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ORIGINAL ARTICLE

Evaluation of extruded debris by different nickel titanium systems and hand files from apical foramen and simulated root perforation areas

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ABSTRACT

Aim: *This study analyzed debris extrusion during canal preparation using different file systems for simulated root perforation areas and the apical foramen.*
Methodology: *One hundred thirty-five human mandibular premolars were divided into three main groups, each comprising 45 teeth (n=45), and these main groups were further subdivided into three subgroups, each consisting of 15 teeth (n=15). Group 1 served as the control with no perforations, while Groups 2 and 3 had 0.5-mm-diameter perforation areas created in the apical and middle 1/3 of the buccal root surfaces, respectively. The apical foramen was covered with two layers of nail polish in Groups 2 and 3. In each main group, canals were prepared with (a) hand files, (b) ProTaper Next (PTN: Dentsply Maillefer Ballaigues, Switzerland), and (c) WaveOne Gold (WOG: Dentsply Maillefer Ballaigues, Switzerland).*
Debris weights extruded from the apical foramen in Group 1 and from the perforation areas in Groups 2 and 3 were calculated. Groups were compared using a two-way ANOVA test.
Results: *The (a) hand file extruded significantly more debris than the (b) PTN and (c) WOG in Group 1 (P_{ab}<.001, P_{ac}<.001) and Group 2 (P_{ab}=.004, P_{ac}=.005). In Group 3, the a) hand file and the c) WOG file system caused a statistically higher amount of debris extrusion than the b) PTN file system (P_{ab}=.006 and P_{cb}=.024). During the root canal preparation, the most debris extruded from the apical foramen for hand files, from the apical 1/3 perforation for the PTN system, and from the middle 1/3 perforation for the WOG system.*
Conclusions: *Within the limitations of this study, it can be concluded that all the tested files and the location of the perforation area on the root surface influenced the debris extrusion.*

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KEYWORDS *Debris extrusion, NiTi file, root canal preparation, root perforation*

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Introduction

One of the crucial steps in endodontic treatment is the mechanical preparation of root canals (1). Endodontic file fracture, canal transportation, and root canal perforations are among the most common complications during this step (2-4). Perforation refers to the connection between the root canal and the external root surface, which may occur due to factors such as root resorption, radicular caries, or iatrogenic applications (5). During chemo-mechanical debridement, organic and inorganic debris, microorganisms, and irrigation solutions can be extruded into peri-radicular tissues through the apical foramen (6). However, it has been stated that the risk of extrusion should be considered during endodontic procedures due to the possibility of apical root resorption in teeth with apical periodontitis (7). Extrusion of debris during the mechanical preparation of root canals has been associated with post-operative pain and delayed periodontal healing due to the resulting inflammation (8, 9). The amount of extrusion varies depending on factors such as root canal morphology, irrigation technique, depth of irrigant penetration, working length (WL), apical foramen size, file design, preparation procedure, or motion kinematics (10-15).

Manufacturers continually develop new files or modify existing systems to facilitate root canal preparation, preserve the original shape of the canal anatomy, and prevent iatrogenic errors compared to stainless steel instruments.

Recently, ProTaper Next rotary files (PTN: Dentsply Maillefer Ballaigues, Switzerland) made of M-wire nickel-titanium (Ni-Ti) alloy have been produced using a thermal process to increase flexibility and cyclic fatigue resistance (16). WaveOne Gold systems (WOG; Dentsply Maillefer, Ballaigues, Switzerland) have been improved with gold heat processing and feature a new parallelogram shape with two cutting edges. WOG and PTN files both have an off-center design (17). According to the manufacturer, the Gold technology results in increased flexibility and cyclic fatigue resistance of the file. While there are numerous studies (11, 12, 18) on apical debris extrusion caused by various endodontic systems in the literature, none have focused on the effect of root perforations on debris extrusion.

The aim of this study was to assess the amount of debris extruding from root canals with simulated perforation and apical foramen during the preparation of root canals with PTN, WOG, and hand files. The null hypothesis was that the amount of debris extruded by file systems would not differ significantly depending on the apical foramen and perforation areas.

Materials and Methods

Sample selection

This ex vivo study was approved by the Clinical Research Ethics Committee of the Akdeniz University, Faculty of Medicine (05.05.2021 - 289). The sample size was determined by using the data of a prior study (12), which indicated that the sample size for each sub - group be at least 15, with a significance criterion of $\alpha = 0.05$ and power = 0.80. Freshly extracted 135 human mandibular premolar teeth with less than a 10° curvature angle and without immature apices, caries, resorption, calcification, fractures, or cracks were used (19). Radiographs from the mesiodistal and buccolingual aspects were taken before the start of the experiment phase to verify the existence of a single canal. All tooth crowns were partially cut using diamond burs under water cooling to achieve a standardized length of 18 ± 1 mm. The access cavities of teeth were opened with high-speed diamond round burs. The apical patency of the roots was examined with a #10 K-file (Golden Star Medical Co., Ltd. Guangdong, China) under an X20 dental operating microscope (Stemi 508, ZEISS Germany). The WL was determined by subtracting 1

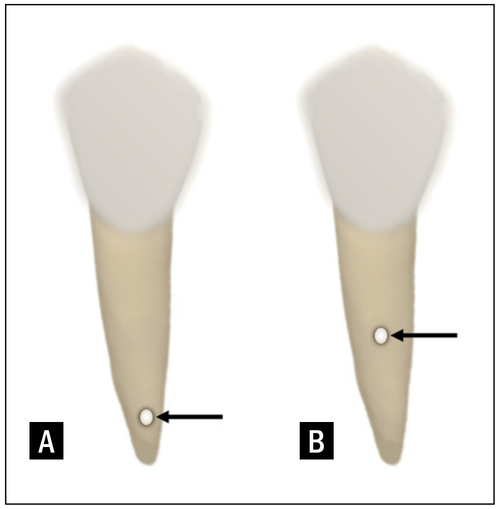

Figure 1
Perforations on the **A)** apical 1/3 and **B)** middle 1/3 of the buccal root surface of the teeth.

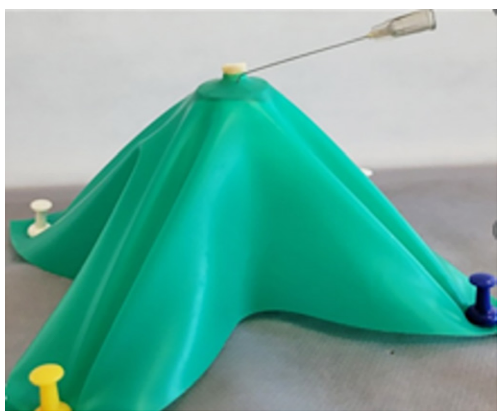

Figure 2
A modification of the experimental setup developed by Meyers and Montgomery was used for debris collection.

mm from the first length of each canal when the file tip reached the apical foramen under magnification. The #15 K-file was advanced to the WL, and the size of the minor constriction was checked. If the file extruded the apical foramen, the teeth were excluded. All the selected teeth were kept in the saline solution until used.

Creation of Perforations
The chosen teeth were randomly distributed into three main groups (*n:45*), and each main group was divided into three subgroups (*n:15*).
No perforation was created in the teeth in Group 1, and in this group, only the debris amount extruding from the apical foramen was examined. A perforation was created on the apical 1/3 and middle 1/3 of the buccal root surfaces of the teeth in Group 2 and Group 3, respectively (figure 1). Perforations were created using burs with a tip diameter of 0.5 mm. Whether the perforation area reached the root canal was examined and checked under a stereomicroscope. Then, the apical foramen was closed with two layers of nail polish in the Group 2 and 3. This enabled the creation of a closed-end canal model to evaluate the influence of the perforation area on debris extrusion.

Test Apparatus
A modification of the experimental setup developed by Meyers and Montgomery (20) was used to measure the amount of extruded debris. Due to the large amount of irrigation solution extruded from the perforation areas in the pilot study, extruded debris was collected in glass vials. The weights of empty glass vials were measured three times with an analytical balance (Shimadzu AP225WD, Kyoto, Japan) to an accuracy of 10^{-5} g, and the average value was recorded.
Holes were made on the stoppers of the glass vials, and the teeth were adapted to these holes. The needle (27-gauge) was positioned through the plastic stopper to balance the pressure in and out of the vials.
The glass vials were wrapped with aluminum foil to blind the operator, and the teeth were isolated with a rubber dam to avoid irrigation leakage through the hole. Figure 2 shows the setup of the experimental apparatus.

Root Canal Preparation and Evaluation of Debris Extrusion
For root canal preparation, the same procedures as explained below were used in all subgroups.

Preparation with the Hand Files (Group 1a, 2a, and 3a)
The canals were prepared using the step-back technique with #15-40 K-files (Golden Star Medical Co., Shenzhen, China). Apical preparations of the roots were conducted up to size 25 and then the step-back method was applied with a 1 mm decrease for each file until size 40.

Preparation with the PTN File System (Group 1b, 2b, and 3b)
In the PTN program, a Dentsply X-Smart Plus (Densply Maillefer, Ballaigues, Switzerland) endodontic motor with a torque of 2.0 N cm and a speed of 300 rpm was used, as the manufacturer's guidelines. PTN X1 file (17/0.04) (Dentsply Maillefer, Ballaigues, Switzerland) and then X2 file (25/0.06) were used in a brushing outstroke motion up to the WL.

Preparation with the WOG File System (Group 1c, 2c, and 3c)
The WOG Primary file (25/0.07) (Dentsply Maillefer, Ballaigues, Switzerland) was used in WOG ALL mode of Dentsply X-Smart Plus endodontic motor. The WOG Primary file was removed from the root canal after every three reciprocating movements (pecking motion) or when resistance was encountered, cleaned, and rinsed with distilled water. This procedure was continued until the WL was reached.
An operator conducted all the procedures. All teeth were irrigated with a total volume of 10 mL distilled water using a double-sided port needle (NaviTip 29-gauge; Ultradent South Jordan, UT, USA) positioned 2 mm short of the WL. Debris on the root surface of each tooth was rinsed with 1 ml of distilled water into a glass vial and collected. After that, the glass vials were placed in an incubator at 37 °C for 14 days to vaporize the solution. Then, all vials were weighed three times, as previously, and the average values were recorded. The weight of the debris was calculated by subtracting the vial's preoperative weight from its postoperative weight.

Statistical Analysis
The Shapiro-Wilk test showed that the values have a normal distribution, and the Levene test revealed that the data showed a homogeneous distribution. The effects of the files used and the areas where the debris extruded were examined with the two-way ANOVA test. Differences between groups were determined by pairwise comparisons with Bonferroni correction. Statistical tests were performed using SPSS Windows (SPSS for Windows, Version 22 SPSS, Inc., Chicago, IL, USA) software, and the significance was evaluated at the level of $P < 0.05$.

Results

Table 1 shows the average values with standard deviations (SD) of the weight of extruded debris for each test group.
Group 1 (Apical Foramen): the (a) hand file significantly extruded more debris compared to both (b) PTN and (c) WOG (Pab<.001, Pac<.001).
Group 2 (Apical 1/3 Perforation): Similar to Group 1, the (a) hand file produced significantly more debris than the (b) PTN and (c) WOG (Pab=.004, Pac =.005).
Group 3 (Middle 1/3 Perforation): in this group, (b) PTN extruded significantly less debris than (a) hand file and (c) WOG (Pba=.006, Pbc=.024). There was no statistically significant difference between (a) hand file and (c) WOG in terms of debris extrusion.
When examining the impact of each file system on the amount of debris extrusion from the apical foramen and perforation areas:
For preparation with (a) hand files, the highest amount of debris was extruded from the apical foramen (Group 1), and this amount exhibited a statistically significant difference when compared to the debris extrusion from the middle 1/3 perforation (Group 3) (P=.024).
For preparation with the (b) PTN System, the most debris was extruded from the perforation area in the apical 1/3 (Group 2), and this amount was statistically higher compared to the amount of debris extruding from the apical foramen (Group 1) (P=.001).
For preparation with the (c) WOG System, the most debris was extruded from the perforation area in the middle 1/3 of the root (Group 3), and the amount of debris extruding from this perforation area was statistically higher than the amount of debris extruding from the apical foramen (Group 1) (P=.035).

Table 1

Mean and SD values for the weight of extruded debris.

	Preparation Technique								
	(a) Hand file			(b) ProTaper Next			(c) WaveOne Gold		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Grup 1 (apical foramen)	15	.00187^{Aa}	.00082	*15*	.00040^{Ba}	.00020	*15*	.00078^{Ba}	.00028
Grup 2 (apical 1/3 perforation)	15	.00173^{Aab}	.00071	*15*	.00111^{Bb}	.00040	*15*	.00112^{Bab}	.00047
Grup 3 (middle 1/3 perforation)	15	.00135^{Ab}	.00066	*15*	.00075^{Bab}	.00023	*15*	.00126^{Ab}	.00056

In each column different lower-case letters show a statistically significant difference at the (0.05) level.
Different capital letters indicate a statistically significant difference at the (0.05) level in each row.

Discussion

Post-operative pain and swelling, which are undesirable complications for both the patient and the specialist, may occur because of debris extrusion during root canal preparation (21, 22). During endodontic treatment, the root canal contents, consisting of dentin chips, necrotic pulp tissues, and bacteria, can be pushed into the periapical region and trigger an inflammatory reaction (23). This ex vivo study investigated the amount of debris extruding from the apical foramen and the perforation areas created in the apical and middle 1/3 of the root surface during the preparation of root canals with two different NiTi file systems (WOG, PTN) and hand files.
The results indicated that there were significant differences in the amount of debris extruded by file systems from the apical foramen and perforation areas. Thus, the null hypothesis was rejected.
Numerous studies assessing the amount of debris extruded apically demonstrated that hand files extrude more debris than multi-file rotary systems and reciprocating single-file systems (11, 24, 25). Consistent with these finding, in current study, in all groups, hand file preparation resulted in the highest amount of extruded debris. Additionally, in Group 3 (middle 1/3 perforation), no statistically significant difference was found between WOG and hand file preparation in terms of the amount of extruded debris. During hand file preparation, the most debris extruded from the apical foramen, followed by the perforations in the apical 1/3 and middle 1/3. This can be attributed to the hand files' push-pull filing motion, akin to a piston, and the limited space between the file and dentinal walls, hindering the coronal transport of debris. Koçak et al. and Çakıcı et al. (26, 27) compared the amount of debris extrusion from the apical foramen using the PTG, Reciproc, PTN and PTU file systems, and found that the PTN file system caused significantly less extrusion. Similarly, our data indicated that PTN resulted in the least debris extrusion in all groups, with no statistically significant difference between PTN and WOG in Groups 1 (apical foramen) and 2 (apical 1/3 perforation).
During the preparation with PTN, the most debris extruded from the perforation in the apical 1/3, the perforation in the middle 1/3, and the apical foramen, respectively. The observed extrusion can be linked to the standardized closure of the apical foramen with two layers of nail polish and the continuous increase in taper of the X1 and X2 files up to 9 mm,

which could lead to debris being trapped in the dentin walls. Additionally, the brushing motions during the procedure may have contributed to higher debris extrusion, particularly in the apical 1/3. Eliasz et al. (18) reported no statistically significant difference in debris extrusion between PTN, WOG, and Twisted Files. Similarly, in our present study, no statistical difference in extruded debris was found between PTN and WOG in Groups 1 and 2. However, in Group 3, the WOG and hand file preparations resulted in statistically higher debris extrusion compared to the PTN. The WOG file system exhibited the least debris extrusion from the apical foramen but the highest amount of debris from the middle 1/3 perforation area, and these differences were statistically significant. This outcome can be attributed to the WOG system's pecking action, limited dentin contact at 1 or 2 points due to its cross-sectional design, and the presence of ample space for coronal debris transport, thanks to its decreasing taper towards the coronal part.
In previous studies, researchers usually created perforation cavities on root surfaces using diamond or carbide burs, and the diameters of the simulated perforation cavities in these studies ranged from 0.25 to 1.5 mm (28-30).
Topçuoğlu et al. (7) created a simulated external resorption area by horizontally removing the 2 mm apical part of the root with a fissure drill after completing root canal filling in a mandibular premolar tooth. They then evaluated the amount of debris extruding from the apical area during the retreatment process. On the other hand, Silveira et al. (31) developed a demineralization protocol using solutions of nitric acid and sodium hypochlorite (NaOCl) to simulate internal root resorption.
This approach resulted in resorption cavities with varying diameters and depths, making standardization challenging. In our study, we created perforations with burs featuring a 0.5 mm tip diameter to ensure standardization. Additionally, before the prepation procedures, the apices of all roots in Groups 2 and 3 were sealed with two layers of nail polish to simulate a closed-end canal model, as previously described (32, 33). The use of different file systems and techniques may lead to changes in the results of debris extrusion studies (6, 26).
There is no study in the literature investigating the effect of various file systems on the amount of debris extruded from the perforations created on the root surface. As a result, no direct comparison with other studies was possible.
It's important to acknowledge that studies investigating debris and irrigating solution extrusion using extracted teeth have inherent limitations. In vivo, the periodontal tissue surrounding the apical foramen offers natural resistance to debris extrusion. While attempts have been made to simulate this resistance using materials like floral foam and agar gel, these methods have been associated with certain challenges, including the absorption of irrigants by foam and the difficulty in precisely determining the agar gel thickness at the apex to replicate the size of the apical lesion (34, 35). Therefore, we opted not to use an apical barrier. Another critical consideration is the choice of irrigation solution, which can significantly impact study outcomes (36). The formation of crystals due to the use of sodium hypochlorite (NaOCl) may affect the amount of extruded debris. To mitigate this potential influence, we selected distilled water as the irrigation solution.
Within the limitations of this research, all the file systems used in root canal preparation led to varying amount of debris extrusion from both the apical foramen and perforation areas. To gain a comprehensive understanding of the impact of debris extrusion from perforation areas on the success of endodontic treatment, further investigations, both *in vitro* and *in vivo*, will be necessary.

Conclusions

All the instruments used caused the debris extrusion. Hand files exhibited the highest amount of extruded debris in all tested groups. Careful selection of instruments and techniques during endodontic procedures, especially in cases involving perforations, can significantly reduce debris extrusion and improve patient comfort and post-operative results.

Clinical Relevance

This study underscores the critical role of instrument choice in reducing complications, improving treatment success, and enhancing patient comfort during root canal procedures. Insights into the impact of various file systems and perforation sites on debris extrusion offer valuable guidance to clinicians. Furthermore, the study advocates for future research to optimize endodontic procedures, aiming for better overall clinical outcomes.

Conflict of Interest

The authors declare that they have no conflict of interest.

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