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The Penetration of Sealer into Coronal Third After Irradiated by Er, Cr: YSGG Laser: A confocal Microscope Study

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Abstract:

Objectives: This study aims to detect the penetration of the AH Plus sealer in the coronal third using a pulsed (Er, Cr: YSGG) laser with a short pulse duration when the SWEEPS was used to activate irrigation (Shock wave Enhanced Emission Photoacoustic Streaming). **Methods:** A total of 28 single-rooted mandibular premolars. The laser used is pulsed Er, Cr: YSGG assisted by the SWEEPS technique. There are four groups of samples (n = 7) for each: Group 1: Traditional syringe irrigation using 5 mL of 17% EDTA**.** Group 2: passive ultrasonic irrigation using mL of 17% EDTA. Group 3: Er, Cr: YSGG laser-induced SWEEPS using 5 mL of 17% EDTA. Group 4: Er, Cr: YSGG laser-induced SWEEPS using 5 mL of 5.25% NaOCl and 5mL of 17% EDTA**.** The laser parameters were selected according to the pilot study (Air and water 1%, 0.75 W, 5 Hz, and a short pulse duration of 60µs). The irradiated teeth were obturated by AH plus sealer mixed with Rhodamine B, and the weight percentage was 0.001. Horizontal sectioning was performed at 9mm lengths away from the apex. Four different sites (lingual, distal, mesial, and buccal) were used to determine the depth of sealer penetration. A confocal laser scanning microscope was used to detect the deepest penetration of the sealer. Statistical analysis was conducted using Dunnett t-tests with a significant level set at $p \leq 0.05$**.** **Results:** The obtained results revealed that AH plus sealer reached the wall of canals in four positions (lingual, distal, mesial, and buccal) at G4 in comparison to G3 and G2 for the selected laser parameters (Air and water 1%, 0.75 W, 5 Hz, and a short pulse duration of 60µs). The data are summarized as follows (mean ± standard deviation in µm) in G1 is 206.20±16, G2 is 593.02±131.67, G3 is 818.58±97.99, G4 is 986.94±27.9 for the lingual side. **Conclusion:** it is concluded that the pulse duration(60µs) of Er, Cr: YSGG laser was authorized successfully upon irrigation activation to achieve the deepest point in the root canal for four positions (lingual, distal, mesial, and buccal), so the lingual side was the best values of the sealer penetration. The best parameters are used in G4. These results suggest that the use of Er, Cr: YSGG laser with SWEEPS technique enhance the penetration of endodontic sealers into dentinal tubules thereby improving the seal quality.

Keywords: Er, Cr: YSGG, SWEEPS, irrigations, confocal laser microscope, endodontic.

1. Introduction

Irrigation plays a fundamental role in endodontic treatments, serving various critical functions, it helps remove organic debris, flushes debris away from the root canal system, and disinfects the canal system to promote tissue healing. Sodium Hypochlorite (NaOCl) is an effective antibacterial irrigation. Ethylenediaminetetraacetic Acid (EDTA), a chelator that effectively removes inorganic debris, the combination of both is particularly effective in the complete removal of the smear layer, especially in the middle and coronal thirds of the root canal. Addressing anatomical complexity despite their effectiveness, the apical third of the root canal often remains incompletely cleaned due to its intricate anatomy, making it more challenging to achieve thorough disinfection[1]. The effectiveness of irrigation solutions varies based on several factors anatomical variations, such as curved canals or multiple branches, can hinder the effectiveness of irrigation, the ability of the irrigation to penetrate dentinal tubules is crucial for effective cleaning and disinfection, and the method of activation influences how effectively the irrigation removes debris and disinfects the canal [2]. During endodontic instrumentation, a smear layer forms on the dentinal walls, the presence of this layer can weaken the bond between filling materials and the dentin, it leads to inadequate sealing of the root canal, increasing the risk of microleakage, effective removal of this layer is essential to achieve an airtight (air-tight) seal during obturation. Additionally, disinfection is vital for the healing of the periradicular tissues, preventing post-treatment complications [3].

Historically, traditional needle irrigation (NI) has been the standard method for delivering irrigation. The introduction of ultrasonic irrigation, developed by Martin et al., represents a significant advancement in the field. This technique enhances irrigation activation and facilitates better penetration of irrigation into complex root canal systems. Various factors, including duration of activation, type, and size of the ultrasonic tip, and power of the ultrasonic device, influence the effectiveness of ultrasonic activation.

Applications in endodontics, the pulsed Er, Cr: YSGG laser, when used in conjunction with PIPS, effectively eliminates mature Enterococcus faecalis biofilms in complex root canal systems, this is particularly important for ensuring thorough disinfection in challenging anatomical areas [4]. Research has also explored the efficiency of the pulsed Er, Cr: YSGG laser for debonding lithium disilicate laminates, varying pulse durations and exposure times were tested, indicating the versatility of this laser in restorative procedures. Other applications of Er, Cr: YSGG laser, power, and pulse duration are both vital parameters in the surface roughness of zirconia ceramic for enhancement of the bonding strength to the resin cement[5,16,7]. Laser-assisted irrigation, especially when combined with the Shock Wave Enhanced Emission of Photoacoustic Streaming (SWEEPS) technique, has demonstrated superior effectiveness to traditional irrigation methods. Utilizing the pulsed Er, Cr: YSGG laser at a wavelength of 2780 nm, this approach leverages the unique properties of lasers to enhance root canal cleaning and disinfection, the pulsed Er, Cr: YSGG laser is highly absorbed by water, and the energy from the laser causes quick vaporization of the irrigation, this vaporization generates bubbles within the irrigation, which play a crucial role in cleaning, the alternating laser pulses create shock waves that push the irrigation deeper into dentinal tubules, efficiently removing the smear layer from even distant regions of the root canal.[8-10]. Studies, including those by Ozbay et al., have confirmed that this laser method is particularly effective in removing the smear layer, highlighting its advantages in endodontic procedures [11].

The SWEEPS technology brings several distinct advantages to endodontic treatment; the cavitation source can be positioned within the pulp chamber at a safe distance from the apex, reducing the risk of apical extrusion of irrigation. Simultaneous, the SWEEPS technique allows for continuous irrigation throughout the entire root canal system, regardless of its anatomical complexity, this includes effective delivery to lateral canals, isthmuses, and other irregularities [12]. To assess the effectiveness of irrigation and sealer penetration into dentinal tubules, various advanced imaging techniques are employed: confocal laser microscopy, stereomicroscope, and scanning electron microscopy (SEM). These methods provide detailed insights into the extent of sealer penetration, crucial for evaluating the success of endodontic procedures [13].

This study aims to determine the pulsed Er, Cr: YSGG laser parameter in activation on irrigation using the SWEEPS technique on the penetration of AH plus root canal sealer using confocal laser microscopy.

2. Materials and Methods

A total of 28 single-rooted, straight human mandibular premolars were selected randomly distributed from patients undergoing orthodontic or periodontic procedures. Each tooth was clinically and radiographically inspected to confirm the lack of root resorption, open apices, and fractures. After collection, the teeth were instantly washed with distilled water to remove any debris or blood. The cleaned teeth were then placed in a plastic container containing 0.1% thymol solution to prevent microbial contamination, and each tooth was standardized to a uniform length of 12 mm from the anatomical apex, teeth were secured in a bench vice, a double-faced diamond disc was utilized to split the roots perpendicular to the long axis. The cleaning and shaping of the root canals were done using Pro Taper Gold rotary Ni-Ti files, the following: SX, S1, S2, F1, F2, F3, and F4. The canals were irrigated with 2 mL of 5.25% sodium hypochlorite (NaOCl) between each rotary file to improve disinfection and remove debris. Any remaining NaOCl was neutralized by flushing the canals with 5 mL of distilled water. A passive fitting of the ultrasonic activator tip into the canal followed. At 2780 nm, the pulsed Er, Cr: YSGG laser irradiates the teeth in laser groups. The pilot study was done to determine the suitable power and pulse repetition rate for the SWEEPS technique. Ten samples were optimized for a pilot study into two groups (n=5) for each:

GA (n=5): Er, Cr: YSGG laser 2780 nm+17% EDTA (0.25 W, 0.5 W, 0.75 W1, W, 1.25 W).
GB (n=5): Er, Cr: YSGG laser 2780 nm+17% EDTA+5.25Naocl (0.25 W, 0.5 W, 0.75 W1, W, 1.25 W).

From the pilot study, the suitable parameter (Air and water 1%, 0.75 W, 5 Hz, and a short pulse duration of 60µs) according to those parameters, there are randomly assigned four groups of samples (n = 7) for each:

Group 1: Control group

A side-vented irrigation needle was positioned 2 mm shorter than the working length and used to irrigate the samples for one minute with 5 mL of 17% EDTA.

Group2-Ultrasonic activation

After injecting 5 mL of 17% EDTA into the root canal, the ultrasonic activator tip was passively inserted 2 mm shorter than the working length. Each root canal was irrigated three times, taking 20 seconds each time.

Group 3: Er, Cr: YSGG laser-induced SWEEPS using 5 mL of 17% EDTA

The samples were agitated using the pulsed Er, Cr: YSGG laser 2780 nm with 5 ml of 17% EDTA. The fiber tip was placed directly into the canal orifice, and each fiber tip was used in only one canal. Then, five mL of distilled water were placed in each sample and dried using a paper point.

Group 4: Er, Cr: YSGG laser-induced SWEEPS using 5 mL of 5.25% NaOCl and 5 mL of 17%

The samples were agitated using the pulsed Er, Cr: YSGG laser 2780 nm with 5 mL of 17% EDTA+5.25% NaOCl. The fiber tip was placed directly into the canal orifice. Each fiber tip was used for a single canal before being removed. Then, five mL of distilled water were placed in each sample and dried using a paper point. All specimens were obturated with AH plus sealer, which was mixed with Rhodamine B at a weight percentage of 0.001. The obturation method is a cold lateral technique; the chosen master cone was X4, and the sealer was placed inside the canal using a paper tip. After the master cone was inserted and fitted, a finger spreader was employed 1-2 mm shorter than the measured length. After that, additional gutta percha with a 0.02 tapering was inserted until the root canal was completely sealed. Radiographs were collected to evaluate obturation. The root samples were then coronally sealed using glass ionomer cement. After that, the samples were kept in an incubator set at 37 °C for a week. The roots were separated from their tubes, and the samples were mounted in polyester resin. Then, horizontal sectioning was performed for each root at 9mm lengths away from the apex. Sectioning was done using a diamond saw with a continuous water jet and a spinning speed of 500 rpm. Then, the surfaces of the samples were polished using sandpaper discs (P1000) installed on a polishing apparatus. A confocal laser scanning microscope operating at 532 nm was used to examine the sectioned root slices, and each slice's depth of sealer penetration was assessed at four different locations (lingual, distal, mesial, and buccal). Ten times the magnification was employed. And photographs with a resolution of 1,024_1,024 pixels.

3. Statistical Analysis

Image analysis was done using Adobe Photoshop 7.0. At each site, the greatest depth of sealer penetration in the dentinal tubules, beginning from the canal wall, was measured and recorded on ten distinct lines, as shown in Figure 1.

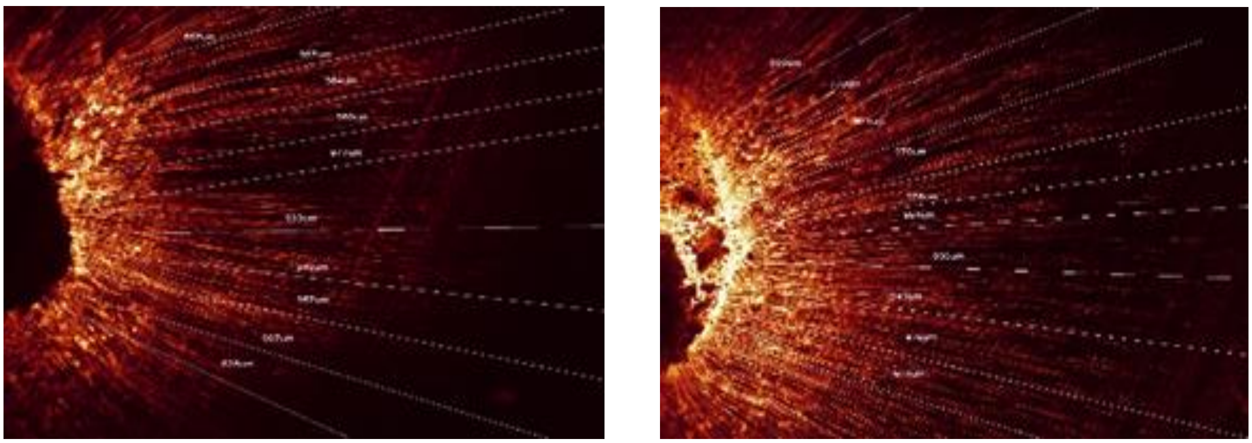

Figure 1: The calculation in ten distinct lines in each site, the sealer's maximum penetration depth into dentinal tubules, beginning from the canal wall, was recorded.

The t-test was used to analyze repeated measures of the tested and control groups—data expressed as mean±SD and other descriptive statistics. The normal distribution of all values was assessed using the Tests of Normality, including the Kolmogorov-Smirnov and Shapiro-Wilk tests. Dunnett t-tests made multiple comparisons between the tested groups and the control group. LSD test was used to calculate the significant differences between the tested mean, the letters (A, B, C, D), LSD represented the levels of significance, highly significant start from the letter (A) and decreasing with the last one. A power analysis was conducted prior to the study using G*Power software, confirming that a sample size of $n = 7$ per group provided a statistical power of 80% to detect significant differences in sealer penetration depth between groups. Values of $p>0.05$ were considered statistically non-significant, while $p \leq 0.05$ were considered significantly different. The statistical analysis was carried out by SPSS (v 20).

4. Safety and Clinical Application

This study was conducted entirely in vitro. Rhodamine B was used exclusively as a fluorescent tracer and is not approved for clinical use due to its toxicity. While the Er,Cr:YSGG laser is FDA-approved for dental applications, its clinical use in endodontic irrigation should be approached with caution. Care must be taken to avoid apical extrusion, minimize thermal damage, and ensure safe fiber positioning to reduce the risk of periapical complications.

5. Results and discussion

The results illustrate the descriptive statistics of the penetration depth of AH plus sealer for four locations (lingual, distal, mesial, and buccal) of the coronal third, with the lingual side having the highest values of penetration, as shown in Table 1. Pulse duration (60µs) was approved effectively in activation of irrigation; better results were obtained in G4 when compared with G1 (pair3) and also when compared between tested groups themselves, with high results in G4 (pair5). G4 has the highest values of penetration (P value =0.0001), as shown in Table 2. Mean± standard deviation of sealer penetration in **µm** in four direction-coronal third as shown in Table 3. As seen in Figure 2, the bar chart shows the mean (um) value of sealer penetration in four groups of a coronal third (lingual side).

Table 1. Comparison of three groups, G2, G3, and G4, with a control group for the coronal third (lingual side), and between them

Paired Samples t Test

Control group vs Tested groups Coronal third Lingual		Paired Differences					t	Df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair1	G1CL - G2CL	-386.81857	102.45196	38.72320	-481.57083	-292.06631	-9.989	6	0.0001
Pair2	G1CL - G3CL	-384.70143	49.63216	18.75919	-430.60352	-338.79934	-20.507	6	0.0001
Pair3	G1CL - G4CL	-612.38143	98.26834	37.14194	-703.26449	-521.49837	-16.488	6	0.0001
Pair4	G1CL - G5CL	-780.74571	79.11534	29.90279	-853.91520	-707.57623	-26.109	6	0.0001

Tested groups Coronal third Lingual	Paired Differences					t	Df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			

Pair1	G2CL - G3CL	2.11714	105.75723	39.97248	-95.69198	99.92627	.053	6	0.959
Pair2	G2CL - G4CL	-225.56286	139.07085	52.56384	-354.18194	-96.94377	-4.291	6	0.005
Pair3	G2CL - G5CL	-393.92714	140.63266	53.15415	-523.99066	-263.86363	-7.411	6	0.0001
Pair4	G3CL - G4CL	-227.68000	77.35783	29.23851	-299.22406	-156.13594	-7.787	6	0.0001
Pair5	G3CL - G5CL	-396.04429	72.89616	27.55216	-463.46199	-328.62658	-14.374	6	0.0001
Pair6	G4CL - G5CL	-168.36429	89.94507	33.99604	-251.54960	-85.17897	-4.952	6	0.003

Table 2. Statistical results for four groups in the On-Way ANOVA.

	Statistics/One-way ANOVA				P value
Coronal third Lingual	**G1CL**	**G2CL**	**G3CL**	**G4CL**	
N	7	7	7	7	0.003
Mean/µm	D 206.20±70.85	C 593.02±131.67	B 818.58±97.99	A 986.94± 27.91	

LSD test was used to calculate the significant differences between the tested mean, the letters (A, B, C, and D) indicate statistically significant differences ($p \leq 0.05$) according to the LSD test. Group "A" shows the highest significant value, while "D" shows the lowest. Groups sharing the same letter are not significantly different.

Table 3. Mean± standard deviation of sealer penetration in µm in four direction-coronal third.

Group	Lingual	Buccal	Mesial	Distal
G1	206.20±16	322.14±57.02	218.09±41.75	202.32±48.26
G2	593.02±131.67	414.05±21.67	513.12±11.40	448.27±139.86
G3	818.58±97.99	703.11±52.85	772.47±93.97	693.46±79.04
G4	986.94±27.91	969.33±75.94	929.21±59.76	969.25±57.22

G4 exhibited the highest penetration values in all aspects, with statistically significant differences compared to G1–G3 ($p < 0.05$).

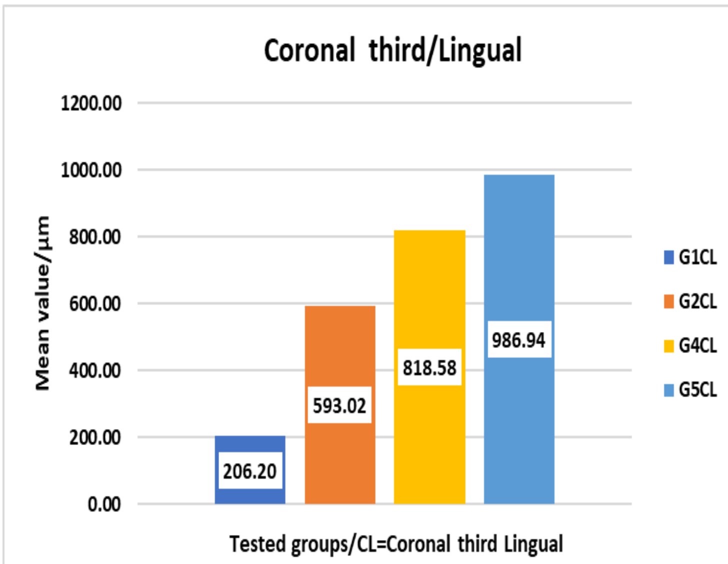

Figure 2: Bar chart showing the mean depth of sealer penetration (µm) on the lingual aspect of the coronal third in groups G1 to G4. The Y-axis shows penetration depth in micrometers (µm), and the X-axis lists the group numbers.

In this study, the best outcomes were observed in (G4), especially on the lingual side, the efficacy of this group can be attributed to the combination of NaOCl (sodium hypochlorite) and EDTA (ethylenediaminetetraacetic acid), this dual approach effectively targets both organic and inorganic materials due to the antibacterial properties. Additionally, the short pulse duration (60µs) of the laser led to a high energy density, resulting in effective shock waves that enabled the irrigation to access remote regions inside the root canal [14-16]. The increased penetration in the pulsed Er, Cr: YSGG laser group is likely due to the photomechanical effects of the pulsed Er, Cr: YSGG laser. This laser has a high absorption rate in water, which generates bubbles in the irrigation, enhancing fluid dynamics and creating a more effective push of the irrigation into the dentinal tubules, this mechanism helps improve the distribution and activation of the irrigation, leading to high sealer penetration. These findings are consistent with the work of Ayca Yilmaz et al. (2020), who reported greater sealer penetration in laser-assisted irrigation groups using confocal laser scanning microscopy [17-19]. Research indicates that the irrigation flow rate is more critical than its concentration. Factors that contribute to effective irrigation include the volume of the irrigation, proximity to the apex, the temperature of the solution, and activation methods used [20]. Different sealers have varying physicochemical properties, including viscosity, flowability, and setting time, which can influence their ability to penetrate the tubules. Sealers designed for better flow characteristics tend to achieve greater penetration depth. To facilitate a detailed assessment of sealer penetration, 0.1% Rhodamine B dye was added to the Ah Plus sealer, this approach enhances visibility when using confocal laser microscopy, allowing for precise measurement of sealer depth within dentinal tubules [21].

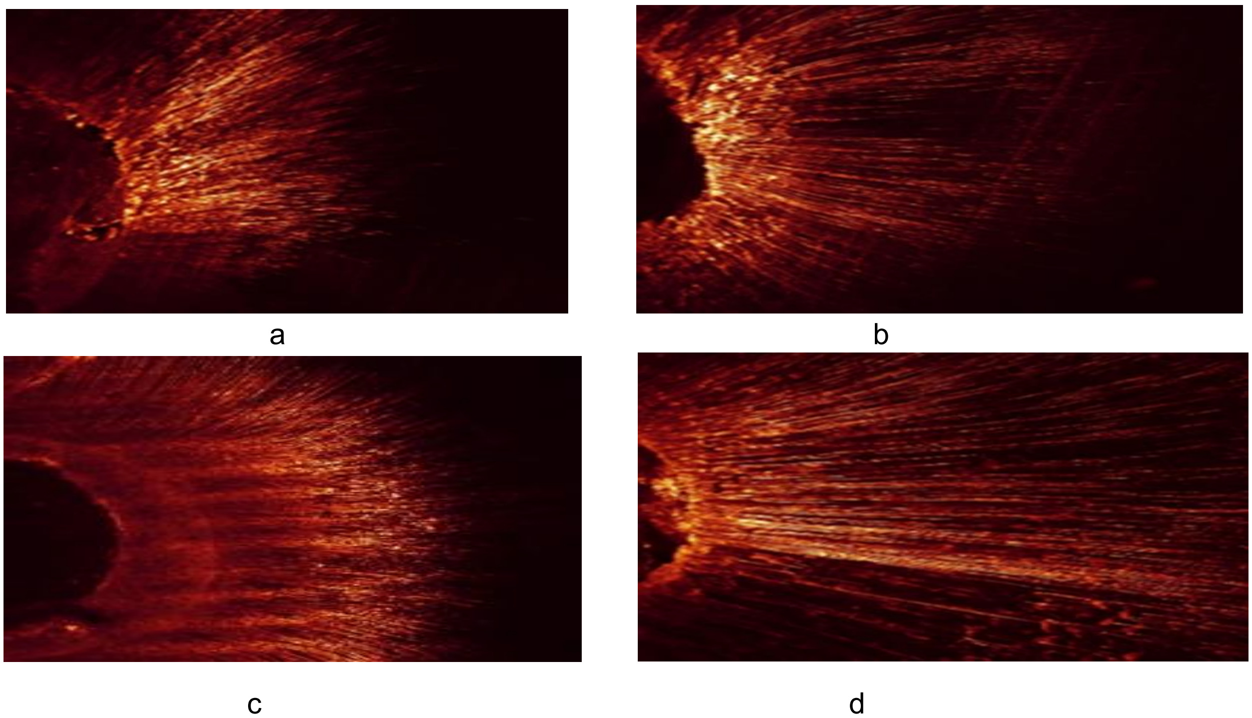

Figure 3: Confocal laser microscopic images showing the sealer's penetration into the coronal third lingual side of four groups. b.G2, c.G3, d.G4, and a.G1.

In this study, the diameter of dentinal tubules varies between different regions of the tooth. Generally, coronal tubules are larger in diameter compared to apical tubules, which are narrower, the greater permeability of coronal dentin allows for more effective sealer penetration in this area compared to the apical region, the apical region of teeth often exhibits narrower tubules, and the presence of sclerotic dentin, which can significantly reduce permeability. It was noted that sealer penetration was generally greater in the buccolingual direction compared to the mesiodistal one, this may be attributed to the (butterfly effect) which suggests that increased sclerosed dentin in the mesial and distal areas of the root canal impedes sealer flow, the anatomical configuration and the presence of variations in dentin density can contribute to these directional differences in sealer penetration. CLSM was preferred over scanning electron microscopy (SEM) due to it is ability to provide devices to detect detailed images of the specimen at lower magnification without disturbing the flow properties of the sealers, this method proved to be a quick and efficient evaluation of the sealer penetration. CLSM represents a versatile method in the study of dentin and provides adequate information on the adaptation and distribution of the sealer within dentinal tubules [22-24]. The effectiveness of the pulsed Er, Cr: YSGG laser in removing the smear layer and disinfecting the root canal system can improve the overall quality of the procedure, leading to better long-term results, the use of pulsed Er, Cr: YSGG laser can potentially reduce the number of visits required for root canal therapy. The development of flexible fiber tips has made the pulsed Er, Cr: YSGG laser even more versatile and effective in endodontic treatment. These tips allow the laser to be used in the narrow spaces of the root canal, ensuring more cleaning and disinfection, this study indicate that using SWEEPS technology together with the Er,Cr:YSGG laser enhance irrigation efficiency and sealer penetration, especially in complex root canal anatomies [25].

6. Limitation

The study's limitations included the possibility of microscopic residues forming during the cutting stage and these remain on the sample surfaces causing artifacts of confocal images, this has been dealt by a polishing device used to polish the surfaces of samples. Another constraint was the physical properties of the sealer, high-viscosity materials may not flow effectively into the tubules, even when aided by laser activation, and sealers may undergo setting reactions that limit further penetration after initial application, so we use AH plus sealer which is characterized by good handling and superior physical properties.

7. Conclusion

From the obtained results. It is concluded that the pulse duration(60µs) of Er, Cr: YSGG laser successfully activates irrigation to reach the root canal's deepest point in four different places (lingual, distal, mesial, and buccal). The SWEEPS technique is based on the pulsed Er, Cr: YSGG laser with certain parameters (Air and water 1%, 0.75 W, 5 Hz, and a short pulse duration of 60µs), so the lingual side was the best value of the sealer penetration. The best parameters are used in G4.

8. Suggestion for future work

1. Using another laser to compare the same objectives during the SWEEPS procedure.
2. Utilizing alternative irrigants.
3. Comparing various types of sealers regarding their penetration.

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تغلغل مانع التسرب الى الثلث التاجي بعد تعرضه الى ليزر الايربيوم: دراسة بالمجهر البؤري

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الخلاصة: تهدف هذه الدراسة إلى تقييم مدى تغلغل مادة الاغلاق AH-Plus في الثلث التاجي من الجذر باستخدام ليزر نبضي (Er, Cr: YSGG) بمدة نبضة قصيرة عند استخدام SWEEPS لتنشيط عملية الغسيل (Shock wave Enhanced Emission

(Photoacoustic Streaming تم إجراء ما مجموعه 28 ضرسًا سفليًا أحادي الجذر. الليزر المستخدم هو ليزر نبضي الاربيوم كروميوم SWEEP.بمساعدة تقنية .هناك أربع مجموعات من العينات (ن = 7) لكل منه المجموعة 1:
المجموعة 2: الري بالموجات فوق الصوتية السلبية باستخدام مل من EDTA 17 الري بالمحقنة التقليدية باستخدام 5 مل من 17% %EDTA
المجموعة 3 :Er, Cr : المسح الضوئي المستحث بالليزر YSGG باستخدام 5 مل من 17 .المجموعة 4 Er, Cr: المسح الضوئي المستحث بالليزر YSGG باستخدام 5 مل من NaOCl 5.25 %و5 مل من EDTA17 % تم اختيار معلمات الليزر وفقًا للدراسة التجريبية (الهواء والماء 1%، 0.75 واط، 5 هرتز، ومدة نبضة قصيرة 60 ميكروثانية). تم سد الأسنان المشعة بواسطة مانع تسرب AH plusمخلوطًا مع رودامين ب، وكانت النسبة المئوية للوزن 0.001. تم إجراء التقطيع الأفقي على أطوال 9 مم بعيدًا عن القمة. تم استخدام أربعة مواقع مختلفة (لساني، بعيد، أوسط، وخدي) لتحديد عمق اختراق المادة المانعة للتسرب. تم استخدام مجهر مسح ليزري بؤري للكشف عن أعمق اختراق للمادة المانعة للتسرب. تم تحليل البيانات إحصائيًا بواسطة اختبارات Dunnett t وكانت قيمة.p≤0.05 .
أظهرت النتائج التي تم الحصول عليها أن مادة مانعة التسربG4 بالإضافة إلى المادة المانعة للتسرب وصلت إلى جدار القنوات AHفي أربعة مواضع (لساني، بعيد، أوسط، وخدي) عند بالمقارنة مع G3 و G2 لمعلمات الليزر المحددة (الهواء والماء 1٪، 0.75 وات، 5 هرتز، ومدة نبضة قصيرة 60 ميكروثانية). استنتج أن مدة النبضة (60 ميكروثانية) من ليزر Er، Cr: YSGG تم ترخيصها بنجاح عند تنشيط الري لتحقيق أعمق نقطة في قناة الجذر لأربعة مواضع (لساني، بعيد، أوسط، وخدي)، لذلك كان الجانب اللساني هو أفضل قيم لاختراق المادة المانعة للتسرب. يتم استخدام أفضل المعلمات في G4 وبما ان هذه دراسة مختبرية يوصى باجراء دراسات سريرية مستقبلية لتأكيد فعالية التقنية وتحسين نتائج المعالجة اللبية.