ORIGINAL ARTICLE

Durability of Self-Adjusting File (SAF) Used in Canal of Different Curvatures

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ABSTRACT

INTRODUCTION This study aimed to evaluate the safety and durability of Self-Adjusting File (SAF) in preparing root canals of different curvatures.

METHODS A total 47 SAFs were tested in 5 groups of mesial canals of extracted lower molars with different angles (α) and radii (r) of curvatures. The file was operated in one canal for a maximum of 4 minutes. The file was removed after every minute of use and examined under magnification to detect any mechanical failures: fracture or deformation. If there was no failure, the operation was resumed with the same file in the same canal. After a total of four minutes, if the file was still intact, the procedure would be continued in a new canal. In any event of failure, the experiment was stopped. A new SAF would be used in a new canal and the experiment repeated. The time when the first mechanical changes occurred was recorded. Then the file was examined in details under a stereomicroscope, followed by Scanning Electron Microscope.

RESULTS SAF operated in relatively straight canals showed the greatest durability of 19 minutes followed by severe-sweeping (7.2 minutes), severe-acute (7.0 minutes), moderate-sweeping (5.7 minutes) and moderate-but-acute curvature (4.9 minutes). There was a significant difference between the straight and all other curved canal groups ($p < 0.01$). Failure of SAF occurred most commonly on the middle portion. Fractographic images revealed the presence of fatigue striations and dimpling patterns.

CONCLUSION: There was a significant difference in usage time of SAF before first failure detection between straight canals and those that were curved.

KEYWORDS Self-Adjusting File (SAF), Durability, Fracture, Deformation, Angle, Radius

INTRODUCTION

Instruments used for root canal preparation have undergone significant transformation throughout the last few decades, from the hand-operated rigid stainless steel files of the past to the flexible rotary nickel-titanium (NiTi) instruments nowadays. NiTi files were almost three times more flexible and resistant to torsional fracture compared to stainless steel files [1]. NiTi possesses super-elasticity that allow files made of this material to be rotated in curved root canals. It has been shown that hand NiTi files preserve the canal anatomy with a lesser incidence of canal mishaps such as zips, ledges, apical foramen transportation or perforations than stainless steel files [2,3]. With the introduction of engine driven-system, variations in rake angle, radial lands design, helical pitch or thickness of the core are also introduced [4]. Although the design varies, the great majority of NiTi files have similar features where they possess spiral blades for cleaning the canal in circular motion [5]. Rotary NiTi instruments can significantly improve the final shape of the prepared root canal [6].

Self-Adjusting File (SAF) (ReDentNOVA, Ra'anana, Israel) is a new innovation in endodontics. It is the only file that abrades, rather than cuts the dentine wall. SAF comes with a distinctive design; with a hollow and compressible tube-like structure that tapers towards the tip. It is composed of 120 µm thick NiTi lattice meshwork with high torsional and fatigue resistance [7]. Farmakis et al. 2013 described this lattice meshwork to consist of arches and struts - arches are in the shape of a dome that attached to the external beams while the struts connect one arch to another [8]. When inserted into the canal, the SAF will become compressed. It has a tendency to rebound (expand) its original dimensions, hence exerting a constant outward pressure on the canal walls while adapting according to canal's anatomy, both longitudinally and in cross-section. SAF has been claimed to have good durability and could undergo severe "abuse" before mechanical failure ensues [7]. The maximum operation time was reported to be 29 minutes before the first sign of failure [5]. Mechanical failure of the file components (arch, strut or their junctions) may leave the separated fragment in the canal. Its outwards pressure and well adaptation to the canal wall may block the canal, be difficult to remove and prevent effective cleaning of the canal afterwards.

The aims of this study were to evaluate the safety and durability of SAF when used in root canals of different curvatures by determining the maximum time that SAF can be used before any sign of material failure, evaluate the prevalence and location of SAF failure and to analyse the cause of fracture by examining under Scanning Electron Microscope (SEM).

MATERIALS AND METHODS

This ex vivo study was approved by Research and Ethics Committee of the UKM (UKM 1.5.3.5/244/DD/2011/040). One operator performed all the procedures by using extracted human mandibular molar. It was conducted at the Endodontic Specialist Clinic, Faculty of Dentistry, Universiti Kebangsaan Malaysia (UKM) and Science and Technology Research Institute of Defence (STRIDE), Kajang, Selangor, Malaysia during the period of September 2012 to December of 2013.

A total of brand-new 47 SAFs with a diameter of 1.5 mm and length of 25mm were used. Before the experiment, all files were examined at x6 magnification under an optical stereomicroscope (OSM) (SV 11; Carl Zeiss, Germany) to rule out any possibility of pre-existing damage.

Tooth Selection

Only those mesial canal roots with normal root shape, two separate canals and patent, fully formed apices were selected. There should be no evidence of previous root canal treatment. Teeth with existing root canal treatment, merging mesial canals, open apex, dilacerated roots, and non-negotiable canals are excluded from the study.

Determination of canal curvature

The teeth were radiographed in both mesiodistal and buccolingual direction. The buccolingual radiographs were used to determine the root canal curvatures. The canal curvature parameters were: angle (α) and radius (r) 8. From the measurement, the angle of curvature was classified as straight (<200), moderate (20-400), or severe (>400). From the radius parameter, the curvature was considered as abrupt (r<6mm) or sweeping (r>6mm). These two parameters were then combined to establish the canal curvature for randomization of samples.
Grouping

The teeth were stratified into 5 groups according to the canal curvature: (i) MA (moderate but abrupt curvature; α=20-400, r<6mm, (ii) MS (moderate but sweeping α=20-400, r>6mm), iii) SA (severe abrupt curvature, α>400, r<6mm, (iv) SS (severe sweeping curvature; α>400, r>6mm) and (v) ST (Straight; α <200, as control).

Pilot study and sample size calculation

One SAF file was tested by running it in a number of mesial canals and examining it under dental operating microscope repeatedly until the first sign of failure was noticed. This pilot test revealed that the maximum duration of SAF was 16 minutes with total 4 canals prepared. Based on this result, the sample size was estimated for the actual experiment to be 10 SAFs with 40 canals for moderate and severely curved groups, and 7 SAFs with 28 canals for the control group.

Canal enlargement prior to SAF Operation

Access cavity was done by using high-speed diamond round and Endo-Z burs (Dentsply Maillefer, Ballaigues, Switzerland). Coronal flaring was achieved with #2 and # 3 Gates Glidden burs (Dentsply Maillefer) to 2-3mm below the cementoenamel junction. A #10K file was then introduced into the root canal until its tip was seen at the apical foramen and the working length (WL) was set at 0.5 mm short of this length. Each canal was manually enlarged to size 20 K-file to provide a glide path with patency by using a K-file. Distilled water was used to irrigate the canal and the teeth were hand-held during preparation. After size #20 was achieved, the teeth were then mounted into a block of Plaster Of Paris. The blocks were trimmed at approximately 30-40 degrees to simulate the position of the patient during endodontic treatment. The tooth blocks were stored in distilled water.

Canal preparation with SAF

The SAF was operated in a slow speed handpiece (NSK EC, Tokyo, Japan) with an RDT3 contra-angle head (Re-Dent-Nova). It was operated at a frequency of 83.3 Hz (equivalent to 5000rpm) and amplitude of 0.4mm. The file was inserted into the canal and gently advanced apically with intermittent in-and-out hand pecking movement until it reached the WL. The file was operated in one canal for a maximum of 4 minutes as recommended by the manufacturer. After every minute of operation, the file was removed from the canal and checked for any signs of mechanical damage under a dental operating microscope (Global Inc. St Louis, MO) at 3.2x magnification. Mechanical damage was divided into either fracture (of any components or junction) or deformation. The fracture was recorded when any component has partially or fully detached from the bulk of the instrument, be it at the arch/es, the longitudinal beams or the strut/s to the arch. Deformation was defined as permanent twisting or distortion of any components.

In the event of no failure, the operation was resumed, that is, with the same file was reinserted into the same canal. After a total of 4 minutes, if the file was still intact, it would be operated in a new canal (that had been pre-enlarged). If a failure was detected at any time, the experiment would be stopped immediately. Another brand-new file would be used in a new canal and the experiment repeated using the same procedure. The same operator was assisted by a timekeeper who would record the time used for each SAF.

Optical stereomicroscope (OSM) and Scanning Electron Microscopy (SEM)

The files were first examined under OSM at x6 to x10 magnifications to look for general signs of failure. Each file was divided into 3 sections: coronal, middle and apical third to locate the failure part.

Then the damaged parts were mounted vertically on a stub for further viewing under SEM (VPSEM1430, Carl Zeiss, Germany) at various magnifications (x500 to x2000). Evaluation under SEM was carried out blindly by an operator who was trained in SEM analysis.

Statistical Analysis

Data were collected and analysed using SPSS version 20 (IBM Statistical Package for Social Science, New York, United States). One-way analysis of variance (ANOVA) was used to compare the mean maximum time of SAF operation before first failure detection, followed by post-hoc comparison with Bonferroni correction. Descriptive statistic was used for prevalence and location of file failure. Statistical significance was set at a confidence level of 95%.

RESULTS

The files in the ST (control) group showed the highest mean maximum time of use whereas MA group exhibited the least mean maximum time before first failure detection at 19 and 4.9 minutes respectively (Table 1). There was a statistically significant difference between ST group and all other experimental groups (P=0.0001). However, there was no significant difference among all the experimental groups.

Failure of the file was found to occur most commonly on the middle portion (55.3%) and least frequently at the apical part (Figure 1). All except one file survived for 28 minutes of operation time without any failure. This longest surviving file belonged to the ST group.

Analysis of failure revealed that most files were failed due to fracture rather than deformation. Fractures were found in all three locations (coronal, middle and apical) but with a preponderance to the middle part. File deformation tended to take place on the apical portion.

SEM fractographic analysis revealed the presence of fatigue striations and dimple on the fracture surface of the component involved (Figure 2).

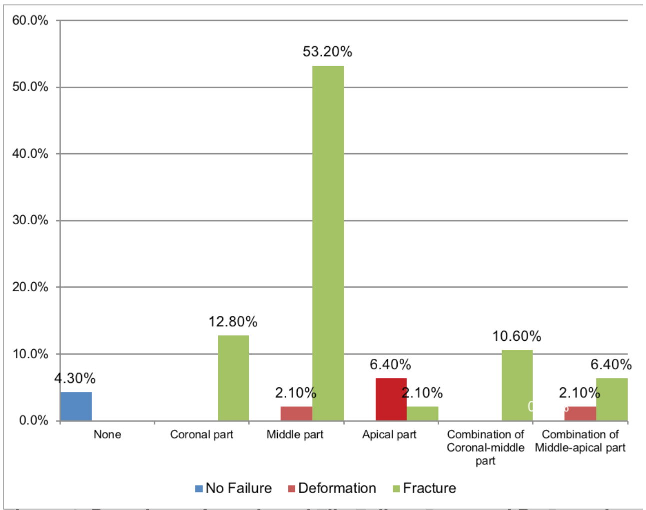

Figure 1. Prevalence Location of File Failure Detected By Dental Operating Microscope

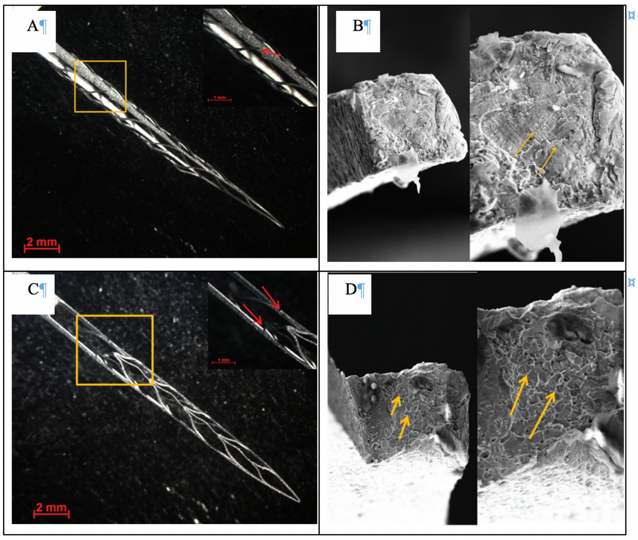

Figure 2. Examples of instrument failure.(A). Partial detachment of the arch at the junction with the longitudinal beam in the coronal portion (red arrows), which was shown in high magnification(B) to contain fatigue striation pattern (arrows); C. Fracture of lattice meshwork resulting in full detachment of an arch on the coronal portion (red arrows in the diagram inset) that(D), showed elongated dimples which are characteristic of ductile failure (arrows).

Table 1. Mean Maximum Time of SAF Operation Before First Failure Detection (n=10)

Group	A	B	C	D	E
	(MA) α= 20-400 r <6mm (mac) 10	**(MS) α=20-400 r>6mm (msc) 10**	**(SA) α>400 r<6mm (sac) 10**	**(SS) α>400 r>6mm (ssc) 10**	**(ST) α<200 (straight curvature) 10**
Mean Maximum Time (min)	4.9 (±1.969)	5.7 (± 2.584)	7.0 (±2.625)	7.2 (± 2.098)	19 (±3.471)*

Values in parentheses denote the standard deviations. The symbol * indicates only Group E showed a statistically significant difference between all the groups tested (P < 0.05). α= angle of curvature; r = radius of curvature; mac= moderate abrupt curvature; msc= moderate sweeping curvature; sac= severe abrupt curvature; ssc= severe sweeping curvature

DISCUSSION

The canal curvature was quantified by two parameters that were widely used to define the characteristics of a curvature, and both of which would affect the fatigue life of rotary NiTi instruments [9-11]. The literature review revealed only one study has been done to examine the influence of these two parameters on SAF; however, only simulated canals were used [12]. Our study used extracted teeth rather than simulated canals because they were much more clinically relevant. The instrument was set to perform its function in the canal, rather than subject to a fatigue-to-failure test because the SAF system did not engage the canal wall with a rotation motion [6, 7].

Our control, ST group gave rise to the greatest durability of SAFs with a mean maximum time usage of 19 minutes (Table 1). The figure was slightly shorter than (about 0.6 times) the value of 27 minutes in human teeth 7, or 29 minutes in standard plastic artificial canal block [6]. The difference in the hardness of dentin and resin blocks, as well as the irregular shape of the former, might have influenced the durability of the files. There was a statistically significant difference between this ST group and all the other experimental groups (P=0.0001), which result was expected as files in the ST group were operated in a relatively straight canal where there would be fewer stresses imposed on them. It is not surprising for SAF instruments in other groups to fail sooner, as they were used in curved rather than straight canals. Our result was inconsistent with the previous study wherein the straight canal, SAF was durable up to 29 minutes [5].

There was no significant difference among the four experimental groups ($P > 0.05$). In the curved canals, the SAF instrument tended to fail slightly earlier in the MA than the MS group, and the same for SA versus SS group. It is suggested that the abrupt curvature had resulted in a decreased maximum usage time for SAF; akin to the significant decrease in the number of cycles to fatigue failure for rotary NiTi instruments [9,13]. On the other hand, it was ironic that for those canals with a similar radius of curvature, the more severe curve angle allowed for a longer duration of use, as indicated by the results for group MA versus SA, and MS versus SS (see Table 1). It seemed that the usual prediction for fatigue failure based on the angle and radius of curvature cannot be accurately applied for SAF instrument.

None of the files from the experimental groups survived the third round of use in the moderately to a severely curved canal. This is in contrary to a previously reported finding that SAF could be used up to 12 and 10 minutes in moderate and severely curved canals, respectively [12]. The result of our study, strongly suggests that SAF should only be used as a disposable instrument. In fact, the dimension and design of the instrument would hardly allow it to be properly cleaned and sterilized for reuse.

The SAFs were repeatedly used and stopped for assessment at one-minute interval until first mechanical failure identified under a dental operating microscope. This protocol was similar to the methodology of an earlier study [6]. Other studies have adopted a two-minutes 12 or four-minutes protocol to assess the durability of SAF [8]. The current one-minute protocol was judged to be appropriate as changes to the file could be detected after the first 60 seconds of use. Thus, failure might go unnoticed when SAF continued to operate for 2 or 4 minutes in other reports.

Fracture of the files due to fatigue has been suggested as a result of repeated use of rotary instruments in the curved root canal. In our study, the curved portions of the canal were situated mostly in the middle part of specimens. The file assumed a greater diameter at this location and, hence, subject to more strains and stresses. Although two SAFs that failed showed fully detachment of the arches and struts, no fragment could be found in the root canal. This was confirmed with radiographs. It was considered a favourable event; otherwise, the canal would have been blocked and subsequently prevent proper cleaning and shaping. The meshwork connection along the longitudinal beams and its vibration movement might also have prevented the detached fragment from penetrating down to the apical part and was expelled from the canal by continuous irrigation instead. This finding supports the outcome of previous studies [6, 8, 12, 14].

Deformation of SAF was found to occur at the apical to the middle part of the instrument. This is probably due to pre-enlarged of the canal to size [20], which is slightly smaller than the tip dimension of the SAF being used. When the apical part of the file was jammed in the canal and the operator pulled it out at the same time, it would result in twist-distortion. At this point, there was no study that examines this kind of mechanical failure.

Despite the multiple radiographs taken in this study to standardize the curvature parameters, no two canals are identical. Considering such limitations due to variations in the internal anatomy of natural teeth, there was a significant difference in usage time that SAF would persevere before the first sign of failure in straight versus curved canals. SAF was more durable in the straight canal than that with moderate or severe curvature. In multi-rooted teeth with moderate to severely curved canals, more than one SAF might be needed to complete the cleaning and shaping procedure, especially if safety and absence of material failure are of prime concern. It may be fortunate that fracture of SAF occurred mostly in the middle or coronal part of the file and less likely at its apical portion. This would alleviate the challenge of removing fracture fragment at the apical part of the canal that may lead to an unfavourable outcome of endodontic treatment.

Fractography using SEM has been employed to identify the fracture origin, the direction of crack propagation, failure modes, material defects, environmental interaction and natural of stresses [21]. In our study, SEM analytical image revealed the pattern of fatigue striations and dimpling of metal (Figure 2). Fracture surface that occurred on arches and struts produced fatigue striations that were associated with brittle failure, while fracture surface on external beams showed dimple pattern without striations is an appearance indicative of ductile failure. “Brittle failure” of metals was a result of material fatigue. Fatigue was defined as a process of incremental crack propagation that was driven by the cyclic stresses when rotary instruments were rotated inside a curved canal [15]. As the motion of SAF inside canal was not continuous rotation, fatigue in SAF was induced by vibratory movement while it was adapting (exerting an outside pressure) to canal wall and hence was under compression at most times. It was postulated here that cracks started at the junction of arches or struts with the main (longitudinal) beams, and which propagated towards these beams. The fractographic surface features were similar to those revealed in other studies done on different brands of rotary NiTi instruments [15, 16, 17, 18, 19, 20].

In summary, there was a significant difference in durability of SAF when used in a straight canal and those that were curved, before the first sign of failure was detected. There was no difference between groups of different degrees or radii of curvature.

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