ORIGINAL ARTICLE

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Comparison of different laser-activated irrigation modalities in terms of calcium hydroxide removal and apical extrusion in curved root canals

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Purpose: The aim of this study was to compare the photon-induced photoacoustic streaming (PIPS) and the shock wave-enhanced emission photoacoustic streaming (SWEEPS) in terms of calcium hydroxide (CH) removal and apical extrusion in curved root canals.

Methods: The mesiobuccal roots of 20 maxillary molars were split longitudinally. CH was placed into the artificial grooves prepared in the apical third, and the root halves were reassembled. The samples were randomly divided into two groups for irrigation protocol (n = 10): PIPS (Group 1) and SWEEPS (Group 2). After irrigation activation protocols using EDTA (2 mL, 17%) for 3 × 20 s, the tooth halves were separated, and the remaining CH was measured as pixels under a stereomicroscope at 10× magnification. Apical extrusion was calculated using a cube-shaped flower arrangement foam by subtracting the initial weights from the final weights (mg). The data were analyzed using the Mann–Whitney U test. The level of significance was taken as $p< 0.05$.

Results: There was no significant difference between SWEEPS and PIPS in terms of residual CH values ($p> 0.05$). CH was completely removed in 4 samples in the PIPS group and only 1 sample in the SWEEPS group. Both groups exhibited similar apical extrusion.

Conclusion: The SWEEPS modality performed similar efficacy as the PIPS modality in terms of CH removal and apical extrusion during irrigation activation procedures.

Keywords: Apical extrusion, calcium hydroxide, laser, PIPS, SWEEPS.

Introduction

The purpose of endodontic treatment is to provide a hermetic seal of root canals after the removal of necrotic and/or infected pulp and microorganisms (1). Preparation and irrigation protocols may not be sufficient for complete disinfection, especially in necrotic teeth, because of the irregular canal anatomy (2). Therefore, it is recommended to use intracanal medicaments to ensure adequate disinfection (3). Calcium hydroxide (CH) is an intracanal medicament that provides a significant reduction of bacteria in the root canals (4). However, because CH residues on the dentine walls prevent tubule penetration of the sealer, it is crucial to remove it completely before obturation (5). The use of irrigation activation systems has recently become popular for CH removal because it is not possible to remove all the resi-

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dues with only syringe irrigation, especially from apical ramifications.

Photon-induced photoacoustic streaming (PIPS) and shock wave-enhanced emission photoacoustic streaming (SWEEPS) are two current irrigation activation systems that are applied with Er:YAG laser (6,7). PIPS uses low energy levels and provides deeper irrigant penetration into the ramifications by generating intense shock waves and rapid fluid movement (8). However, it is claimed that the desired rapid movement cannot be achieved in narrow canals because of the friction on the canal walls and lack of space for movement (9). Recently, SWEEPS was developed to improve the PIPS method. In this technique, a laser pulse pair is emitted into the solution, and subsequent bubbles cause pressure on the first bubbles. Therefore, accelerated collapse and strong shock waves occur (7). Although solution agitation protocols are preferred for better cleaning efficiency, apical extrusion should also be considered because they accelerate the fluid movement and provide deeper irrigant penetration, and the extrusion of the irrigant into the periapical tissue may cause inflammation, necrosis, and severe pain and consequently have negative effects on the healing process (10).

The aim of this study was to compare the two recent Er:YAG laser modalities in terms of CH removal and apical extrusion in the narrow and curved root canals. The null hypothesis was that there is no difference between SWEEPS and PIPS modalities in terms of CH removal and apical extrusion.

Materials and Methods

Local ethics committee approval was obtained from the Ethical Review Committee under the Research Foundation at the Medical Faculty of Recep Tayyip Erdoğan University (No.: 2022/40).

Fifty freshly extracted human maxillary first molars with a curved mesiobuccal single root canal and completely formed apices were collected. Soft tissues and calculus were removed using an ultrasonic scaler. The calcification was verified radiographically, and the degree of curvature was established using IMAGE J software (Image J 1.47V, National Institute of Health, USA) with the Schneider technique (11). Intact and mature roots with curvature angles between 25° and 30° and apical diameter size up to 15-K files were included. The exclusion criteria were having more than one root canal and apical foramen, root canal treatment, internal/external resorption, immature root apices, and caries/cracks/fractures on the root surface. Both buccolingual and mesiodistal preoperative digital radiographs were obtained to confirm the canal anatomy. According to the inclusion criteria, 42 teeth were obtained. An access cavity with 3 mm diameter was created with a diamond bur with a diameter of 2.3 mm (Komet, Dusseldorf, Germany, 340.202.001.001.023, American size 8). Mesiobuccal root was removed, and all the root lengths were standardized at 15 mm. The root was covered all around with a sticky wax for 4 mm deep of reservoir form. Working length (WL) was set to 14 mm, and root canals were instrumented with ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) up to size F3. Apical patency was maintained using a 10-K file at 1 mm longer from the WL. During preparation, the root canals were irrigated with 1 mL of 2.5% NaOCl (Endosolve HP, Imicryl, Karatay, Konya) solution. After preparation, the specimens were inserted in a silicone material (Optosil: Heraeus Kulzer, Hanau, Germany) to create a unique mold for each root. After removal from the silicone material, vertical grooves were created along the mesial and distal surface with a fine diamond disc (Multicut diamond disc/354, Edenta Ag Dental Products, Haupstrasse, Switzerland) under the operating microscope. Then, the blade of a wax carver (Medesy, Maniago, Italy) was wedged into the groove and twisted gently at several spots to achieve the splitting of the curved roots. At the end of the splitting, the samples with inappropriate or deformed pieces were excluded (n = 22) from the study. Finally, the total sample size was determined as 20 (n = 10 for each group).

A longitudinal artificial standardized groove of 3 mm length, 0.2 mm width, and 0.5 mm depth was created at a distance of 2–6 mm from the apex on one half of the root canal using an ultrasonic device (Satelec Acteon, Merignac, France) with a size 20 file (Mani, Utsunomiya, Japan) under an operating microscope, to imitate root canal irregularities. The debris was cleaned with a toothbrush, and 5 mL of 17% EDTA (Saver, Prime Dental, Kalher, India) and 5 mL of 2.5% NaOCl were applied for 1 min. Finally, the root canals were flushed with 5 mL of distilled water and dried with paper points. The CH (Kalsin & Barium Sulfat: Spot Dis Deposu A.Ş. İzmir, Turkey) paste was prepared with powder and water in a 1:1 ratio and placed and slightly condensed into the artificial grooves using a paper cone 30–40. Extruded material was removed from the surface of the samples using a scalpel. A periapical radiograph was taken to confirm the complete filling of the grooves (12). The root halves were reassembled using wax and positioned in their silicone molds, and the temporary restoration material was placed. The apical parts of the silicone molds were removed using a scalpel. The specimens were stored at 37°C with 100% humidity for 1 week. Prior to irrigation protocols, each root was embedded in a cube-shaped flower arrangement

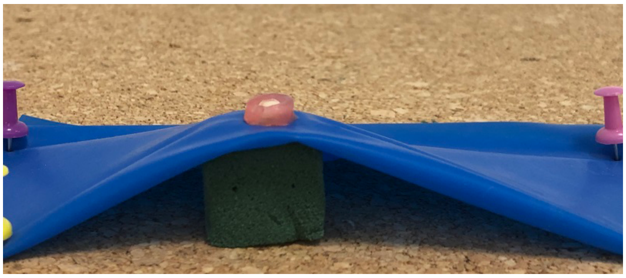

Fig. 1. Experimental setup for irrigation protocol.

foam up to the coronal reservoir. The root was isolated with a rubber dam to isolate the foam from the coronal extrusive irrigant. The rubber dam was fixed to the root surface using cyanoacrylate adhesive to prevent coronal leakage (13) (Fig. 1). The teeth were divided randomly into two experimental (n = 10) groups by a blinded examiner.

Group 1: PIPS

The laser irradiation protocol was performed using a 2940 nm wavelength Er:YAG laser device (LightWalker, Fotona, Ljubljana, Slovenia) via H14-N handpiece with a 14-mm long 300-µm diameter tapered and striped fiber tip (PIPS 300\14, Fotona) at 0.3 W, 15 Hz, and 20 mJ without air or water. A 27-gauge open-ended needle was positioned 2 mm short of the WL, and 2 mm of the fiber tip was positioned in the center of the reservoir. The root canals were irrigated continuously with EDTA (2 mL, 17%) for 3 x 20 s with a resting time of 30 s between each cycle. During laser activation, the tip was submerged in an irrigant that was continuously applied with the needle.

Group 2: SWEEPS

In this group, the laser-activated irrigation was performed with the same Er:YAG laser device and handpiece via an 8.5-mm long conical fiber tip, which has a diameter of termination of 600 µm (SWEEPS 600, Fotona) at the same power as the previous group but with SWEEPS modality. Irrigation and activation protocols were the same as in the previous group, except for the activation modality.

For both experimental groups, the total activation time was 1 min, and the total volume of EDTA was 6 mL. Finally, the roots were flushed with 1 mL distilled water and dried with paper points. After the irrigation procedures, the roots were removed from the silicone molds and the root halves were separated. The residual CH was detected using a stereomicroscope (Zeiss, Axiocam 105 color, Jena, Germany) at 10x magnification. The entire artificial groove area and the percentage of residual CH was measured as pixel2 (Zen 2 lite microscope and imaging software program). The amount of remaining CH was calculated by the ratio of residual CH area to the total artificial groove area (Fig. 2). The initial and post-irrigation weights of each foam cube were weighed using a precision balance (AB204; Mettler-Toledo, Greifensee, Switzerland), and the total apically extruded material was calculated by subtracting the initial weight from the post-irrigation weight (mg).

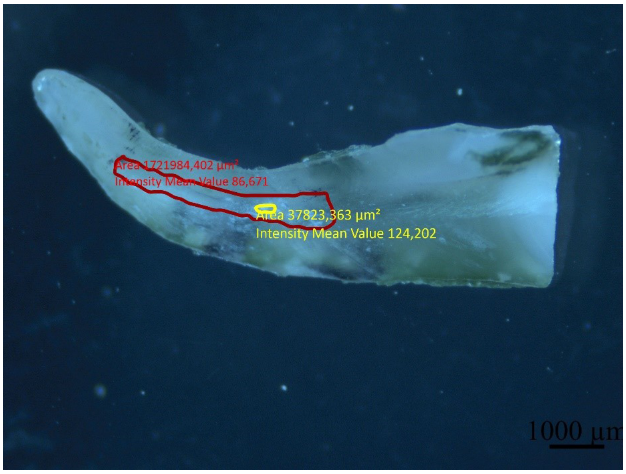

Fig. 2. Measurement of residual CH on stereomicroscope image.

Statistical Analysis

IBM SPSS V23 Software (IBM SPSS, Inc., Armonk, NY, USA) was used for all statistical analyses. Normal distribution was examined using the Shapiro–Wilk test. Since the data set did not conform to the normal distribution, the Mann–Whitney U test was used in comparisons between groups. The level of significance was taken as $p< 0.05$.

Results

According to the CH removal data, the mean values of residual CH (%) were 11.52 ± 15.63 and 12.90 ± 12.35 for PIPS and SWEEPS, respectively (Table 1). The difference was not statistically significant ($p> 0.05$). However, the stereomicroscope analysis showed that while CH was completely removed in 4 of 10 samples in the PIPS group, only 1 of 10 samples in the SWEEPS group was completely cleaned. Maximum residual CH values were 34.2% and 36.85% for PIPS and SWEEPS groups, respectively.

In terms of apical extrusion, minimum and maximum values were 897.89 and 2171.01 mg for PIPS group, whereas they were 1180.91 and 2899.26 mg for SWEEPS group. As shown in Table 2, no significant difference was detected between the experimental groups at the same power setting, and therefore no correlation was found between the laser modalities and extrusion rate ($p> 0.05$).

Table 1. Comparison of residual CH according to the groups (%)

Group	n	Mean	SD	Min.	Max.	p
PIPS	10	11.52[a]	15.63	0.00	34.20	0.315
SWEEPS	10	12.90[a]	12.35	0.00	36.85	

There is no significant difference between groups with the same lowercase letters (p< 0.05).

Table 2. Comparison of apical extrusion according to groups (mg)

Group	n	Mean	SD	Min.	Max.	p
PIPS	10	1546.85[a]	376.31	897.89	2171.01	0.496
SWEEPS	10	1900.66[a]	702.70	1180.91	2899.26	

There is no significant difference between groups with the same lowercase letters (p< 0.05).

Discussion

In endodontic treatment, the removal of bacteria and by-products from the root canals is crucial for the success of endodontic treatment (14). Besides the mechanical root canal preparation using antibacterial irrigant, intracanal medicament plays an important role in inactivating the microorganisms and their products (15). CH is the most commonly used intracanal medicament due to its high antibacterial efficacy (16). However, when CH residues are not removed from the walls, it prevents the hermetic penetration of sealers into the dentine tubules, and this may reduce the success of treatment (5). It has been shown that it is difficult to completely remove CH using only irrigating solutions, especially in curved and narrow root canals (17). Therefore, various irrigation activation methods have been introduced.

The mechanism of laser treatment is based on the absorption of light by the water in the hydroxyapatite of dental hard tissue. The water heats up and evaporates, resulting in high vapor pressure, causing a microexplosion in the root walls. At this time, some ultrastructural degenerations such as fusions, melting zones or cracks, and chemical changes of dentine may occur depending on the laser parameters such as output power, frequency, and application mode (18). The PIPS approach was introduced to prevent thermal damage to the root surface and periodontium (19). It has a radial and stripped tip, which is placed into the access cavity. It generates shock waves in liquids at lower energy levels, and a photomechanical streaming effect occurs without a thermal effect (20). It has been shown that it provides a high cleaning effect with high-speed fluid movement along the root canal system (21–23). On the other hand, it was reported that the friction in the narrow root canals negatively affects the cavitation, and the speed of irrigant movement is restricted because of the limited space (9). To overcome this restriction, SWEEPS was proposed to enhance the shock wave generation capacity of laser agitation, causing accelerated fluid movement. While PIPS uses a single laser pulse, SWEEPS uses pulse pair for irrigant activation. In the SWEEPS technique, the second pulse creates a subsequent bubble that causes pressure on the first bubble and accelerates its collapse and also the collapse of secondary bubbles. It is claimed that this mechanism leads to a large number of shock waves that reach the irregularities of the root canal and consequently increase the cleaning efficiency of laser agitation (7). Contrary to expectations, in the present study, SWEEPS exhibited no superior efficacy over PIPS. The number of samples in which CH was completely removed was 1 in the SWEEPS group, while it was 4 in the PIPS group. In addition, more residual CH was detected in the SWEEPS group than in the PIPS group, but the difference was not statistically significant. Thus, the initial hypothesis was accepted.

To date, there is limited study on the effectiveness of SWEEPS modality in the literature. Galler et al. (24) examined penetration depths of irrigation solutions with different activation methods, and significantly lower penetration depths were found in the SWEEPS group compared with PIPS. The authors stated that in SWEEPS mode, the pulse pair and subsequent bubbles might have caused a counter-current impeding irrigant flow within the constricted root canal. In another study, Ivanusic et al. (25) evaluated the cleaning efficacy and pressure measurements of PIPS and SWEEPS modalities using different tips and geometries in a laboratory setup. They reported that pressure was generated, and the penetration of irrigation solution was much larger when using a smaller diameter fiber tip (such as used in the PIPS group) compared with a larger diameter fiber tip (such as used in the SWEEPS group). Therefore, in the present study, the inability of SWEEPS to exhibit superior performance to PIPS may be attributed to the irrigation not penetrating deeply enough and to the larger tip diameter. During practical application, there were some difficulties such as placing this thick fiber tip appropriately into the narrow reservoir, which made us think that the SWEEPS tip was not adequate for narrow-access cavities and should only be used for teeth with larger access cavities. In addition, during the procedure, a large amount of lateral transmission to the outside was observed. In a study, it was reported that due to the total reflection on the fiber walls, the laser beam was expanded to a certain extent when leaving the end of the fiber, and this might cause more scattering out of the root canals (26). Considering the root canal size and scattered laser radiation for the SWEEPS method, it may be beneficial to conduct further studies using a modified resistant fiber tip with a smaller diameter.

In the present study, to evaluate the efficiency of two novel laser modalities, curved mesiobuccal roots of maxillary molars, with Vertucci type 1 configuration, were chosen. While sufficient cleaning can be achieved with conventional needle irrigation in straight and wide canals, narrow and curved root canals are more challenging in removing debris or medicament during root canal treatment (27). Therefore, the use of irrigation activation techniques comes to the fore, especially in curved root canals.

Artificial standardized grooves were prepared in the apical area of roots to simulate the inaccessible root canal irregularities, as well as to standardize the amount of intracanal medicament and provide reproducible data (28). However, a drawback of this experimental model is that it does not completely simulate the complexity of a natural root canal anatomy (29). In addition, the split-tooth model may cause failure in the assembly of all the halves of the samples, causing leakage along the crack line (30). Thus, ineffective irrigation dynamics could occur compared with an intact root canal. To improve the quality of contact between the two parts of the reassembled tooth, the split roots were carefully reassembled using a diamond disc under an operating microscope and then secured tightly with wires from two levels and sealed entirely with sticky wax. Samples that could not be properly separated were excluded. Even under these conditions, it should be emphasized that the interface between the two halves might have influenced the recorded results.

In the current study, apical extrusion was evaluated in addition to cleaning efficacy. It is known that the apical extrusion of debris and irrigant can cause periapical inflammation and reduce the healing of periapical lesions (31). Thus, to prevent apical extrusion, pressure levels of irrigation solutions should be kept lower than periapical tissue resistance (32). In the present study, irrigation with PIPS modality showed similar extrusion to SWEEPS modality. Contrary to our results, in a study under simulated conditions, it was reported that SWEEPS showed lower apical extrusion compared with conventional needle irrigation and PIPS and indicated superior safety regardless of the pulse energy (33). The contradictory results between the limited studies may be due to the methodologic variations such as the in vitro conditions, sample type and size, used laser tip, size of the apical preparation, and imaging and evaluation criteria. The measurements on artificial root canal models cannot reflect the resistance of a dentinal root canal wall and never completely imitate the canals in real teeth (34).

In addition, for an accurate extrusion measurement, it is necessary to use irrigants as in clinical practice, and the periapical tissue resistant must be taken into consideration (35). In this study, specimens with an apical diameter of more than a #15-K file were taken out and flower arrangement foam was used to simulate the periapical tissue. It was reported that the resistance provided by the flower arrangement foam was more realistic than the empty tubes (full of air) with a lack of simulation of periapical tissue resistance (36). However, it is a weak material, and it can absorb some irrigant while acting as a barrier. This may result in false readings during the experimental process. However, it should be mentioned the density of the foam does not completely represent human periodontal tissues, and in the presence of an intact periodontium, the apical extrusion may not be as easy as ex vivo conditions (37). Therefore, the method used in the current study can only facilitate a relative comparison of techniques under standardized conditions, and further clinical studies are needed.

Conclusions

Within the limitations of this study, it can be concluded that SWEEPS with thick conical fiber tip showed no increased efficacy compared with PIPS in terms of CH removal and apical extrusion.

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Ethical Approval: The study protocol was approved by the Recep Tayyip Erdoğan University Faculty of Dentistry Clinical Research Local Ethics Committee (Date: February 17, 2022; Protocol no.: 2022-40).

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