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The Effect of Er.Cr.YSGG Laser with and without the Addition of CNTs Paste on the Occlusion of Dentinal Tubules to Reduce Hypersensitivity: in Vitro Study

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Abstract

To evaluate the efficacy of the Erbium Chromium-Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) laser in sealing dentinal tubules with the incorporation of multi-walled carbon nanotubes (MWCNTs) paste, and without, when used on exposed dentin. Thirty-nine natural posterior teeth were prepared, sectioned, cleaned, and made ready for treatment. Samples were split into 3 groups: Group G1 is the control group (N=10). Group G2 (N=10) was exposed for 2 seconds to a 2780 nm Er,Cr:YSGG laser (Waterlase iPlus, Biolase Technology) in the free-running pulse mode, with 0.25 W power, 20 Hz frequency, a pulse width of 60 µs, a fibre tip size of 600 µm, and non-contact mode, and Group G3 (N=10) was exposed to Er,Cr:YSGG with carbon nanotubes (CNTs) paste along with a pilot research group (N=9). Scanning electron microscopy (SEM) was used to analyze dentinal surfaces. SEM micrographs were obtained after treatment. A qualitative evaluation of the SEM micrographs was conducted to analyze the changes in surface features and calculate the mean difference of tubule occlusion between the groups. The SEM micrographs showed a decrease in the mean diameter of dentinal tubules from 3.13 µm in the control group to 0.733 µm in group G2, whereas group G3 had a diameter of 0.292 µm. The selected parameters of the Er,Cr:YSGG laser (0.25 W/2 s, 70 W/cm²) for groups G2 and G3 were effective in reducing and plugging any exposed dentinal tubules, with the highest effect for group G3 without any sign of fissures or cracks.

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1. Introduction

The utilization of lasers in dental practice has progressively risen across various domains of dentistry, such as their use in gingivectomy, depigmentation, and various surgical procedures, teeth whitening, and other branches [1-4]. In our study, it was utilized to improve the management of hypersensitivity, defined by acute, transient dental pain arising from exposed dentin in response to stimuli, including thermal, evaporative, chemical, osmotic, tactile, or electrical, and not attributable to any other dental condition [5-7]. There are several causes of tooth hypersensitivity. The theory of Brännström's hydrodynamics is among the most well-expressed concepts [8]. This suggests that a painful sensation may arise from fluid movement within the dentinal tubules. The flow increases swiftly when dentinal tubules are subjected to cold, which the patient may experience as discomfort [9]. Various techniques for addressing dentin hypersensitivity are documented in the literature, although they must fulfil specific requirements to be effective. These therapies must be user-friendly, have long-lasting efficacy, act swiftly, and avoid harming the pulp or causing tooth discoloration [10]. Desensitization can be done by obstructing the teeth opened tubules and blocking pulpal sensory neurons resulting in desensitization [5].

Desensitizing products containing potassium nitrate can diminish nerve activity and the associated discomfort by blocking the signals between nerve cells. Furthermore, several compounds, including potassium oxalate, sodium fluoride, and calcium phosphate, have demonstrated the ability to obstruct dentinal tubules. As shown by specific findings, dentinal tubules may also be occluded by adhesives, cements, varnishes, and lasers [5]. The usage of lasers in clinical settings has increased significantly. Hard and soft lasers are employed in dentistry, and numerous varieties are available. Carbon dioxide (CO_2), neodymium-doped yttrium aluminium garnet (Nd:YAG), and erbium-doped yttrium aluminum garnet (Er:YAG) lasers constitute the solid-state lasers. These lasers are effective on soft and hard tissues; nevertheless, they could cause damage to the pulp. Conversely, biostimulation or Low-Level Laser Therapy (LLLT) employs cool or soft lasers generated by semiconductor diode technology, which do not emit heat. Photodynamic therapy, orthodontic exposure of partly and unerupted teeth, excision of hypertrophic, inflammatory tissue, periodontal crown lengthening, and oral medicine procedures involving the removal of various tissue types exemplify the diverse use of lasers in dentistry. They made great strides in easing painful tissue treatments, such as cavity preparation, caries removal, and removal of restorative material [11]. The class 4 laser utilized in this research is the Erbium Chromium-Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) laser), of a wavelength of 2780 nm. Using this type of laser at the dental clinic has multiple benefits for the patient.

Polyvinyl alcohol (PVA) used in the study, is recognized as a biocompatible substance. Owing to its non-toxic, non-carcinogenic, and biodegradable characteristics. PVA is extensively utilized in medical and pharmaceutical applications. PVA is frequently used to fabricate drug delivery systems, dressings, and scaffolds for tissue engineering [12]. Carbon nanotubes (CNTs) are a kind of graphene. Nano-foils with a honeycomb lattice of carbon atoms are twisted within a hollow cylinder, resulting in single-layer CNTs as small as 0.7 nm and stacked carbon nanotubes measuring up to 100 nm, with lengths varying from micrometers to millimeters. The termini of nanotubes may be either empty or capped with a half-fullerene molecule. Nanomaterials such as CNTS are utilized in several dental applications [13].

This study aimed to assess the effect of the Er,Cr:YSGG laser, independently and in conjunction with CNTs paste, on the occlusion of hypersensitive dentin.

2. Material and Methods

2. 1. Preparation of Teeth

Thirty-nine adult human wisdom teeth that had been extracted for various reasons were employed. Crowns that exhibited defects, including cavities, restorations, or fractures, were discarded. The teeth were cleaned, desiccated, and stored in distilled water with 0.1% thymol (2-Isopropyl-5-methylphenol) for 48 hours. Any remaining cementum and concomitant periodontal ligament were removed using a hand scaler. The teeth were subsequently polished for thirty seconds using non-fluoride paste. The teeth were affixed to the surveyor to ensure that the tooth surface was cut uniformly at a zero plane using a double-sided, 0.2-millimeter diamond disc (one disc for each three teeth). Water chilling was employed during the cutting process. Next, the teeth were cleansed with an ultrasonic cleaner to eliminate any debris. After that, teeth were exposed to 17% EDTA(Ethylenediaminetetraacetic acid) for 120 seconds and 35% phosphoric acid for 10 seconds to activate the surface of the hypersensitive dentin and remove the smear layer. Then, the teeth were kept for treatment.

A pilot study on nine teeth was conducted to determine the ideal parameters of the laser (power and exposure time) to use in the study groups. Different laser exposure times of (2, 4, and 8 seconds) and laser powers of (0.25, 0.5, and 0.75 W) were tried. A Power of 0.25 W and 2s exposure time were chosen from two pilot trials. These values were used in this study.

Multi-walled carbon nanotubes (MWCNTs) paste is a versatile material made by dissolving PVA powder in deionized water and stirring until fully dissolved. Subsequently, 10mg MWCNTs powder was incorporated into 10 mL PVA solution and mixed forcefully with a stirrer to achieve uniform dispersion. MWCNTs is thereafter stored in a sealed container at ambient temperature. The FTIR spectrum of the paste was acquired, and the findings are presented in Fig.1. The spectrum exhibited a pronounced wide absorption at 3597.1 cm^{-1} (2780 nm) for the CNTs-infused PVA.

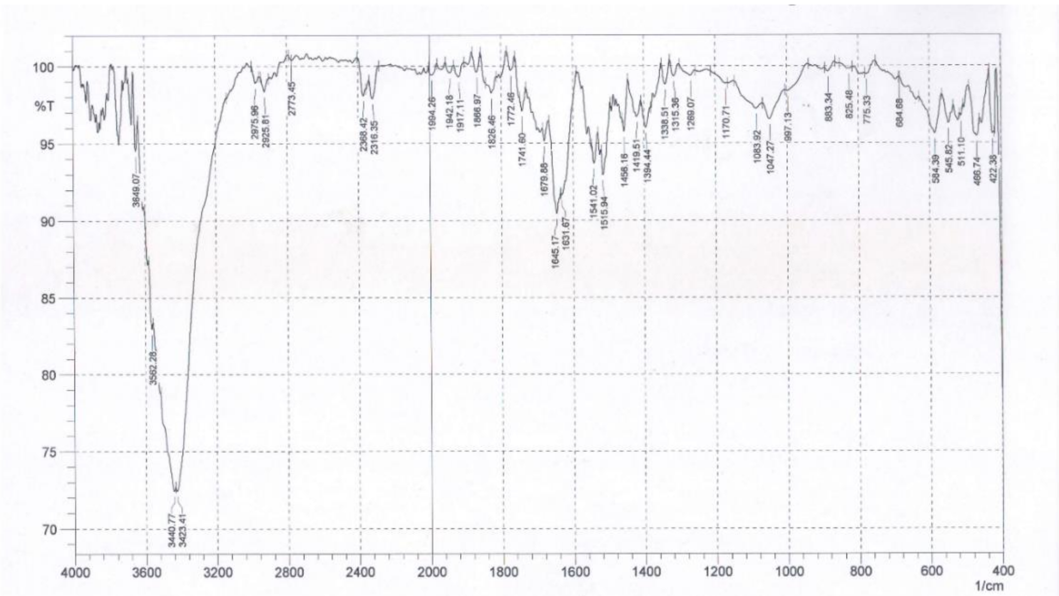

Figure 1: FTIR spectrum of the CNTs-PVA paste.

Three groups were categorized, each comprising ten samples. Group G1 received no therapy (the control group). In study 1, Group G2, which is the Er,Cr:YSGG laser group, was treated with a 2780 nm Er,Cr:YSGG laser (Waterlase iPlus, Biolase Technology) for 2 seconds. This treatment used a laser power of 0.25 W in free-running pulse mode, with a pulse width of 60 μs and a frequency of 20 Hz, as illustrated in Fig. 2. The fiber tip diameter was 600 μm in a non-contact mode. The power density was measured by measuring the spot size of 356,791.936 μm^2 to be 70 W/cm^2. The fibre tip was fixed 1 mm away perpendicularly to the dentin surface using a clamp holder; the device has been operated without water or air, 0% water, and 0% air.

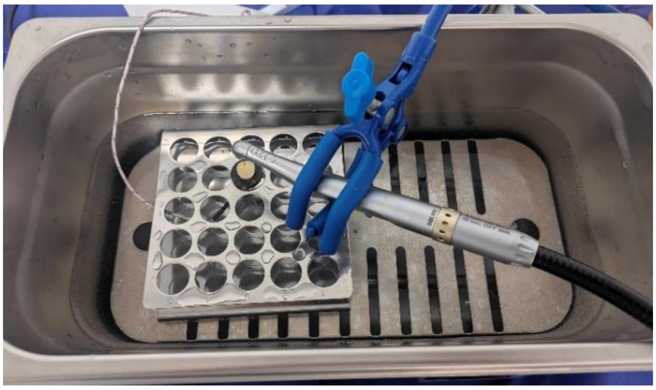

Figure 2: Settings for laser exposure group.

Group G3 (study2) (the Er,Cr: YSGG laser and CNTs paste group). The laser was used with the same settings of group G2. Before laser irradiation, the CNTs paste was scrubbed onto the prepared teeth surfaces using a microbrush.

2. 2. Temperature Measurements

All the 20 teeth of the two study groups were irradiated with a 2780 nm Er,Cr:YSGG laser, and any temperature variations were recorded to document increases in temperature during the lasing period. To assess temperature, one canal in each tooth was produced using the pro taper files, treated with de-ionized water, and subsequently dried using paper point. The probe tip of the digital multimeter (Pro'skit, MT-1232, Germany) was inserted into the pulp chamber to measure temperature (Fig. 3).

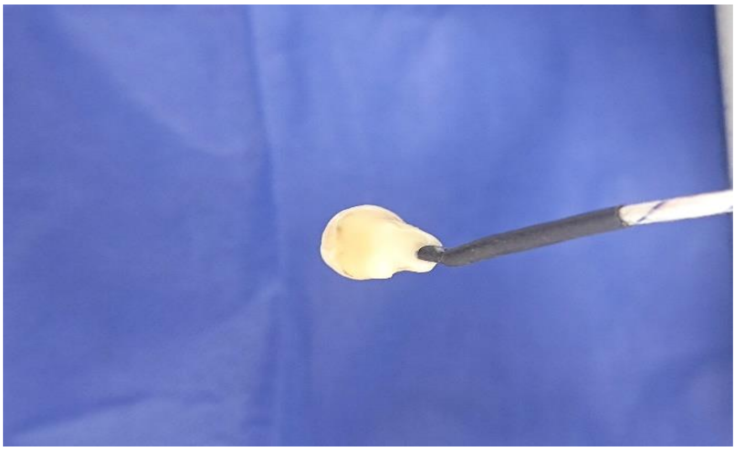

Figure 3: The fixation of thermocouple probe inside the canal.

3. Results

In group G1 (the control group), the dentin surfaces of the ten samples showed varying degrees of dentinal tubule occlusion. Figs. 4 and 5 illustrate SEM micrographs of the control group after treatments with 35% phosphoric acid for 10 seconds and 17% EDTA for two minutes to eliminate the smear layer. The tubules were fully opened, and the dentin was devoid of the smear layer. The control samples' tubules diameters were examined using SEM analysis, and the results indicated a mean of 3.13µm.

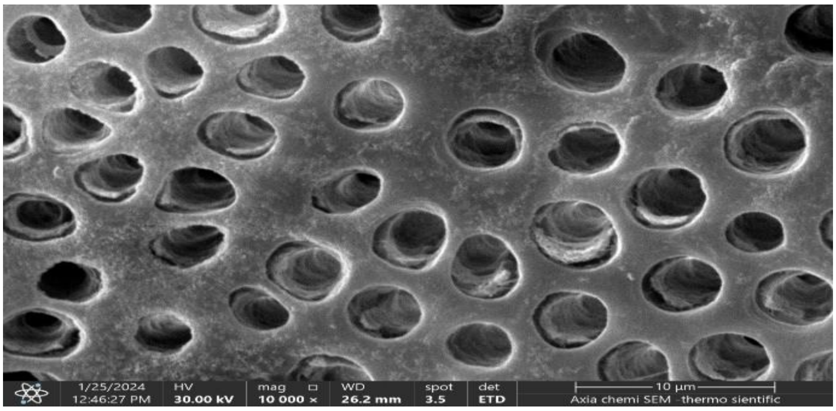

Figure 4: SEM micrograph of the control group (Magnification: 10000x).

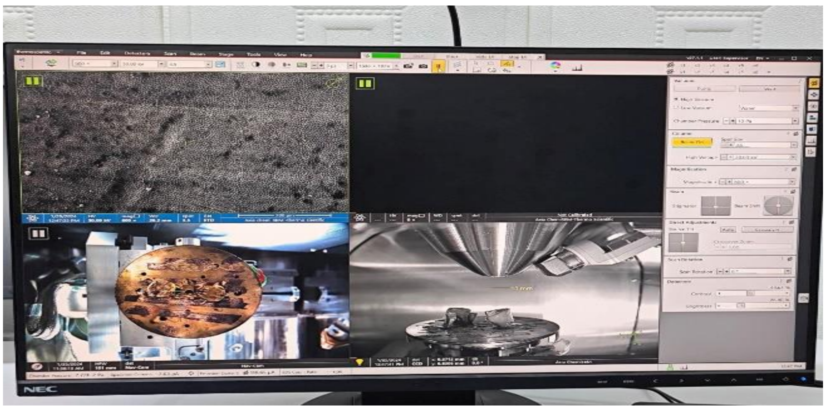

Figure 5: SEM examination for the control group.

Group G2 (study1) was irradiated with Er,Cr:YSGG laser at a power of 0.25 W for 2 seconds; a reduction in tubular diameter, together with the presence of occluded tubules, was found. Fig. 6 demonstrates negligible surface residue and complete occlusion of the majority of the dentinal tubules. There were alterations and a reduction in diameter in the remaining tubules. The dentinal tubule diameter was equal to 0.733 µm, as measured by the SEM image.

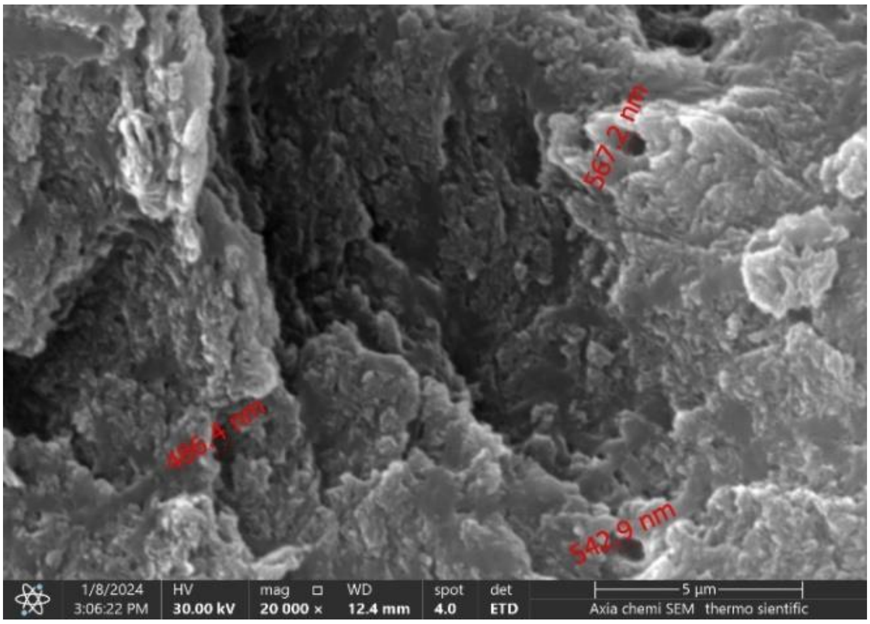

Figure 6: SEM micrograph of the laser treated dentin (Magnification: 10000x).

For group G3 (study group 2) treated by CNTs paste and irradiated with Er,Cr:YSGG laser at power of 0.25W for 2 sec laser exposure, a marked reduction in tubules diameters with occlusion of most tubules were observed (Fig.7). In this group, the average diameter of dentinal tubules was 0.292 µm.

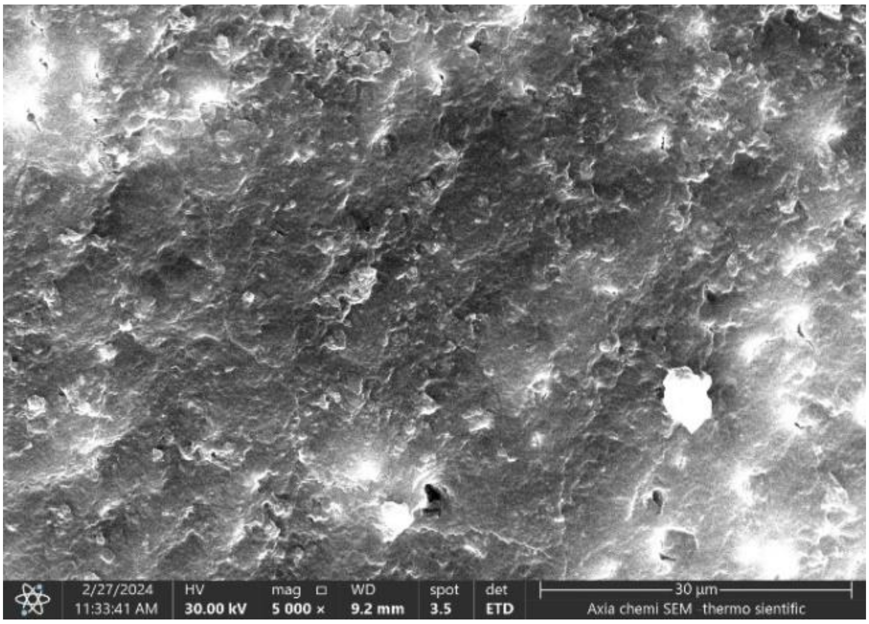

Figure 7: SEM micrograph for the treated dentin with CNTs paste and Er,Cr: YSGG laser exposure (0.25W,2sec)(Magnification: 30000x).

3. 1. Temperature Measurement

Throughout the temperature measuring exposure period, no changes in the temperature of the sample were found.

3. 2. Statistical Results

The distribution of the collected data was checked for normality using the Shapiro-Wilk and Kolmogorov-Smirnov tests. The data were found to be normally distributed (P > 0.05), as shown in Table 1 and Fig. 8.

Table 1: The results of the study.

Tested groups	G1	G2	G3	P value
N	50	50	50	**0.0001**
Mean / µm±SD	C 3.13±0.96	B 0.73±0.31	A 0.29±0.5	

LSD test used to ascertain the differences among the tested means; the letters (A, B, and C) represented various degrees of significance, with A indicating the highest and C the lowest significance. Statistical significance was established for p≤0.05, whereas p>0.05 was considered inconsequential.

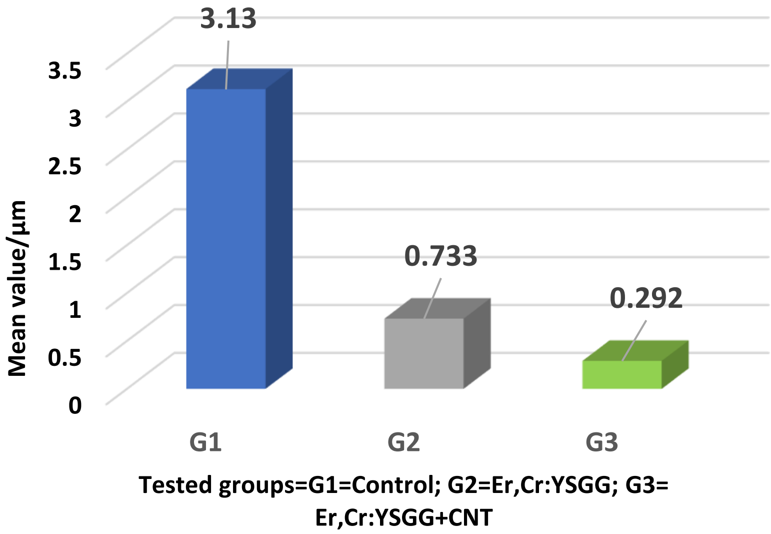

Figure 8: Dentinal tubules diameter comparison between the control and study groups.

4. Discussion

By reducing fluid motions inside dentinal tubules, which disrupt the transmission of stimuli to the odontoblastic process, dentinal hypersensitivity may be lessened [14]. In hypersensitive teeth, the diameter of the tubules is significantly larger than that of non-sensitive teeth. Diverse methods can impede dentinal tubules by sealing the dentin surface, or occluding their openings or the underlying dentin within the tubules [6-15]. In our investigation, effective desensitization was accomplished by diminishing and blocking the diameter of the tubules using an Er.Cr.YSGG laser (0.25W/2s, 70W/cm^2), with and without the addition of MWCNTs paste. This study conducted an assessment utilizing SEM immediately upon exposure. All samples were subjected to ultrasonic cleaning in an apical-coronal direction to remove residual cementum, followed by polishing with polishing paste to remove any debris. Subsequently, they were rinsed, dried, and kept in distilled water containing 0.1% thymol for two days to prevent microbial growth. For this investigation, dentin hypersensitivity was simulated by opening widely the dentinal tubules. Both EDTA 17% gel and an additional 35% phosphoric acid were applied to ensure the wide opening of the tubules for hypersensitive dentin [16]. This crucial action is to make sure that the prepared surface dentin was free of any additional materials, smear layer, and smear plugs.

The Food and Drug Administration (FDA) permitted the application of erbium lasers on hard tissues; thus, the 2780nm Er,Cr:YSGG laser was selected for the study. This aligns with prior studies [16–22]. Schwarz et al. [23] and Birang et al. [24] proposed that reduced power settings would lead to the evaporation of dentinal fluid and the smear layer, resulting in a decrease of dentine permeability and, subsequently, a reduction in dentinal discomfort. 0.25W power Er,Cr:YSGG laser was used for 2 sec. According to previous studies, the Er,Cr:YSGG laser is one of the erbium laser family and exhibits substantial absorption in the water molecule of the tooth's crystalline structure. It results in water evaporation, causing the expansion and disintegration of dental hard tissues [25]. The excellent absorption of the OH−ions from hydroxyapatite by Er,Cr: YSGG laser could promote a good interaction between the laser and the dentin surface.

High- and low-intensity dental lasers have attracted much attention from researchers looking into their potential clinical uses. While LLLT produces photophysical, photochemical, and photobiological effects on the cell's tissues, high-intensity lasers utilize high temperatures to ablate, vaporize, puncture, and coagulate dental tissue. [26].

Meng-Long. et al. (2019) used the erbium laser for desensitization, which was achieved through the absorption of water molecules, resulting in a micro-blasting effect and the deposition of insoluble salts that constrict or occlude the tubules. The diameter of the tubular surface can be reduced by up to 50% [27]. In comparison to our result, a better reduction was achieved.

Carbon nanotubes' biocompatibility, strength, and pliability have made them a leading carbon-based material [28]. Researchers have discovered that carbon nanotubes are not only antibacterial; they also possess mechanical qualities [29]. Due to this property, tubes can now be used as covering materials for dental implants and scaffolds for bone tissue engineering. Dental coatings made of carbon nanotubes have unique properties, such as the ability to regenerate damaged tissue and act as a vehicle for administering antimicrobial drugs [13, 30].

MWCNTs paste applied to the teeth surface increases the absorbed energy of the erbium-chromium laser, corresponding to a specific absorption band of stretching vibrations of a hydroxyl group (O-H) for the CNT-infused PVA that interacts with Er,Cr;YSGG laser , as seen in Fig.1.

In group G3, the MWCNTs paste on the dentin surface absorbs the Er,Cr:YSGG laser. Using the same laser parameters that were used in group G2, crystals and new salts were generated that increased hardness, but with the MWCNTs paste, additional absorption by the paste could enhance localized heating and evaporation, possibly increasing the efficiency of dentin sealing which is confirmed by the results shown in Table 1. The laser could thermally fuse the paste within the dentin forming a carbon-based heat resistant layer that blocks the tubules more effectively; the transmitted laser interacts with dentinal water molecules limiting the fluid movement inside the tubules, and the amount of radiation that penetrates and accumulates in the pulp chamber is minimized [31].

Since the interaction of the 2780nm Er,Cr;YSGG laser with dentin is photothermal, it is crucial to ensure that the temperature increase within the pulp chamber does not cause tissue necrosis. For both G2 and G3, no changes in the sample's temperature were detected during the exposure period. This is due to the small exposure time and short penetration depth of the laser that accentuates the effect on the surface. The study aimed to examine the laser's impact on dentinal tubule occlusion, focusing on the effect of CNTs paste. The average diameter of dentinal tubules decreased from 3.13 µm in the control group to 0.733 µm in group G2 to 0.292 µm in group G3. The effect of lasers on nerves or pulp wasn't taken into consideration.

5. Conclusions

It was found that Er,Cr:YSGG (2780nm) laser affected the patency of the dentinal tubules; this impaction was enhanced when CNTs paste was added, resulting in heightened occlusion or constriction of the exposed dentinal tubules and, consequently, a decrease in sensitivity.

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Conflict of Interest

The authors have no conflict of interest to declare.

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تاثير ليزر (الإربيوم والكروم: الجاليوم الإيتريوم الإسكانديوم الجارنت) على انسداد الانابيب السنية مع اضافة خليط الانابيب النانوية الكاربونية او بدونه:دراسة مخبرية

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[2]قسم طب الاسنان، جراحة الوجه والفكين، جامعة التراث، بغداد، العراق

الخلاصة

تم تقييم فعالية ليزر الاربيوم كروميوم في غلق الأنابيب العاجية باستخدام معجون أنابيب الكربون النانوية متعددة الجدران ودونه عند استخدامه على العاج المكشوف. تم تحضير تسعة وثلاثين سنًا خلفيًا طبيعيًا من الأسنان الخلفية الطبيعية وتم تقطيعها وتنظيفها وتجهيزها للعلاج.المواد والطرق: تم إعداد 39 ضرسًا طبيعيًا خلفيًا، وقُسمت العينات إلى ثلاث مجموعات:المجموعة أ: مجموعة التحكم السلبية (عدد العينات = 10),المجموعة ب: تعرضت لليزر الاربيوم كروميوم بطول موجي 2780 نانومتر، وضع النبض الحر، طاقة 0.25 واط، تردد 20 هرتز، عرض نبضة 60 ميكروثانية، مدة 2 ثانية، حجم رأس الألياف 600 ميكرون، وضع عدم التلامس,المجموعة ج: استخدمت مع ليزر الاربيوم كروميوم مع إضافة معجون أنابيب الكربون النانوية, تم استخدام المجهر الإلكتروني الماسح لتحليل أسطح العاج بعد المعالجة والتقاط الصور وتحليل التغيرات في السمات السطحية وقياس الفرق المتوسط في انسداد الأنابيب بين المجموعات. مع مجموعة بحثية تجريبية(ن=9) النتائج: أظهرت الصور عبر المجهر الالكتروني الماسح انخفاض في متوسط قطر الأنابيب السنية من (3.13 ميكرومتر) في المجموعة (أ) إلى (0.733 ميكرومتر) في المجموعة (ب)، بينما بلغ قطر المجموعة (ج) (0.292 ميكرومتر).الاستنتاج: كانت المعايير المستخدمة (0.25 واط/2 ثانية، 70 واط/سم^2) فعالة في تقليل وانسداد الأنابيب العاجية المكشوفة، مع تحقيق المجموعة ج لأعلى تأثير دون ظهور شقوق أو كسور.

الكلمات المفتاحية: أنابيب العاج، ليزالإربيوم والكروم: الجاليوم الإيتريوم الإسكانديوم الجارنت، أنابيب الكربون النانوية، الليزر المائي، حساسية الأسنان.