

Apically Extruded Debris following Programmed Over Instrumentation of Curved Canals with Three Nickel Titanium Rotary Instruments

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Abstract

Objectives This *in vitro* study aimed to compare the amount of mixed and dried debris extruded with three endodontic NiTi (nickel–titanium) systems at three levels beyond the major apical foramen. The null hypothesis is that there would be no differences between the different rotary systems in terms of apically extruded debris.

Materials and Methods Forty-eight roots of human extracted molars with 20 to 40-degree curvature were divided randomly into three groups ($n = 16$) instrumented with ProTaper Next, BT RaCe, and WaveOne Gold, respectively. Instrumentation was performed at the major foramen and over instrumented 0.5 mm, 1.0 mm and 1.5 mm beyond. Irrigation was performed with sodium hypochlorite. Apically extruded debris was collected.

Results Comparison of *mixed extruded debris (solution/debris)* and *dried debris* according to group and level of instrumentation showed that WaveOne Gold at the foramen and ProTaper Next beyond the foramen ($p < 0.0001$) resulted in significantly less extruded debris than other files and within the four levels using repeated measures analysis of variance ($p < 0.0001b$).

Conclusions All systems exhibit extruded debris during instrumentation but in different amounts.

Keywords

- ▶ apical debris extrusion
- ▶ curved root canals
- ▶ over instrumentation
- ▶ reciprocating system
- ▶ continuous rotation

Introduction

One of the consequences of root canal preparation is the extrusion of irrigant, pulp remnants, and dentinal chips into the periapical space. The extrusion of debris may be affected by natural physical factors associated with the anatomy of the tooth such as root canal curvature, as well as mechanical factors such as the specific design of the instruments and/or type of rotary motion of instruments (continuous or reciprocating).^{1,2} Following cleaning and shaping of the root canal system the extrusion of apical debris is inevitable and can cause postoperative pain.³ Subsequently, instrumentation of narrow and curved root canals is not easy and may cause undesirable aberrations.⁴ None of the current instruments

and preparation techniques could prepare root canals without debris extrusion, although the amount of debris extruded may vary accordingly.⁵ Recently, attention on extended root canal preparation techniques, with or without enlarging the foramina^{5,6} or by over instrumentation^{7,8} was required and investigated.

ProTaper Next and WaveOne Gold have been currently investigated regarding the amount of apical extrusion debris identified in their applications.^{9,10} Other file systems have limited information concerning this subject, such as the BT Race system.^{11,12}

The ProTaper Next system (PTN; Dentsply Maillefer, Ballaigues, Switzerland) is used with continuous rotation. It has five shaping instruments: X1 (17/0.04), X2 (25/0.06),

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X3 (30/0.07), X4 (40/0.06), and X5 (50/0.06). PTN files are manufactured from an M-wire alloy and have a snake-like swagging movement due to the off-centered rectangular cross-section. Both the X1 and X2 files have an increasing and decreasing tapered design on a single file.¹¹

BT RaCe files (BTR) (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) are generated from conventional austenite NiTi (nickel–titanium). BTR instruments are available in size 10(0.06 taper), size 35(0.00 taper), size 35(0.04 taper), size 40(0.04 taper), and size 50(0.04 taper). The BT2 instrument size 35 is cylindrical and not tapered. These files are characterized by a triangular cross-section over the entire working part except for the so-called “booster tip” because of its particular hexagonal shape. According to the manufacturers, the booster tip is the key feature of these files that allows them to follow curvatures in canals without undue stress on the file or the root. The tip of the instrument starts with a noncutting design from 0 mm to 0.17 mm, then turns into a cutting blade upward till the shaft of the file. This feature has been suggested to allow these files to safely follow even very narrow canals.^{11,13}

The WaveOne Gold (WOG; Dentsply Maillefer, Ballaigues, Switzerland) is a novel file system manufactured using a thermal process that enhances the cyclic fatigue resistance and flexibility of the instruments. This single-file reciprocating system has four tip sizes: small (20/0.07), primary (25/0.07), medium (35/0.06), and large (45/0.05). The files have a parallelogram-shaped off-centered cross-section with 85 degrees cutting edges in contact with the canal with a variable and reducing taper.¹⁴

Apically extruded debris can be quantified *in vivo* by measuring neuropeptides in the periodontal ligament,¹⁵ or *in vitro* by weighing the amount of extruded debris collected.¹⁶ Depending on the position of all files apically, with regards to both working length (WL) and patency filing, all file systems applications can result in debris extrusion that may impact the biological status of the periapical tissues. This is especially true due to the controversies surrounding the ideal apical location to terminate all instrumentation procedures.¹⁷

The aim of this investigation was to compare the amount of mixed debris (solution debris) and dried debris apically extruded after preparation of curved root canals of extracted human teeth at the foramen and three levels beyond, using three types of rotary files. The null hypothesis is that there would be no differences between the different rotary instruments in term of apically extruding debris.

Materials and Methods

Sample Size Calculation

For sample size calculation, power analysis was carried based on a prior similar study conducted by Vivekanandhan et al.¹⁸ Taking into consideration debris extrusion as the primary outcome, we used analysis of variance (ANOVA) one-way test for three groups, with 5% error and power of 90%; needed sample size was determined to be 48 based on 16 for each group.

Sample Selection and Preparation

Forty-eight root canals taken from forty-eight extracted human maxillary and mandibular molars were selected based on the following inclusion criteria: (1) maxillary and mandibular mesiobuccal or mandibular mesiolingual canals; (2) complete apices formation; (3) canals with moderate to severe angles of curvature (20–40 degrees) as measured radiographically according to Schneider’s technique¹⁹; (4) no history of root canal treatments. The study was approved by the Ethics Committee of the Lebanese University, Hadath, Lebanon (Number: 262018/142D/CUMED). The study protocol and informed consent were in full accordance with the ethical principles of the Declaration of Helsinki of 1975 as revisited in 2000. The patients were informed about the study objectives and procedures and signed a written consent to use their extracted teeth for research purposes.

Maxillary mesial roots with two canals, root canal calcification, internal or external root or apical resorptions, and cracked roots were excluded from this study. The teeth were cleaned under continuous water flow; debris and residues from periodontal ligament were eliminated using an ultrasonic device. Subsequently, the teeth were stored at room temperature in a 0.9% normal saline solution supplemented with 0.1% thymol (Sigma Chemical Co., St Louis, Missouri, United States) for antibacterial activity.⁷ The storage solution was changed weekly to maintain cleanliness, hydration, and disinfection.

All crowns were sectioned at the cemento-enamel junction area and standardized to a remaining radicular length of 16 mm. Root canal orifices were sealed with cotton pellets and modeling wax. Subsequently, the specimens were positioned in the center of a customized 2-cm-height plexiglass cylinder with the apices facing upward. Fast setting acrylic resin (Paladur Heraeus Kulzer, Inc., South Bend, Indiana, United States) was poured into the cylinder leaving 2 mm of the apices uncovered.

The cylinders containing the specimens were transferred to a second prefabricated light-cured resin mounting device to stabilize the samples during canal preparation (►Fig. 1).

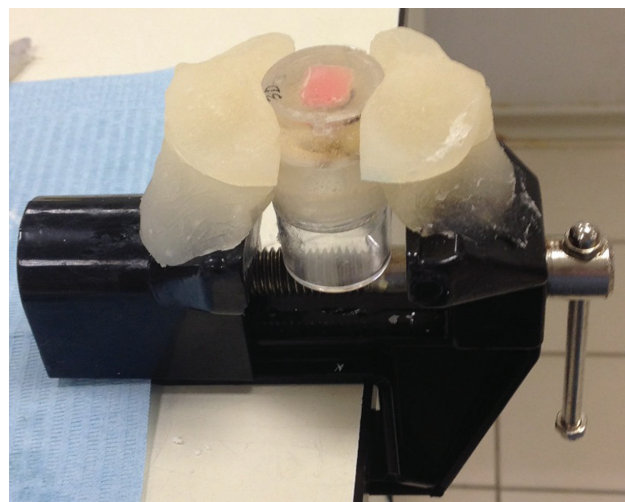


Fig. 1 Prefabricated metal bench vice modified with cold cured resin to stabilize the tooth holder during endodontic procedures.

The canals were identified using an endodontic probe (DG16, Hu Friedy, Illinois, United States), and a manual scouting of the 48 canals was achieved with an ISO k-file size 08. Then, the WL was established with a size 10 k-file (K-File, Dentsply Maillefer) in the presence of hypochlorite as initial irrigant. The file was introduced until the tip was just visible at the apical foramen under a stereomicroscope (SM-1TSZZ-144S, Irvine, California, United States) at $\times 45$ magnifications. The silicone stop was adjusted to the nearest flat anatomical landmark and the distance between the file's tip and the rubber stopper was measured with a ruler (Dentsply Maillefer). The WL was recorded as the reference landmark-file tip measurement retrieving 0.5 mm.

Experimental Design

The 48 selected canals were randomly assigned into three groups of 16 canals each according to the type of rotary NiTi system: Group PTN, Group BTR, and Group WOG. All groups were instrumented as per manufacturer's guidelines.

A preprogrammed electric motor (X-SMART Plus-DentsplyMaillefer) was set for each group of NiTi instruments according to the specific recommendations of the manufacturer in terms of torque, speed, and motion. Instrumentation was performed by single experienced endodontist. One set of new instruments was used for each canal, and after each file the canals was irrigated with 3 mL of 5.25% NaOCl solution. Canals of all specimens were instrumented at the major foramen, and subsequently over instrumented by 0.5 mm, 1 mm, and 1.5 mm beyond the foramen. The WL was recalculated when increasing the file sizes to avoid file protrusion beyond the desired settled levels. An amount of 24-mL sodium hypochlorite 5.25% was used per canal during the experiment (► **Table 1**).

Debris Collection

Two screw-fastened cylinders of equal dimensions were manufactured for debris collection. They were fixed on each other and could be detached each time the contents had to be weighed according to the model described by Yammine et al.²⁰ The teeth were mounted in the upper cylinders. Debris was collected in the lower ones, which were ventilated by performing a hole of 1.0 mm on each one to equalize the atmospheric pressure with the internal pressure (► **Fig. 1**).

The lower cylinders were preweighed three times using analytical microbalance (JF/JTA, JF 1204) with an accuracy of 0.0001 g, and the average values were recorded for each one. The weights of the lower cylinders were noted after instrumentation to the foramen and following the different levels of over instrumentation (0.5 mm, 1 mm, and 1.5 mm beyond the foramen). The weights of the extruded mixed debris (solution and debris) were determined by subtracting the preweighed empty cylinders from the weights of the cylinders containing mixed debris and these weights were noted.

Then, all cylinders were stored open in an incubator at 37°C for 15 days to evaporate the moisture (solution) from mixed debris.²¹ Following desiccation, the dried extruded debris in the cylinders were weighed the same way as the mixed one and also noted. A total of four weight measurements were done for every canal, with mixed debris and dried condition, corresponding to the different levels of instrumentation.

Sodium hypochlorite, NaOCl, is the irrigant of choice which can dissolve the organic components of the pulp as well as dentinal collagen.²²

Good to mention that, when sodium hypochlorite evaporates it leaves salt molecules which are one of its components. To calculate exactly the amount of dry net debris without the salt crystal, a mathematical measurement could be applied: 1 mL of sodium hypochlorite (NaOCl) solution weighed and incubated at 37°C for 15 days and dried equated to 0.0752 g of salt crystals:

$$1 \text{ mL of NaOCl liquid} = 0.0752 \text{ g dry crystal}$$

Extruded debris assessment was performed by an independent examiner blinded to the experimental design and study objectives. Reliability was assessed based on ten repeated weightings of debris following instrumentation of five canals. High intraobserver agreement with intraclass correlation coefficient of 0.962 was calculated.

Statistical Analysis

Descriptive statistics with means and standard deviations were determined. Repeated measures ANOVA was used to compare the amount of apically extruded debris, whether

Table 1 Sequence of instruments and level of irrigation used for canal preparation in the 3 groups PTN, BTR and WOG

	Amount of NaOCl (mL)	PTN group	BTR group	WOG group
Canals negotiation	3 ml	8 K file	8 K file	8 K file
Instruments to WL	3 ml	10 K file	10 K file	10 K file
Instruments to foramen	3 ml	ProGlider	10.06 BT1	ProGlider
	3 ml	X1	35.00 BT2	Small
	3 ml	X2	35.04 BT3	Primary
0.5 mm beyond foramen	3 ml	X2	35.04 BT3	Primary
1 mm beyond foramen	3 ml	X2	35.04 BT3	Primary
1.5 mm beyond foramen	3 ml	X2	35.04 BT3	Primary

Abbreviations: BTR, BT RaCe files; PTN, ProTaper Next system; WOG, WaveOne Gold.

mixed or dried, between groups at each level (instrumentation at the foramen, at 0.5 mm, at 1 mm, and at 1.5 mm beyond) and between levels in each group. *p*-Value was set at 0.05 for statistical significance. Statistical analysis was performed using Statistical Package for Social Sciences, version 21.0 (SPSS, Inc., Chicago, Illinois, United States).

Results

Descriptive and comparative statistics of mixed and dried extruded debris are summarized in ► **Tables 2** and **3**. The comparison between groups for mixed extruded debris showed nonsignificant difference at the foramen level but started to be significant after instrumentation for the three levels beyond foramen. Conversely, the difference between groups for dry extruded debris showed significant difference at 0.5 mm beyond the major foramen and continued to be nonsignificant at the other levels. However, all groups showed significant difference in mixed and dried extruded debris following each level of instrumentation and over instrumentation.

Discussion

The aim of this *in vitro* study was to assess the amount of apically extruded debris following instrumentation and over instrumentation of root canal system with different rotary instruments. With this method, we can evaluate quantitatively the amount of irrigant and debris (dentin components, bacteria, residues from old filling...) ejected through the foramen in the periapical area. Regardless of the diameter of the apical tip of the instrument or its taper, an operative sequence for each system was recommended by the manufacturers as the best sequence you will ever have for cleaning and shaping root canal system with less damage to the dentinal and apical structure. Failure in endodontic treatment has a different meaning.²³ It has been defined that over instrumentation is a failure and can occur accidentally after using rotary instruments or losing the canal WL. The problem of unintentional over instrumentation, if present or happened by inadvertence will compromise the root canal treatment with qualitative changes in the apical area of the root (changes in shape and position of the foramen). In this investigation we did not intend to uncover the superiority of

Table 2 Comparison of mixed extruded debris according to group and level of instrumentation

	PTN group (n = 16)	BTR group (n = 16)	WOG group (n = 16)	<i>p</i> -Value ^d
	Mixed mean ± SD (g)	Mixed mean ± SD (g)	Mixed mean ± SD (g)	
Instrument to foramen	0.162 ± 0.340	0.185 ± 0.478	0.086 ± 0.181	0.712
0.5 mm beyond foramen	0.234 ± 0.352	1.089 ± 0.549	0.821 ± 0.458	<0.000
1 mm beyond	0.459 ± 0.361	1.407 ± 0.586	1.349 ± 0.676	<0.000
1.5 mm beyond foramen	0.629 ± 0.343	1.503 ± 0.543	1.401 ± 0.452	<0.000
<i>p</i> -Value	<0.0001 ^a	<0.0001 ^b	<0.0001 ^c	

Abbreviations: ANOVA, analysis of variance; BTR, BT RaCe files; PTN, ProTaper Next system; SD, standard deviation; WOG, WaveOne Gold.

Note: a, corresponds to significant differences between the three groups using repeated measures ANOVA; b, corresponds to significant differences between the four levels using repeated measures ANOVA; c, corresponds to significant differences between the 4 levels * groups using repeated measures ANOVA; d, corresponds to significant differences between the three groups at each level using one-way ANOVA.

Table 3 Comparison of dried extruded debris according to group and level of instrumentation

	PTN group (n = 16)	BTR group (n = 16)	WOG group (n = 16)	<i>p</i> -Value ^d
	Dried mean ± SD (g)	Dried mean ± SD (g)	Dried mean ± SD (g)	
Instruments to foramen	0.018 ± 0.031	0.017 ± 0.039	0.008 ± 0.014	0.568
0.5 mm beyond foramen	0.024 ± 0.032	0.098 ± 0.063	0.076 ± 0.048	<0.0001
1 mm beyond foramen	0.087 ± 0.192	0.119 ± 0.060	0.126 ± 0.071	0.644
1.5 mm beyond foramen	0.119 ± 0.215	0.131 ± 0.053	0.128 ± 0.044	0.965
<i>p</i> -Value	0.451 ^a	<0.0001 ^b	0.488 ^c	

Abbreviations: ANOVA, analysis of variance; BTR, BT RaCe files; PTN, ProTaper Next system; SD, standard deviation; WOG, WaveOne Gold.

Note: a, corresponds to nonsignificant differences between the three groups using repeated measures ANOVA; b, corresponds to significant differences between the four levels using repeated measures ANOVA; c, corresponds to nonsignificant differences between the four levels * groups using repeated measures ANOVA; d, corresponds to significant differences between the three groups at each level using one-way ANOVA. In this footnote the star defined the statistical significance between groups and within levels

one system over another, but our purpose was to reveal that all rotary system would have a weakness in a certain way. The instruments used were of three types, namely PTN and BTR in continuous rotation and, WOG as a reciprocating file system. The null hypothesis stating that no difference exists between the different groups was rejected.

Different methodologies have been developed to measure the extrusion of debris and the methodology of Myers and Montgomery is mostly used.²⁴ The method and materials used in the present study differ from those of Myers and Montgomery in the collection system and also in the instruments used. However, regardless of the methodology used, biases exist whether severe, medium, or low.²⁵ The singularity in this study resides in: (1) the collection system using specific fixed cylinders mounted on a prefabricated model to simulate as possible clinical conditions; (2) the measurements of collection done beyond the foramen.

While other methods used distilled water for irrigation,^{21,26,27} we applied an irrigation method closely similar and more aligned to clinical practice.^{28,29} To ensure reliability, an equal amount of irrigant was used in every canal. Also, the type and volume of irrigant could have a positive or negative effect on the quantities of generated smear layer and its elimination. Moreover, studies using distilled water as an irrigant^{21,26,27} overcame the problem of overweight samples, especially due to crystal formation of sodium hypochlorite following evaporation of extruded solution. The quantification of extruded debris was done in the laboratory by using an experimental model well-defined to collect the debris, in addition to an analytic balance of high sensitivity used. Contrary to most of the published studies where evaluation of apical extrusion was performed with a WL of 1 mm from the apical foramen,^{10,11,30,31} the instrumentation of the canal system was accomplished at the foramen and beyond, which might limit comparison with previous studies. Most studies related to this subject have calculated the amount of extrusion of debris after instrumentation at the WL which corresponds to the apical constriction.¹⁰ To the investigators' knowledge, no study has reported extrusion of debris beyond the foramen.

In the present study, evaluation of the apical extrusion of debris produced by continuous rotary-file systems versus single-file reciprocating system demonstrated that all instruments created apical debris extrusion, in agreement with the previous studies.^{1,5,10,29,31-33} Dincer et al reported that continuous rotary systems extruded more debris than reciprocating systems (dried extruded debris) at the WL.³¹ In addition, Karataş et al specified that WOG system produced less debris than the continuous rotation systems such as the ProTaper Gold and ProTaper Universal systems.³⁴ Also in the present study, no significant differences were noted in extrusion of mixed or dried debris between the three rotary systems at the foramen. WOG revealed less dried extruded debris at the foramen while PTN showed less extrusion than WOG and BTR at all levels beyond the foramen. This finding confirms the results of Kustarci et al who demonstrated that

the quantity of debris extruded may change according to the preparation technique and file system used.⁵

No difference between groups in the amount of mixed or dried extruded debris was found at the foramen level. At 0.5 mm beyond the foramen, the design of the instrument and its kinematic have an effect on the amount of debris extruded. We have noted a difference between the techniques in both mixed and dried debris. In mixed and dried debris PTN showed less debris extruded than WOG followed by BTR.

We also noted a difference in the volume of mixed extruded debris, regardless of the level of instrumentation in the three systems. However, the amount of mixed extruded debris increased from one level to the next level of instrumentation. Nevertheless, the technique of instrumentation does not affect the amount of dried extruded debris at 1 mm and beyond. Moreover, once the instrument is at 1 mm and beyond, the amount of debris collected does not increase significantly from one level to the higher one.

This study showed that BTR in mixed and dried extruded debris presents significant differences between the four levels. Likewise, PTN causes less extrusion of mixed and dried debris than a single-file reciprocating system WOG when the instruments were used in over instrumentation mode. In contrary, debris collected from the reciprocating WOG file showed less mixed and dried debris at the foramen. This could be explained by the impact of different factors that could play a positive or negative effect on debris extruded through the foramen during instrumentation like diameter of the file, flute and pitch, cutting efficiency, kinematic of the instruments and/or other factors. This finding could not be explained by the present investigation and could be addressed in a new research studying the effects of dynamic action and the design of continuous and reciprocating files on debris extrusion.

Despite the experimental model used to collect debris extrusion, the present results cannot be extrapolated to clinical situation, because of the absence of physical backpressure from periapical tissue that inhibits extrusion of debris. Also, other factors might influence the amount of extruded debris like root anatomy, canal length, age of patient, hardness, and calcification of dentine.^{25,35} However, it allows a quantification of extruding debris of different file systems if instrumented beyond the foramen. There are several conditions in this issue like not avoiding this accident in inadvertence by misestimating the WL at the first measurement, or by the use of instruments with a screwing effect in the root canal, or by the movement of the instrument's stopper or by straightening a curved canal leading to over instrumentation...

What is clear is that over instrumentation is done inadvertently during cleaning and shaping the root canal system. We think it has a big clinical significance and the rational of this study is as important as the extended filling condition in root canal treatment which is very well documented in the literature. Studies of this category would be useful and might be considered as a necessary tool for assessing apical extrusion of debris.^{21,26,36}

Conclusions

Within the parameters of this study that compared the amount of extruded debris associated with the use of rotary instruments, namely PTN, BTR, and WOG, instrumenting root canals at foramen level resulted in the same amount of mixed extruded debris, and at all levels of over instrumentation; application of PTN files exhibited the least mixed extruded debris. When measurements were made for the dried extruded debris, the BTR files delivered more dried debris at 0.5 mm of over instrumentation than the other systems.

The present study confirms the results of previous publications that no method of instrumentation is able to prevent debris extrusion. Despite the limitations of extrapolating these results in clinical situations, all three engine-driven instruments can be used safely up to the foramen level. Care should be taken when the canal is inadvertently over instrumented as the type of the instrument has an impact on the amount of extruded debris.

Note

All the three rotary instruments ProTaper Next, BT RaCe, and WaveOne Gold can be used safely up to the foramen level. Care should be taken when the canal is inadvertently over instrumented as the type of the instrument could have an impact on the amount of extruded debris.

Conflict of Interest

None declared.

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