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Efficacy of photon-initiated photoacoustic streaming on apically extruded debris with different preparation systems in curved canals

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Abstract

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Aim To determine the effect of photon-initiated photoacoustic streaming (PIPS) on the extrusion of debris using multiple-file (ProTaper Next-PTN) and single-file (One Shape-OS) continuous rotary systems in curved canals in human molar teeth.

Methodology Sixty extracted maxillary first molar teeth with curved mesial roots, mature apices and of similar lengths were selected. Teeth having canals with apical diameters larger than size 15 were discarded. The teeth were randomly divided into four experimental groups ($n = 15$ teeth per group) according to the file used and irrigation systems: (i) OS with PIPS with a 2940 nm Er:YAG laser (0.3 W, 15 Hz, and 20 mJ), (ii) OS with conventional needle irrigation (CNI) with a 27-G needle, (iii) PTN with PIPS and (iv) PTN with CNI. The PIPS and CNI was applied during each file change for 20 s. Total irrigation and activation time was 1 min, and a total volume of 7.5 mL of bidistilled water was used as the irrigant. The apically extruded debris was collected into pre-weighed Eppendorf tubes. The tubes were then stored in an incubator at 70 °C for 5 days. The weight of dry extruded debris was assessed by subtracting the initial weight of the tube from the final weight. The results were analysed statistically using one-way analysis of variance and Tukey's *post hoc* tests. Bonferroni correction was used to compare the groups.

Results The PIPS irrigation technique was associated with significantly more debris extrusion than the CNI system ($P < 0.05$). The single-file (One Shape-OS) rotary system was associated with more debris than the multiple-file (ProTaper Next-PTN) rotary systems when the same irrigation system was used ($P > 0.05$). The total amount of debris extruded apically by PIPS activation was significantly greater than that by CNI ($P < 0.05$).

Conclusions All file and irrigation systems extruded debris apically. PIPS activation was associated with significantly more extrusion debris in curved canals compared with no activation.

Keywords: debris extrusion, laser activation, one shape, photon-initiated photoacoustic streaming, ProTaper Next.

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Introduction

Chemomechanical preparation is a crucial stage in successful root canal treatment. Mechanical preparation and irrigants play a key role in achieving debridement and eliminating vital and necrotic tissue, debris and microorganisms (Schilder 1974). To minimize the impact of negative factors such as complex apical anatomy and the inability of irrigants to penetrate into lateral canals, sonic, ultrasonic and various laser activation techniques have been introduced (Guerisoli *et al.* 2002, De Moor *et al.* 2009, DiVito & Lloyd 2012, Pedulla *et al.* 2012).

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Debris, pulpal components, irrigation solutions, microorganisms and their by-products are extruded into the periapical region during chemomechanical instrumentation (al-Omari & Dummer 1995, Ferraz *et al.* 2001, Kustarci *et al.* 2008a, Elmsallati *et al.* 2009). The debris can lead to postoperative inflammation, flare-ups, pain and delay of periapical healing (Seltzer & Naidorf 1985, Siqueira 2003). Although various studies have indicated that all instrumentation techniques and file systems are associated with the extrusion of debris, the amount of extrusion can vary due to the size, type and kinematics of the endodontic instruments, preparation techniques, direction of instrumentation and irrigation techniques employed (Ferraz *et al.* 2001, Kustarci *et al.* 2008a).

A systematic review and meta-analysis investigated the influence of the number of files (full-sequence rotary file versus reciprocating single-file systems) used during root canal preparation on the apical extrusion of debris and its biological relationship with the occurrence of symptomatic apical periodontitis All root canal preparation systems were associated with debris extrusion, and there was great heterogeneity in the results. After analysis of these results, the authors concluded that the design of the instrument was the most influential factor for neuropeptide expression after root canal preparation, regardless of the number of files or the type of movement (Caviedes-Bucheli *et al.* 2016).

ProTaper Next (PTN) (PTN, Dentsply Sirona, Ballaigues, Switzerland) is a novel multiple-file NiTi rotary system designed with progressive and regressive percentage tapers, it has a snake-like swaggering movement owing to an off-centred rectangular cross-section. These designs make it possible to completely prepare root canals using fewer instruments than the number required by the ProTaper Universal System (Ruddle *et al.* 2013). In addition, this system uses an M-Wire alloy to increase flexibility and cyclic fatigue resistance (Alapati *et al.* 2009).

The single-file NiTi system, One Shape (OS, Micro Mega, Besançon, France), is claimed to be able to completely prepare root canals of a size 25 with a .06 taper using a single instrument (Burklein *et al.* 2013). The OS features different cross-sectional designs over the length of the working part, which suggests an optimal cutting movement (Burklein *et al.* 2014).

A novel laser activation irrigation system, photon-initiated photoacoustic streaming (PIPS), is used with an erbium: yttrium-aluminium-garnet (Er:YAG) laser. Low energy (20 mJ), pulse repetition rate (15 Hz) and very short pulse length (50 μs) are used with a radial, stripped novel tip in this system (Olivi & DiVito 2012). PIPS differs from other techniques in that the tip is placed in the pulp chamber and kept stable without advancing into the canal orifice (Pedulla *et al.* 2012). DiVito *et al.* (2012) indicated that PIPS improves canal cleanliness with a greater number of open tubules compared to nonactivation irrigation. No study has yet analysed the influence of the PIPS activation technique on the amount of apically extruded debris. Thus, the purpose of this study was to determine the effect of the PIPS technique on extrusion of debris using a multiple-file PTN and a single-file OS continuous rotary system in curved canals. The null hypothesis tested was that there would be no difference between PIPS and conventional irrigation techniques associated with two types of instrumentation systems in terms of the weight of apically extruded debris.

Materials and methods

Selection and preparation of teeth

Maxillary human first molars extracted for periodontal and orthodontic reasons were obtained from the Department of Oral and Facial Surgery with the approval of the Ethics in Research Committee of Bezmialem Vakif University, Istanbul, Turkey (Ethics number; 2016.78). Fifteen samples were indicated by the chi-square test family and variance statistical test (G*Power 3.0.10 software with a α-type error = 0.05 and β = 0.95) for each group. Curved mesiobuccal canals of maxillary molar teeth were selected to compare the file and irrigation systems. The external root surfaces of the teeth were cleaned using ultrasonic devices, and the degree of curvature was calculated (Schneider 1971). Angles of canal curvature ranging from 10° to 20° were included. The roots were viewed radiographically, and the following exclusion criteria were applied: mesiobuccal root with calcification, more than one canal and apical foramen, an immature root apex or root canal treatment and apical diameters larger than size 15 K-file. The 60 teeth selected with these criteria were immersed in 4 °C distilled water until use.

After preparing the access cavities using a fissure bur, the occlusal surface of the buccal cusps was levelled to form a stable reference point. A size 10 K-file was then inserted into the canal until it was just visible at the apical foramen, and the working length (WL) was recorded 1-mm short of this length.

Pre-weighing of the Eppendorf tubes

Empty Eppendorf tubes without stoppers were weighed three times with an electronic scale (AUW-220D; Shimadzu, Tokyo, Japan) with an accuracy of 10^{-5} precision. The mean weight was recorded as the initial weight.

Test design

The experimental model, as defined by Myers & Montgomery (1991), was used. A hole was created in each stopper, and each tooth was inserted up to the cementoenamel line and was then fixed in the stopper using self-acrylic resin. To equalize the air pressure, a 27-gauge open-ended needle was immersed in each stopper. Each stopper with the tooth and needle was then passed into the Eppendorf tube, and all the tubes were seated in vials during instrumentation to avoid hand contamination of the Eppendorf tubes.

A total of 60 test models were randomly divided into four experiment groups (n = 15) as follows. For randomized dividing of the test models into four groups, a test model received a number code, and another examiner selected 15 numbers randomly for group 1, 15 for group 2, 15 for group 3, and the rest for group 4.

Group 1: OS with PIPS-activated irrigation.
Group 2: OS with conventional needle irrigation (CNI).
Group 3: PTN with PIPS-activated irrigation.
Group 4: PTN with CNI.

Irrigation and instrumentation procedures

For each canal, the total irrigation and activation time was 1 min, and a total volume of 7.5 mL of bidistilled water was used as the irrigant. 2.5 mL bidistilled water was applied for 20 s between each file and three in-and-out movements (pecks). Two irrigation methods were used:

Conventional needle irrigation
The canal was irrigated with bidistilled water using a 27-gauge open-ended needle. The needle was inserted into the canal within 2 mm of the WL and was moved in an up-and-down motion.

PIPS-activated irrigation
An Er:YAG laser with a wavelength of 2940 nm (Fidelis AT; Fotona, Ljubljana, Slovenia) was used with an A 14-mm long, 300-μm quartz laser tip. Setting parameters were 0.3 W, 15 Hz, and 20 mJ per pulse, and pulse duration was 50 μs. Water and air were turned off. The root canals were slightly dampened with 0.3 mL of bidistilled water, and the tip was placed into the pulp chamber only and was activated for 20 s. During the PIPS irradiation cycles, root canals were continuously irrigated with 2.5 mL distilled water to maintain hydration levels applied with a 27-gauge open-ended needle positioned above the laser tip in the coronal aspect of the access opening.

Group 1 (OS + PIPS)
Canal preparation was achieved with a One Shape file size 25 at the tip with a taper of .06 using a rotational motion and a speed of 400 rpm. The torque was adjusted to 4 Ncm according to the manufacturer's instructions. The file was used with a brushing outstroke motion until resistance was felt in the canal. The instrument was then withdrawn and cleaned. The PIPS activation irrigation was applied according to the above-described protocol, and a size 10 K-file was used to confirm patency. These procedures were repeated twice until the file reached the WL.

Group 2 (OS + CNI)
Canal preparation was performed in the same way as for the OS + PIPS group. The teeth were irrigated with 27-gauge open-ended needle between each pecking sequence according to the protocol described above.

Group 3 (PTN + PIPS)
Canal preparation was achieved using ProTaper Next files in the sequence X1 (size 17, .04 taper) and X2 (size 25, .06 taper) using a rotational motion and a speed of 300 rpm and 2 Ncm torque, according to the manufacturer's instructions. When resistance was felt during preparation, the instrument was removed and cleaned. Instrumentation with X1 was completed in two pecks, whilst X2 instrumentation was completed in one. The PIPS was applied during each file change according to the protocol described above.

Group 4 (PTN + CNI)
Instrumentation was performed in the same way as for the PTN + PIPS group. The teeth were irrigated

with a 27-gauge open-ended needle during each file change according to the protocol described above.

During instrumentation and irrigation, a rubber dam was used to prevent leakage of the solution through the hole. An aspirator was used to aspirate overflow solution from the coronal reservoir. To avoid interoperator variability, a single operator performed all preparation procedures. Each instrument was only used once. All instrumentation was performed with an endodontic motor (X-Smart Plus; Dentsply Sirona).

Post-weighing of the Eppendorf tubes

After instrumentation of the root canals, the Eppendorf tubes were removed from the test models. The tubes were incubated at 68 °C for 5 days to evaporize the extruded distilled water and were then weighed using the same criteria as in the initial weight calculation. After evaporization, the tubes were weighed three times with the same analytical scale, and the mean weight was recorded as the final weight. The weight of the extruded dry debris was computed by calculating the difference between the initial and the final weight of the tubes.

Statistical analysis

IBM SPSS 20 Software (IBM SPSS Inc., Armonk, NY, USA) was used for all statistical analyses. A significance level of 0.05 was used for all statistical tests. The results were analysed using one-way analysis of variance (ANOVA) and Tukey's *post hoc* tests for multiple comparisons. Comparison of groups was conducted using the Bonferroni correction method.

Results

Mean, standard deviations (SD) of the amount of apically extruded debris of each groups in $\log_{10}$ transformed data are shown in Table 1. The mean, minimum and maximum values and the SD data of each group are shown in Table 2. Statistical analyses were achieved using the data in Table 1. The results indicate that both file and irrigation systems caused measurable apical extrusion of debris. The mean weight of the apically extruded debris was in the sequence; OS with PIPS > PTN with PIPS > OS with CNI > PTN with CNI. A significant difference was found amongst the groups ($P < 0.05$). There was a significant difference between the PIPS and CNI groups, whilst there were no significant differences between the file groups when the same irrigation system was used ($P > 0.05$).

Table 1 Mean, standard deviations (SD) of the amount of apically extruded debris of each groups in milligrams and $\log_{10}$ transformed

Group	*N*	Mean	SD
OS with PIPS	15	-2.874^{a}	±0.281
OS with CNI	15	-3.608^{b}	±0.608
PTN with PIPS	15	-3.118^{a}	±0.196
PTN with CNI	15	-3.686^{b}	±0.196

Different superscript letters represent significant differences $P = 0.000 < 0.005$, F: 13.621.

Discussion

Various irrigation methods and file systems have been evaluated for apical extrusion of debris in many studies as a result of its potential for postoperative flare-ups and delayed periapical healing (Kustarci *et al.* 2008b, Kustarci & Er 2015, Borges *et al.* 2016, Kocak *et al.* 2016, Silva *et al.* 2016, Topcuoglu *et al.* 2016). Recent studies have reported effective debris and smear removal with minimal or no thermal damage to the organic dentinal structure through a photoacoustic technique called photon-induced photoacoustic streaming or PIPS (DiVito *et al.* 2012, Deleu *et al.* 2015, Arslan *et al.* 2016).

The method of Myers & Montgomery (1991) was used to collect debris extruded apically. Although periapical tissues and the pressure at the apex, which act as a barrier against apical extrusion, cannot be mimicked in laboratory conditions, standardization of methodology could provide information to compare the instruments tested in terms of apical extrusion (Tanalp & Gungor 2014).

Because sodium crystals cannot be separated from debris, distilled water was used as an irrigant instead of NaOCl to avoid misleading measurements (Tanalp & Gungor 2014). Although single and straight roots have most often been used in various studies, it has been recorded that, when the treated canal is curved, the frequency of post-endodontic pain is significantly higher (Arias *et al.* 2013). Therefore, in the present study, curved mesiobuccal canals of maxillary molar teeth were selected to compare the file and irrigation systems for apically extruded debris.

Previous studies reported that the width of the apical construction may affect the amount of apically extruded debris. Thus, to standardize the samples in all the groups, teeth with an apical width of size 15

Table 2 Mean, standard deviations (SD), minimum and maximum of the amount of apically extruded debris of each groups (in milligrams)

Group	*N*	Mean	SD	Minimum	Maximum
OS with PIPS	15	1.6280[a]	±1.09769	0.47	4.00
OS with CNI	15	0.4993[b]	±0.53781	0.01	1.53
PTN with PIPS	15	0.8313[a]	±0.33541	0.33	1.48
PTN with CNI	15	0.2753[b]	±0.17772	0.01	0.60

Different superscript letters represent significant differences.

were used. Because the apical size of the final instrument and movement kinematics may affect the width of the apical construction and the amount of apical debris extrusion, both file systems used in this study had a tip diameter equivalent to a size 25 and a .06 taper, and both worked in continuous rotation to achieve a standardized method (Lambrianidis *et al.* 2001, Tinaz *et al.* 2005).

In the current study, chemomechanical preparation of the root canals using OS and PTN file systems with PIPS and CNI irrigation systems were evaluated and compared in terms of the weight of extruded debris. The results revealed that all instruments and irrigation systems resulted in apical extrusion of debris (Table 1 and 2). This is consistent with previous studies (al-Omari & Dummer 1995, Bidar *et al.* 2004, Kustarci *et al.* 2008a, Burklein *et al.* 2014). The amount of apically extruded debris during instrumentation with the multiple-file PTN continuous rotary system was less than with the single-file OS. However, these differences were not significant when the files were used with same irrigation system.

As stated above, several factors affect the amount of apically extruded debris. Movement kinematics, early flaring, instrument design and type of irrigation system can also affect the results. The OS is manufactured with a modified triangular cross-section, three sharp cutting edges in the apical and middle part and an S-shaped design with two cutting edges near the shaft. It was reported that OS size 25, .06 taper had the ability to move along the canal curvature and was safe to use in severely curved root canals (Burklein *et al.* 2013). The PTN differs from the ProTaper Universal due to the increased flexibility of M-Wire and decreased contact points between the file and the canal wall (Elnaghy 2014).

It has been reported that the number of files used during instrumentation procedures may be a critical factor in extruding debris (Ruddle *et al.* 2013, Elnaghy 2014). In this study, the amount of debris cannot be associated with the number of files. PTN ensures greater cross-sectional space for enhanced cutting and movement of debris towards the crown. It can be speculated that this may account for the reduced amount of extruded debris observed in the multiple-file systems (PTN) compared to the single-file system. Burklein *et al.* (2014) reported that the OS had similar results for extruded debris with multiple-file systems. Also, the design of rotary NiTi files is likely to move debris in a coronal direction.

It has been reported that great amounts of debris remain on the root canal wall after the use of CNI, because the irrigants go no more than 0–1.1 mm beyond the needle tip and thus the penetration depth of the irrigant and its antimicrobial capacity are limited (Mancini *et al.* 2009, Guidotti *et al.* 2014). To eliminate these adverse factors, a laser-activated irrigation treatment with an erbium laser (Er:YAG wavelength 2940 nm) has been presented as an activation method of irrigation solution (Blanken & Verdaasdonk 2009, Matsumoto *et al.* 2011). Because the Er:YAG laser has the highest water absorption and a high affinity for hydroxyapatite, it provides effective removal of debris and of the smear layer from the root canal (Kivanc *et al.* 2008). The effect is based on explosive vapour bubbles with a secondary cavitation effect from the pulsed energy transferred to solutions (Blanken *et al.* 2009, De Moor *et al.* 2009). In recent studies, PIPS was reported to enable effective debris and smear layer removal with a newly designed, tapered, stripped tip (DiVito *et al.* 2012). As described above, this technique is effected by a different mechanism in which the tip is placed only in the pulp chamber without moving into the root apex. This technique uses low-energy levels and short microsecond pulse rates (20 mJ at 15 Hz, 0.3 W average power) to generate peak power spikes. The profound photoacoustic shock wave causes movement of the irrigation solutions three-dimensionally without needing to enlarge the canal (DiVito & Lloyd 2012).

Previous studies have shown that the use of erbium lasers with traditional tips and fibre in the root canal may result in side effects: thermal damage, cracks or carbonization (Kimura *et al.* 2002, Matsuoka *et al.* 2005). The PIPS technique uses a low-energy laser, generates a minimal thermal effect and reduces all the above-mentioned risks and disadvantages due to the positioning of the tip in the coronal orifice only (DiVito *et al.* 2012).

The position of the fibre tip during laser-activated irrigation has a major impact on the pressure generated in the root canal. In their study, Peeters & De Moor (2015) demonstrated that changing the position of the fibre tip from the level of the orifice to 5 mm deep in the orifice resulted in a 10-fold increase in the pressure registered in the most apical part of the shaped root canal. It can be expected that, due to the position of the PIPS tips in the pulp chamber, no excessive pressure will be generated. This finding has been confirmed by the studies of Arslan *et al.* (2015) and Yost *et al.* (2015) who examined solution extrusion with PIPS activation.

This study used PIPS activation between each shaping file step to improve the streaming of fluids into the canal system according to PIPS clinical protocol (Olivi & DiVito 2012). During laser irrigation, the root canal was irrigated continuously to maintain hydration. By selecting molars with intact coronal wall, an access cavity and pulp chamber act as a reservoir for the irrigant. The shock waves generated during the activation of PIPS allow for 3D movement of the irrigation solutions, and this may also result in the remaining debris, which is left after each file or each peck of a file, being transported apically. Thus, the greater amount of debris extrusion with PIPS activation may be explained by these shock waves.

Kustarci & Er (2015) speculated that laser-activated irrigation has a significant effect on the amount of debris extrusion when used with an Er:Cr:YSGG laser with a radial firing tip for irrigation activation. Yost *et al.* (2015) and Arslan *et al.* (2015) compared PIPS irrigation and needle irrigation techniques in NaOCl apical extrusion and speculated that PIPS activation resulted in the largest quantity of NaOCl. However, the difference between these groups was not significant. According to present results, PIPS significantly increased the weight of debris extrusion with both file systems. To explain the contradiction between these studies, it should be appreciated that the latter studies used PIPS activation for final irrigation, whereas in the present study it was used during chemomechanical preparation between each pecking sequence or between each file change. It can be speculated that because the greatest amount of debris is created during canal preparation, more debris extrusion may increase.

Conclusion

All file and irrigation systems caused apical debris extrusion. PIPS activation during the chemomechanical preparation process was associated with greater extrusion of debris in curved canals compared with no activation and caused significantly more debris extrusion than CNI. As the greatest amount of debris is present in the canal system during preparation, PIPS activation may be recommended by the final irrigation when chemomechanical preparation has been completed.

Conflict of interest

The authors have stated explicitly that there are no conflict of interests in connection with this article.

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