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Evaluation of the effects of different file systems and apical functions of integrated endodontic motors on debris extrusion: an *ex vivo* experimental study

Sıla Nur Usta[1,*], Antonio Magan-Fernandez[2], Cumhur Aydın[1]

[1]Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Ankara, Turkey
[2]Department of Stomatology, Faculty of Dentistry, University of Granada, Granada, Spain

ABSTRACT

Objectives: This study aimed to evaluate the effects of two different file systems operated with three apical functions of an endodontic motor integrated with an electronic apex locator on debris extrusion.
Methods: Sixty single-rooted teeth were prepared and divided into two main groups and three subgroups based on the file system (OneShape [Micro-Mega SA] and WaveOne [Dentsply Maillefer]) and apical function of the endodontic motor used (auto apical stop [AAS], auto apical reverse [AAR], and auto apical slowdown [ASD]). The teeth were mounted in pre-weighed glass tubes filled with 0.9% sodium chloride to complete the circuit with the apex locator. Files were advanced until the respective apical function (stop, reverse, or slowdown) was activated. The extruded debris was collected, dried, and weighed by subtracting pre-weighed values from post-weighed values. Preparation time was also recorded. Statistical analyses were performed to compare the groups.
Results: OneShape was associated with significantly less debris extrusion compared to WaveOne, regardless of the apical function ($p < 0.05$). The ASD function resulted in the least debris extrusion compared to AAS and AAR ($p < 0.05$). Preparation time was significantly longer in the ASD function ($p < 0.05$), while no differences were observed between the file systems ($p > 0.05$).
Conclusions: The OneShape file system and the ASD function produced the least amount of apical debris. While the ASD function requires more preparation time, its potential to minimize debris extrusion suggests it may reduce postoperative symptoms.

Keywords: Apical extrusion; Apical function; Endodontics; Reciprocal; Rotary

INTRODUCTION

An accurate working length (WL) assessment is crucial for a successful endodontic treatment since it allows a complete disinfection and obturation of the root canal space by preserving the periapical tissues [1]. WL can

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***Correspondence to**
Sıla Nur Usta, DDS
Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Emrah Mah, Etlik, Keçiören, Ankara 06018, Turkey
Email: silandeniz29@gmail.com

be defined as the distance between a coronal reference point and the apical constriction, which is the natural narrowing of the root canal and almost the termination of the pulp [2]. In routine endodontic treatments, the WL is measured with the aid of dental radiographs and electronic apical locators (EAL) [3]. Based on the present findings, EALs have shown to be a faster and more reliable visualization method under different conditions that avoid radiation exposure, compared to conventional radiographs [4,5].

During the mechanical instrumentation process, irrigation solutions, debris, pulp tissue, and microorganisms can be extruded beyond the apical foramen. These events have been related to postoperative pain, flare-ups, and reduced long-term success of the endodontic treatment [6]. All currently used endodontic file systems and preparation techniques have been associated with apical debris extrusion [7], but controlling the WL and the position of the endodontic instruments during the root canal treatment with EALs could limit these possible complications [8]. For this purpose, endodontic motors with integrated EALs have been developed as more straightforward and faster devices to measure WL and maintain apical constriction throughout root canal preparation [9].

Endodontic motors with integrated EALs have two main apical functions as follows: auto apical stop (AAS) and auto apical reverse (AAR) [3]. In the AAS function, the file tip stops and moves upwards slightly when it reaches the reference point and starts rotating again. In the AAR function, the file automatically reverses the rotation when the reference point is reached or passed, moves upwards slightly, and then returns to the original rotation direction [10]. All apical functions start to work through the insertion of the instrumentation into the root canal space, and the WL can be detected with indicators on the endodontic motor during mechanical preparation. In addition to the previously described apical functions, a new one has been recently introduced called apical slowdown (ASD). In this function, the motor automatically starts rotating at the canal orifice, reverses direction, slows down to a set final speed as the file tip approaches the apical reference point, and stops when leaving the canal entrance. Therefore, it was stated by the manufacturers that this motion preserves the cementodentinal junction and provides a safer preparation even in the narrowest root canals along with reduced risk of file separation [11].

It is considered that the above-mentioned apical functions have an impact on the apical debris extrusion of instrumentation systems with different kinematics and designs that already cause varying degrees of debris extrusion [12,13]. In this sense, while the ASD function represents a relatively recent innovation, its influence on debris extrusion and clinical outcomes warrants further investigation. To date, no study has comprehensively evaluated the influence of different file systems utilized with distinct apical functions on apical debris extrusion, while simultaneously assessing preparation time. Therefore, this study aimed to compare the effects of rotary and reciprocal file systems (OneShape [Micro-Mega SA, Besançon, France] and WaveOne [Dentsply Maillefer, Ballaigues, Switzerland]) when operated with three different apical functions—AAS, AAR, and ASD—of an endodontic motor integrated with an electronic apex locator, on debris extrusion and preparation time. The null hypothesis of the study was that different apical functions and file systems would not differ regarding the apical debris extrusion and preparation time.

METHODS

Sample size calculation and teeth selection

The protocol of the study was approved by the Ethics Committee of the University of Health Sciences (No. 2024-494). The G*Power ver. 3.1 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany) software was employed to perform the sample size calculation. The test family was set to F tests, and the statistical test was selected as analysis of variance (ANOVA): fixed effects, omnibus, and one-way. Input parameters included the effect size (0.57), which quantifies the expected magnitude of differences among the groups, the alpha level (set at 0.05), and the desired power (set at 0.90) based on a similar study in the literature [14]. The required teeth number per group was determined as 10.

Sixty extracted human teeth with caries-free, single-rooted, mature apex, and less than 10º curvature were collected and evaluated under a stereo microscope

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for any possible fractures or anatomical malformations. Cone-beam computed tomography (PlanmecaProMax 3D; Planmeca, Helsinki, Finland) images of teeth were obtained, and the angle of curvature of the root canal was measured according to the method of Schneider [15], which is widely used in endodontic studies to measure canal curvature. The exclusion criteria for the selected teeth were calcified root canals, the presence of external or internal root resorption, and apical constriction greater than a size #15 K-file (Dentsply Maillefer). Subsequently, the periodontal tissues of selected teeth were removed from the external root surfaces with periodontal curettes, and teeth were stored in 0.1% thymol solution at 4°C until use. Access cavities were prepared with a round bur (856L314-014; G&Z Instrumente, Lustenau, Austria) by a high-speed handpiece with water-cooling. The WL was determined as 1 mm short of where a #15 K-file became visible at the apical foramen and adjusted to 16 mm under a dental operating microscope (LABOMED; Labo America, Inc., Fremont, CA, USA).

Experimental design

A method previously reported was followed to assess apical extrusion, with some modifications [16,17]. Firstly, 20-mL ampules with rubber stops were selected, and holes were punctured in the middle of the plastic rubbers to place the teeth. After that, tubes were cleaned and placed in an incubator to remove residual materials. Glass tubes were filled with 0.9% sodium chloride (NaCl) to simulate the electric current in the human body and close the circuit between the EAL and the tooth. The same NaCl preparation was used for all samples to avoid differences in the ion capacity between solutions that may affect the measurements. Additionally, the same amount of NaCl was added to all tubes, ensuring that the root apexes of all teeth were in contact with the solution. A 27-gauge irrigation needle was stabbed into the rubber stopper to equalize the inner and outer pressure (Figure 1). Filled tubes were pre-weighted three times using an analytical microbalance (Mettler Toledo AT201, Greifensee, Switzerland) with an accuracy of 10^{-4} g. The mean values of the obtained measurements were recorded as a baseline. The outer surfaces of all glass tubes were covered with aluminum foil to ensure the researcher was blinded with respect to the used apical functions.

Mechanical instrumentation

Following the stabilization of the teeth with cyanoacrylate in the experiment apparatus, they were divided using randomization software (https://www.randomizer.org/) into two main groups as follows: OneShape (n = 30) and WaveOne (n = 30) to reduce the number of files, and detecting the apical extrusion more accurately. Afterward, each main group was divided into three subgroups according to the used apical functions: AAS (n = 10), AAR (n = 10), and ASD (n = 10). Mechanical instrumentation was performed using Woodpecker Ai-Motor (Woodpecker Medical Instrument Co., Ltd, Guilin, China). The OneShape file was operated in a continuous rotary motion at a speed of 400 revolutions/min (rpm) and a torque of 4 N/cm. The WaveOne file was used with "Reciproc ALL" mode (170°/50° at 350 rpm) [18]. To evaluate the different apical functions of EAL, the lip clip was placed on the syringe, and the file holder was attached above the stopper on the metal shank of the files. The endodontic motor started to rotate automatically when the files were inserted inside the wet root canal system. File systems were allowed to move through apical constriction until the apical action of the endodontic motor stopped, reversed, and slowed

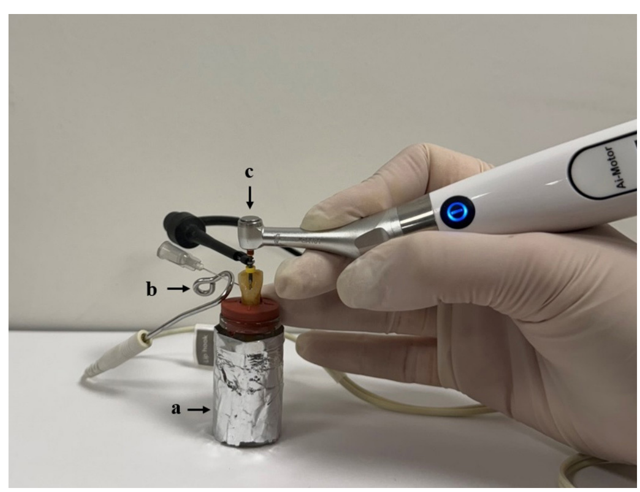

Figure 1. Experimental apparatus used to evaluate apically extruded debris. (a) The cover of the outer surface of a glass tube with aluminum foil. (b) The placement of the lip clip on the syringe in order to complete the circuit. (c) The operation of the file.

down the motion. Root canals were irrigated with 2.5-mL 0.9% NaCl and 2.5-mL distilled water, respectively, using a 27-gauge syringe after completion of the instrumentation process. Vacuum suction was used to remove the overflow of the irrigation solution. The preparation time was also recorded in seconds by a chronometer. All instrumentation procedures were performed by a single operator (SNU) with more than 5 years of experience under a dental operating microscope, and the later assessment of the debris extrusion was observed by a different blinded operator (CA) for the experimental groups, as previously described.

Teeth were removed from the tubes carefully, and filled tubes were incubated for 5 days at 70°C to evaporate the irrigation solution. Furthermore, tubes were post-weighted three times in the same conditions, and the mean values of all measurements were recorded. The amount of apically extruded debris was calculated by subtracting the baseline mean values from the final mean values.

Statistical analysis

Data were analyzed using a specific statistical package software (IBM SPSS version 16.0, IBM Corp, Armonk, NY, USA). Shapiro-Wilk test showed a non-normal and normal distribution for debris extrusion value and preparation time, respectively. The Kruskal-Wallis and Mann-Whitney *U* tests with Bonferroni correction were used to compare the different apical functions and file systems. A two-way ANOVA test was used to compare the three functions and two file systems in terms of preparation time. The level of significance was set at $p < 0.05$.

RESULTS

Table 1 shows the mean and standard deviation values of the apically extruded debris based on the different apical functions and file systems. Regardless of the used apical functions and file systems, OneShape and ASD were associated with statistically lower debris extrusion, respectively ($p < 0.05$). For the OneShape group, while AAS and AAR functions resulted in similar debris extrusion ($p > 0.05$), ASD caused significantly lower extruded debris values ($p < 0.05$). Moreover, extruded debris values were significantly higher in AAR function followed by AAS and ASD in the WaveOne group.

Both OneShape and WaveOne file groups have caused similar apical debris extrusion when they were operated with AAS and ASD functions ($p > 0.05$). However, the WaveOne group was associated with significantly higher debris extrusion compared to the OneShape group when it operated with the AAR function ($p < 0.05$).

The preparation time was significantly affected by the apical functions ($p < 0.05$) as shown in Table 2. For both OneShape and WaveOne groups, the mean preparation time was slightly higher in the ASD function; however, time values did not significantly differ between AAS and AAR ($p > 0.05$). Additionally, the used file system had no

Table 1. The apically extruded debris in terms of three different apical functions and two file systems

File system	Auto apical stop	Auto apical reverse	Apical slowdown	*p*-value
OneShape	0.0090 ± 0.0030[a,1]	0.0081 ± 0.0025[a,1]	0.0045 ± 0.0021[a,2]	0.037
WaveOne	0.0103 ± 0.0042[a,1]	0.0263 ± 0.0203[b,2]	0.0050 ± 0.0025[a,3]	
p-value		< 0.001		

Values are presented as mean ± standard deviation.
Different superscript lowercase letters in the same column indicate a statistically significant difference ($p < 0.05$).
Different superscript numbers in the same row indicate a statistically significant difference ($p < 0.05$).

Table 2. The preparation time in terms of three different apical functions and two file systems

File system	Auto apical stop	Auto apical reverse	Apical slowdown	*p*-value
OneShape	43.078 ± 1.700[a]	45.131 ± 1.880[a]	48.875 ± 2.241[b]	0.929
WaveOne	43.126 ± 1.815[a]	45.120 ± 1.939[a]	48.698 ± 2.411[b]	
p-value		< 0.001		

Values are presented as mean ± standard deviation.
Different superscript lowercase letters in the row indicate a statistically significant difference ($p < 0.05$).

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significant impact on the preparation time regardless of the apical function ($p > 0.05$).

DISCUSSION

The use of endodontic motors integrated with the EALs ensures a more controlled and faster root canal preparation and prevents over-extended instrumentation [19]. Monitoring the WL during mechanical instrumentation allows the endodontic files to work within the root canal system, thereby minimizing apical debris extrusion from the apical region [20]. Since different apical functions and file systems operate with variable kinematics in apical constriction, it is important to investigate the effect of these variables on apical debris extrusion. This study stands out due to its investigation of the effects of different apical functions on apical debris extrusion by an advanced endodontic motor with an integrated electronic apex locator. Moreover, this is the first study that has evaluated and compared the effect of three apical functions (AAS, AAR, and ASD) in both rotary and reciprocal file systems (OneShape and WaveOne) in terms of debris extrusion and preparation time. The findings of this study provide new insights into the interplay between file systems and apical functions, being a valuable contribution to endodontic practice and future research. According to the present findings of this study, the null hypothesis was rejected due to the fewer debris extrusion values in ASD function and the OneShape group.

Tooth morphology and the file systems used could have had an impact on *in vitro* debris extrusion. Although teeth with similar anatomy were selected for the experiments, the results may have been affected due to different factors such as microhardness and mineralization of dentine [21]. Moreover, single-file rotary and reciprocal file systems, OneShape and WaveOne, were used to assess the effect of different apical functions on debris extrusion more objectively since the reduced number of files could improve the quality of measurement of the debris extrusion by minimalizing possible complications during chemomechanical preparation of the samples [22].

In this study, glass tubes were filled with NaCl solution to allow EAL readings, and NaCl was also used as an irrigation solution. However, the remaining crystals after the evaporation of the solution could have caused an increase in the amount of debris collected [23]. To overcome this limitation, baseline values of the tubes were obtained after they were filled with NaCl. Moreover, the same bottle of solution was used to ensure standardization and reduce manufacturing errors. Another important point to address is the inability to mimic periapical tissues and periapical backpressure due to insufficient laboratory conditions [24]. Although the use of agar gel or foam has been suggested to simulate clinical conditions, these materials could not be utilized due to the working mechanism of the EALs and the process of collecting extruded debris.

The accuracy of the AAS and AAR functions in detecting apical constriction has been previously indicated in the literature [8,25]. However, there is limited information regarding their effects on apical debris extrusion. Apical functions are designed to help determine the WL through electrical signals sent by a file inserted into the root canal. Different operational settings of the apical functions influence the movement of the endodontic file and, consequently, may result in apically extruded debris at varying rates. Based on the findings of this study, the AAR function caused more debris extrusion than other tested functions for both file systems. This result can be explained by the fact that AAR automatically reverses the direction of the file towards the coronal direction when apical constriction is reached. Compared to the AAS, the disengagement of the flutes of the files during their removal from the root canal space in the AAR function may perform additional mechanical preparation and cause the extrusion of more debris [5]. Moreover, the potentially increased safety of the AAS function, achieved by disengaging the flutes of the endodontic instrument before completely stopping the motion while preventing jamming or tip lock could limit the instrumentation and cause lower debris extrusion [3,25].

ASD is a relatively new function that has been integrated into endodontic motors, and therefore, there is limited information regarding the possible effects and accuracy of this function in the literature [11,26]. This function allows the endodontic motor to slow down to a set final speed as the file tip approaches the apical reference point. In this study, all apical functions caused apical debris extrusion at different levels; however, the values were significantly lower with the ASD function. It was considered that ASD function controlled the mechanical preparation limits at a continuous and slowing rate, resulting in safer and more efficient performance. Therefore, this controlled movement of the files, particularly in the apical region, may have caused less extrusion of debris. However, it is important to note that the ASD function does not guarantee the complete prevention of apical debris extrusion alone. Other factors, such as the skill and technique of the clinician, the type of instrumentation used, proper irrigation protocols, the type of tooth, the apical diameter, and the preparation size, also play a significant role in minimizing debris extrusion [4,27–29].

Regardless of the apical functions and file systems, OneShape resulted in lower debris extrusion in this study. Similarly, Sinha *et al.* [30] reported lower debris extrusion values in the OneShape group compared to the WaveOne Gold. Moreover, Topçuoğlu *et al.* [31] also reported that the WaveOne files produced significantly more debris compared with OneShape. This result can be explained by the fact that OneShape, operating with continuous rotational motion, has a mechanism that may enhance the coronal transportation of dentine chips and debris, functioning like a screw conveyor [31]. Another possible explanation could be the different taper sizes of instruments. It can be hypothesized that the larger taper at the tip of WaveOne files may lead to increased debris extrusion compared to OneShape files, as it results in more extensive preparation of the dentinal walls. However, some studies in the literature have shown that the amount of apical debris extrusion is higher in rotary files [32] or similar [33] compared to reciprocal systems. Differences in methodologies and clinician-based factors could account for these varying results.

There is only one study that assessed the effect of different apical functions on apical debris extrusion, which demonstrated no statistically significant difference between groups, contrary to the findings of this study [13]. However, some concerns should be noted regarding that study. Firstly, a multiple rotary file system was used for the root canal preparation, which may have jeopardized apical debris extrusion due to the increased sensitivity. Moreover, the authors did not consider the presence of remaining crystals after the evaporation of the solution. Therefore, there is a gap regarding the elimination of the weight of crystals in the apical debris calculation. These methodological differences may explain the different outcomes found in our study.

Although the modified model of Myers and Montgomery [16] has a leading role in the measurement of debris extrusions due to advantages such as practicality, simplicity, reproducibility, and the possibility of comparison between different systems and methodologies, some drawbacks need to be underlined [21]. Addressing the artificial representation of periapical tissues [34], the lack of backpressure [35], being technique-sensitive and the contact of moist or greasy fingertips [34] are crucial to improve the reliability and applicability of findings. In this sense, micro-computed tomographic assessment could be a valid alternative by allowing a volumetric analysis of apical debris extrusion rather than weight [36].

The EALs provide advantages to clinicians in the WL control; however, their accuracy and working mechanism can be affected by many factors [37,38]. This may change the efficiency of the file in the canal, resulting in the extrusion of different amounts of debris *in vivo* which could be associated with postoperative pain and inflammation [39,40]. Although ASD function has the potential to minimize apical debris extrusion, this hypothesis is based on theoretical considerations and indirect evidence. Thus, further well-designed clinical studies are required to understand the additional impacts of the apical functions on debris extrusion using different types of instruments and teeth.

CONCLUSIONS

Within the limitations of this study, all apical functions caused apically debris extrusion. OneShape and ASD were associated with statistically lower debris extrusion. The preparation time was significantly longer in ASD function.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization: Usta SN, Magan-Fernandez A, Aydın C; Data curation: Usta SN; Formal analysis Usta SN, Magan-Fernandez A; Investigation: Usta SN; Methodology: Usta SN, Magan-Fernandez A, Aydın C; Software: Usta SN; Supervision: Aydın C; Validation: Usta SN, Magan-Fernandez A, Aydın C; Visualization: Usta SN, Magan-Fernandez A, Aydın C; Writing - original draft: Usta SN; Writing - review & editing: Usta SN, Magan-Fernandez A, Aydın C.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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