخدم في المجموعة الأولي نظام EndoWave (J. Morita Co., Kyoto, Japan) وفي المجموعة الثانية نظام K3,(SybronEndo,CA,USA) أما المجموعة الثالثة فقد أستخدم فيها نظام ProFile (Dentsply Maillefer, Ballaigues, Switzerland) . تم تحديد الوزن المفقود من المبرد فى المرحلة الاولى أما في المرحلة الثانية فقد أخذت صور مجهريه للمبارد الآلية بعد استخدامها في عشر قنوات جذرية وتم تحليل ودراسة التغيرات الشكلية التي حدثه للمبارد. تم تحليل بيانات فقد الوزن بطريقة One-way ANOVA وأستخدمت طريقة Two-way ANOVA and Fisher's PLSD لتحليل التغيرات الشكلية عند مستوى الدلالة (0.05). أظهرت النتائج أن مقاومة EndoWave لتآكل أقل من مقاومة نظام K3 و ProFile (P<0.05). وأظهر نظام ProFile أفضل مقاومة للتآكل مقارنه مع باقي الأنظمة (P<0.05).

ABSTRACT

The objective of this in vitro study was to evaluate and compare the abrasion wear resistance of three different Ni-Ti rotary file systems; ProFile, K3 and EndoWave, after repeated use. Thirty extracted intact, single-rooted human mandibular and maxillary premolar teeth with a single canal were used. They were randomly divided into three groups of 10 teeth each. The root canal was instrumented using a crown-down sequence with EndoWave (J. Morita Co., Kyoto, Japan), K3 (SybronEndo, CA, USA) or ProFile (Dentsply Maillefer, Ballaigues, Switzerland). In Stage 1, the loss of file weight was measured, and in Stage 2, photomicrographs of the instruments were taken after 10 canal preparation cycles and analyzed to examine the morphological changes caused by instrumentation. Data were analyzed by one-way ANOVA Method for loss of weight, and two-way ANOVA and Fisher's PLSD for the morphological changes at 0.05 significance level.

The results showed that EndoWave had significantly less wear resistance than K3 and ProFile (P<0.05) and that ProFile exhibited significantly better wear resistance than the other Ni-Ti rotary instruments (P<0.05).

KEY WORDS: Abrasion; Defect; Instrument design; Nickel-Titanium; Rotary

INTRODUCTION

Nickel-Titanium (NiTi) alloy has become a popular material for endodontic files because it has a much lower elastic modulus than stainless steel [1]. The wear resistance of NiTi alloy depends on its mechanical properties, such as hardness of alloy and work hardening. Each of the mechanical properties contributes to a higher or lower level of wear resistance in different wear modes [2]. The wear of NiTi rotary endodontic instruments may occur during root canal preparation in three forms; fatigue, corrosion and abrasion.

An important perceived disadvantage of rotary NiTi instruments is their propensity to develop intraoperative defects, particularly fractures [3]. The NiTi rotary endodontic instruments usually fracture through two mechanisms of fatigue. The first mechanism is torsion or metal fatigue caused by flexure. Fracture due to torsion occurs when the tip of the file or any part of the instrument becomes locked in the root canal, while the shank continues to rotate in the hand piece [4]. The other type of fracture is caused by stress leading to fatigue of the metal itself (cyclic fatigue) [5].

The corrosion of NiTi rotary instruments occurs either prior to or during instrumentation due to disinfection, sterilization and irrigation, which could lead to early fracture of the instruments [6-10]. The abrasion wear is cutting away of a surface by abrasive asperities. (Hard surface in contact with a softer surface as NiTi instrument and dentine) Abrasive wear occurs when a material is removed due to contact with hard particles. Cheung et al. [11] mentioned that torsional failure is characterized by circular abrasion marks. Therefore, there could be a relationship between fatigue and abrasion wear of NiTi rotary instruments. Xiaopeng & Xie [12] reported that the surface wear of metal is attributed to material fatigue destruction; a result of repeated friction which is related to the stress state.

Numerous factors have been implicated in the fracture of NiTi endodontic instruments, among which are operator proficiency [3,13-14], method of use [15-16], anatomic configuration of the canals [3,17], design of the instrument [18] and rotation speed [4,19]. Unfortunately, many of these fractures happen unexpectedly without any signs of permanent deformation [20]. To reduce the risk of instrument fracture within root canals, all files should be carefully examined after each use [21]. Any file showing defects should be discarded immediately. Minor defects due to manufacturing errors cannot be detected by naked eye and might lead to instrument fracture even during the first use [3,21]. Such fractures may occur due to internal cracks or external instrument defects. A minute defect on the external surface may gradually increase in size, without any detectable gross deformation.

Manufacturers have attempted to improve NiTi rotary endodontic instruments by varying the designs, cross-sectional shape, surface treatment, flexibility, pitch, helical angles, rotation speed, etc. On the other hand, the instrument design factors influence defect rate [3]. Nevertheless, the influence of many design variables is not fully understood [22].

Extensive research has been done on fatigue and corrosion of different designs of NiTi rotary endodontic instruments, but not many have concentrated on abrasion wear of NiTi rotary instruments. The purpose of this in vitro study was to evaluate and compare abrasion wear resistance of three different NiTi rotary instruments after repeated use.

MATERIALS AND METHODS

Thirty extracted intact single-rooted human mandibular and maxillary premolar teeth with a single canal, which had been stored in distilled water containing 0.1 per cent thymol, were used. Dental digital radiographic images (DDRI) were taken in both the buccolingual and mesiodistal directions to evaluate the root canal anatomy and to confirm the canal curvature (<10°) using the Schneider's method [23].

Root canal preparation

Before root canal preparation, the crowns of the teeth were removed at the level of the proximal cemento-enamel junction with a low-speed diamond blade (Isomet®, Buehler Ltd., Illinois, USA) under copious water irrigation to allow access to the root canal and establish a level surface, which would help to maintain a standardized working length of 15 mm. A size 10 K-file (Zipperer, Munich, Germany) was introduced into the canal until the tip of the file became visible at the major apical foramen. The working length was determined by subtracting 1 mm from this measurement. All canals were checked with a size 10 K-file to ensure the initial canal diameter size before canal enlargement. All canals exceeding the initial canal diameter size were excluded. The teeth were then randomly divided into three groups of 10 teeth each.

For Groups A, B and C, a new set of three types of Ni-Ti rotary instruments: EndoWave (J. Morita, Kyoto, Japan), K3 (SybronEndo, CA, USA) and ProFile (Dentsply Maillefer, Ballaigues, Switzerland) were used, respectively. Every set had four brand new rotary files (size 40, 35, 30 and 25, 0.06 taper), which were used for ten teeth in each group. All instruments were used with a low-torque motor (Dentaport ZX, J Morita, Kyoto, Japan) at a constant speed of 300 rpm, according to the manufacturer's recommendations. Each instrument carried into the canal and allowed to advance just where resistance was met and only allowed to rotate for 8 s in the canal, totaling to 80 s for ten root canals. All canals were instrumented using the crown-down sequence for all instruments. Patency was constantly checked using a size 10 K-file. Every instrument was inserted while rotating in an up and down pecking motion without application of any apical pressure. After the use of each instrument, the canals were irrigated with 2 ml of 6 per cent sodium hypochlorite solution (NaOCl) using an endodontic syringe with a 27-gauge needle (Nipro, Osaka, Japan).

Before and after the canal preparation, the instruments were ultrasonically cleaned (US-2, As One, Osaka, Japan) for 6 min in distilled water, elaborately wiped with a piece of 4×4 cm cotton gauze soaked in ethanol solution, and then autoclaved at 121°C for 15 min. Complete removal of all debris from the file was ensured under a digital microscope (VH-S30, Keyence, Osaka, Japan; DM) at ×100 magnification. The experiment was divided into two stages as follows:

Stage 1: Measurement of file weight

Each brand new NiTi file was weighed with a rubber stop before canal preparation (Wb) and after preparing ten canals (Wa). All weight measurements were performed using a Metller AE 240 balance (Metller Instrument, Greifnsee-Zurich, Switzerland) with an accuracy of 1×10^{-4} mg. The weight was carefully measured three times for each file and the mean values were calculated. Then, the weight loss of all files in percentage (W %) was calculated as follows:

$$W\% = \frac{W_b - W_a}{W_b} x100$$

Stage 2: Assessment of wear by photomicrograph analysis

The cutting element of the file was divided into three portions (coronal, middle and apical) to estimate the defect on the entire cutting element. The instruments were analyzed morphologically under a DM before canal preparation (control) to differentiate manufacturing defects from usage defects such as blunt cutting edge, discontinuity of cutting edge, metal flash, pitting, deformation and grooves, and analyzed again after preparing ten canals (Figure 1 a,b,c). For each portion, the files were sequentially examined on four sectors by rotating them by 90 degrees.

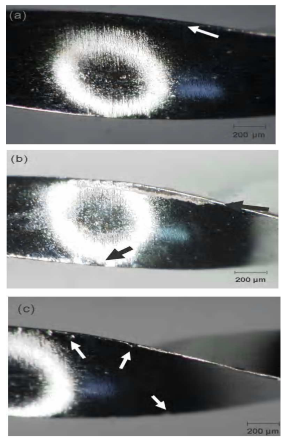

Figure 1a: Photomicrographs of EndoWave files. (a) EndoWave files before use (control) showing pitting and discontinuity of cutting edge (size 40). (b) Wear of EndoWave file after the tenth use (size 30). (c) Micro-fractures (arrows) after the tenth use (size 25).

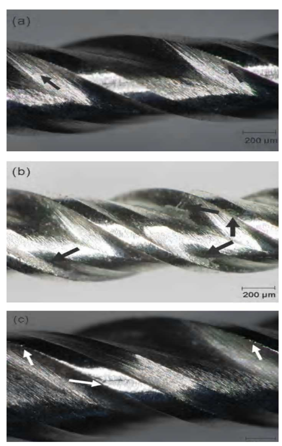

Figure 1b: Photomicrographs of K3 instruments (a) K3 file before use (control) showing micro-crack (size 35). (b) K3 file after the tenth use showing chippings (size 25). (c) Chipping and micro-crack after the tenth use (size 40).

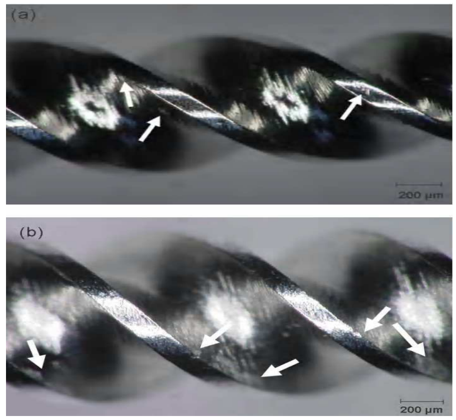

Figure 1c: Photomicrographs of ProFile instruments. (a) Photomicrograph of unused ProFile instrument (control) showing discontinuity of cutting edge and pitting (size 25). (b) Photomicrograph of ProFile instrument after the tenth use, showing signs of wear on the cutting edge (size 35).

The photomicrographs were taken at ×200 magnifications. Then, the length of the largest chipping defect on the file surface was measured, and also the number of chippings in each photograph was determined. (The chipping is a small defect of metal on the file blade that resulted from abrasion with dentinal walls during canal preparation). The chippings were analyzed using Adobe Photoshop version 7.0 (Adobe system, CA, USA). Chipping length scores were given according to the measured chipping length as shown in Table (1). The data were stored in a personal computer for statistical analysis.

Table 1: Chipping score in relation to measured chipping length

Chipping length score	Measured chipping length (mm)
1 (little)	< 0.50
2 (mild)	0.50 ~ 1.00
3 (moderate)	1.01 ~ 1.50
4 (severe	1.510 ~ 2.00

Statistical analysis

One-way analysis of variance (ANOVA) and Fisher's PLSD test were used to evaluate differences in weight loss amongst the groups. Two-way ANOVA and Fisher's PLSD test were used to evaluate differences in chipping defects amongst the groups. Values were expressed as mean ± SD, and p-values less than 0.05 were considered significant. The analyses were carried out with "Stat view 5.0" software (Abacus Concepts, USA).

RESULTS

File weight

Table (2) shows the mean weight of the three different instruments before and after preparing ten canals. After being used ten times, the weight of EndoWave, K3 and ProFile decreased by 0.25%, 0.18%, and 0.10% on the average, respectively. EndoWave exhibited significantly more weight loss than K3 and ProFile (P< 0.05), and ProFile showed significantly less weight loss than K3 and EndoWave (P< 0.05).

Table 2: Mean weight with SD before and after the tenth use and weight loss (%) for different instruments

	Weight before use	Weight after the tenth use	Weight loss (%)
Instrument	Mean ± SD	Mean ± SD	Mean ± SD
EndoWave	0.4065 ± 0.01	0.4055 ± 0.01	0.25 ± 0.07
K3	0.4586 ± 0.01	0.4577 ± 0.01	0.18 ± 0.03
ProFile	0.5829 ± 0.02	0.5823 ± 0.02	0.11 ± 0.03

File surface wear

The defects before use of EndoWave, K3 and ProFile were found in 18%, 12% and 8%, respectively. The results of the photomicrographic analysis of the files concerning the chipping length after tenth use are summarized in Table (3). The file type had a significant influence on the chipping length score after use (P< 0.05). EndoWave showed a significantly higher chipping length score than K3 and ProFile (P< 0.05). High scores (3 and 4) were obtained (39%) for EndoWave, 32% for K3 and 23% for ProFile, respectively.

Table 3: Assessment of chipping length on the file surface after the tenth use for all groups

	EndoWave				K3				ProFile			
Score	Coronal	Middle	Apical	total	Coronal	Middle	Apical	total	Coronal	Middle	Apical	total
1	24	10	12	46	26	13	11	50	31	17	12	60
2	12	17	13	42	14	17	17	48	12	20	19	51
3	12	17	17	46	8	15	16	39	5	9	14	28
4	0	4	6	10	0	3	4	7	0	2	3	5
n	48	48	48	144	48	48	48	144	48	48	48	144

n=number of photomicrograph specimens

In all instruments, the surface wear was more obvious in both the apical and middle thirds than in the coronal third for all scores except score 1 (P< 0.05). Table (4) showed the mean number of chippings in different file systems after tenth use. Here, statistically significant differences were found between EndoWave and ProFile for all sizes. However, there was a significant difference between EndoWave and K3 only in the size 35 file. (P< 0.05) (Data not shown).

Table 4: Mean chipping numbers with standard deviations for all groups after the 10th

	Coronal portion	Middle portion	Apical portion
Instrument	Mean ± SD	Mean ± SD	Mean ± SD
EndoWave	4.8 ± 1.00	5.3 ± 0.70	5.8 ± 0.95
K3	4.6 ± 0.70	5.1 ± 0.73	5.4 ± 0.95
ProFile	4.1 ± 1.00	4.3 ± 0.77	4.5 ± 0.75

Nearly all specimens demonstrated abrasion wear in one or more cutting edges and/or at the radial land of the instrument. Also, small chippings with microcracks at the cutting edge were observed in some specimens as shown in Figure (1). The defects were caused without any visible signs of permanent deformation. No instruments were fractured during the course of this study.

DISCUSSION

This study proposed a new method for evaluating and comparing the abrasive wear resistance in different types of NiTi instruments. Clinically, observing defects of NiTi instruments is more difficult than observing those of stainless-steel instruments [24]. Before canal preparation, photomicrographs were taken as control to differentiate manufacturing defects from usage defects. Machining of NiTi instruments may be a factor responsible for the manufacturing defects on the instrument surface, which in turn might increase resilience since they could act as points of tension capable of initiating fracture [25].

The loss of file weight after canal preparation may be related to pitting, fritting, metal flash and blunting of cutting edge. In this study, the file defect was evaluated in terms of the number and length of chippings on the file blade that may reflect weight loss of the file. Troian et al. [22] reported that each time the canal was prepared, the surface of instrument was abraded, resulting in surface defects. The present study revealed that weight loss, chipping length score and chipping number varied among the three different NiTi instruments. Such defects were produced without any signs visible by naked eye even after the tenth use.

Lee et al. [27] reported that superelastic NiTi alloy could be strained 10 times more than ordinary spring material without irreversible plastic deformation. In addition, in the current study, NiTi files were used only in straight canals, which may produce less stress on files compared to curved canals. Accordingly, no visible permanent deformation was observed for any files.

Parashos et al. [3].reported that the degree of file defect was influenced by a complex interplay of factors, including brand, size, taper, cross-sectional shape and instrument designs. In the current study, EndoWave lost significantly more weight than K3 and ProFile after the tenth use. This may be due to the design of EndoWave that may produce more cutting friction against canal walls Koch & Brave [28] reported that files with a modified triangular blade design and progressive taper exhibited more cutting efficiency Diemer & Calas [29]. also mentioned that the cross-sectional shape of instruments plays a significant role in file defect and breakage. On the other hand, thermal nitridation and nitrogen–ionic implantation of the file surface during manufacturing forming a layer of titanium nitride on the instrument surface might increase its hardness and give it more wear resistance [30].

A previous study by Herold et al. [31] found that electropolishing, another method of treating the file surface, did not inhibit the development of microfractures. The results of the present study are in agreement with the above finding, which is applicable to EndoWave treated by electropolishing Tripi et al. [32] mentioned that the instrument design and surface treatment seem to play an important role in wear resistance. Parashos et al. [3] reported on instruments discarded by fourteen endodontists due to defects before use. These findings indicate that there may be considerable scope for improvement in metallurgic properties and flute design to make the instruments more robust.

K3 showed significantly less weight loss than EndoWave. This may be partly due to its design with unequal land width, flute width, and flute depth, which could provide the file with wear resistance. In general, the cutting angle of the flute could provide an effective cutting surface and friction against dentine. Mounce [33] reported that the K3 body design channels debris away from their tips, leading to somewhat less cutting time and decreased defect and fracture rates. On the other hand, Peña et al. [2] reported that the hardest materials have the most wear resistance. Troian et al. [26] showed that K3 instruments had a smaller surface wear score, which is in agreement with the present study. In this study, ProFile showed better wear resistance than the other files, probably due to its symmetric radial land design and U-shaped grooves providing space to accommodate dentine shavings while planing the canal wall. Elmsallati et al. [34] reported that ProFile tended to entrap debris within the U-shaped grooves, which might reduce cutting friction and occurrence of defects. Alapati et al. [35] stated that dentinal debris was generally found in the rollover and on concave flute surfaces in ProFile. This might also decrease the cutting friction of the file and reduce defects on the file. In addition, the flute design and radial lands of the file may decrease the defect rate. In the current study, the results obtained for ProFile and K3 are in agreement with a previous study [32].

On the other hand, cutting action probably plays a role in the abrasion wear, which may be different among files. In EndoWave, the cutting action is active (knife cutting). In K3 the cutting action is between the cutting and scraping action, while in ProFile scraping action occurs on dentine rather than cutting. During instrumentation, the use of an instrument leading to abrasive wear especially in the cutting edge, will decrease cutting efficiency of the instrument and increase torque, stress and tension on the instrument, which might initiate chipping and microcracks on the instrument.

The anatomy of the root canal system to be worked on may also affect the defects in NiTi instruments. Yared et al. [36] mentioned that ProFile instruments with taper 0.06 sizes #40–25 could be safely used up to 10 times, while EndoWave #40–25 could be used less than 10 times. In the current study, the results obtained were in agreement with a previous study by Alapati et al. [37] which showed that the ProFile instrument had a minor wear at the edges of the flute after the sixth use.

Parashos et al. [3] found that approximately 25 per cent of flexural fractures and 75 per cent of torsional fractures occurred at a distance of 1.5 mm or less from the instrument tip. Coincidentally, the current study found more chipping on files at the apical and middle thirds than in the coronal third.

CONCLUSIONS

The instrument design is one of the most important factors that provide resistance against wear and prevent instrument fractures. The resistance against wear differed greatly between instrument types due to the variation in geometry of design and manufacturing process of each file type. Instruments with a triangular cross-section and long pitch design might be more prone to abrasive wear.

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