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Laser Assisted Smear Layer Removal in Endodontics

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Abstract: ***The success of endodontic treatment depends on effective cleaning and disinfection of the root canal system, including the removal of the smear layer formed during mechanical instrumentation. The smear layer, composed of organic and inorganic debris, negatively affects dentinal permeability, limits the penetration of irrigants and sealers, and negatively affects the sealing ability of root canal fillings. Traditional methods, show limited effectiveness, particularly in the apical third of the canal. Laser technologies have demonstrated improved efficacy, enabling better debris removal and deeper penetration into dentinal tubules. Evidence suggests that combining laser activation with conventional irrigants enhances smear layer removal and sealer penetration, leading to improved treatment outcomes. Overall, laser-assisted irrigation represents a promising adjunct in modern endodontics, though standardized protocols remain to be established.***

Keywords: smear layer removal, laser-assisted irrigation, diode laser, Er:YAG laser, Er,Cr:YSGG laser, Nd:YAG laser, CO_2 laser

The success of root canal treatment relies on thorough cleaning and disinfection of the root canal system to eliminate infection, prevent apical periodontitis and alleviate patient symptoms. Therefore, mechanical instrumentation should be complemented by irrigation protocols, which enhance disinfection, facilitate cleaning of areas inaccessible to endodontic instruments, and aid in the removal of debris and the smear layer [16].

The primary objective of root canal therapy is the elimination and control of infection. At present, this is mainly achieved through a combination of mechanical instrumentation and chemical irrigation. During the mechanical preparation of the root canal, a smear layer with a thickness of 1–5 µm is formed, consisting of dentinal debris, organic components, and inorganic mineralized tissues. It can penetrate dentinal tubules up to 40 µm (even 110 µm in some cases) [23]. The presence of this smear layer has several negative effects, including occlusion of dentinal tubules and restriction of the penetration of irrigants, intracanal medicaments, and filling materials into the tubules. It forms a physical barrier affecting disinfection and sealing of root canal filling materials [12]. Therefore removal of the smear layer is essential for improving sealer penetration in the dentinal tubules and minimizing the risk of microleakage.

Effective root canal therapy, adequate cleaning and disinfection of the root canal system can be improved with laser systems in two main directions- laser activated irrigation and independent final application of laser irradiation [10,16,17,23]. Conventional irrigation protocols primarily rely on chelating agents such as 17% ethylenediaminetetraacetic acid (EDTA), which facilitates smear layer removal through calcium ion chelation. However, its efficacy is limited, particularly in the apical third, where complex anatomy and reduced dentinal tubule density hinder irrigant penetration. Furthermore, syringe-based irrigation alone has been shown to be insufficient in achieving complete debridement of the apical region and irregular canal spaces [10,25]. The adaptability of root canal sealers to the dentinal walls is questionable, especially in the presence of a smear layer which compromises the sealing ability and paves the way for the entry of microorganisms. Findings support the idea that removing the smear layer enhances the penetration of root canal filling sealers into dentinal tubules, leading to increased retention of the root canal filling [15]. This has driven the development of adjunctive techniques aimed at enhancing irrigant activation and smear layer removal.

Contemporary methods for smear layer removal include using chemical solution, sonic, ultrasonic devices and laser irradiation. Lasers can be used to vaporize pulp tissues, remove the smear layer and disinfect the root canals [5].

Conventional needle irrigation is a widely used method for irrigation but it has been proven that it doesn't fully clean the canal of debris, especially in the apical third [9,25]. In contrast to conventional needle irrigation, sonic activated and laser activated irrigation have proven to be more effective in smear layer removal in the coronal, middle and apical thirds of the root canal [25].

The mechanism of laser-assisted irrigation is mainly explained by photoacoustic and cavitation effects. When laser energy is absorbed by the irrigant, it leads to the rapid formation and collapse of vapor bubbles, generating shock waves and fluid movement within the root canal. These dynamic events produce shockwaves along the canal walls which promotes the disruption of the smear layer and the the removal of debris from regions that are difficult to access with conventional irrigation techniques. Furthermore, erbium lasers have a high rate of absorption in water and hydroxyapatite, allowing efficient ablation of the smear layer and exposure of dentinal tubules [14]. This enhances dentinal permeability and creates more favorable conditions for the adhesion of root canal sealers. Diode lasers are sparsely absorbed by hydroxyapatite crystals or water hence allowing it to penetrate deeply into the dentinal tubules [11]. Diode lasers also show promising antibacterial properties when used in root canals [1].

Experimental evidence supports the synergistic effect of combining lasers with conventional irrigants. Pradelli et al. demonstrated that using a diode laser alongside EDTA enhances its effectiveness by not only energizing the EDTA but also heating it, which increases its efficiency in the root canal [27]. The combined use of Er,Cr:YSGG laser and EDTA showed cleaner canal walls in the apical third compared to the use of EDTA alone [14].

The root canal walls have many irregularities which can only be cleaned with thorough irrigation and activation of the irrigant. De Groot et al. demonstrated that laser activated irrigation using Er:YAG laser and NaClO was more effective in removing dentin debris in the apical part of the root canal and uninstrumented canal extensions [8].

Sealer penetration inside of the dentinal tubules of the root canal is important for the outcome of the endodontic treatment as the contact surface between the obturating material and the dentin is sealed. A study comparing conventional irrigation techniques using EDTA and saline, with laser activated irrigation + EDTA showed improved sealer penetration in the diode and the Er, Cr:YSGG laser groups [13]. This could be because the laser light is thought to be able to reach areas that are impossible with the traditional techniques and the diode lasers have a good depth of penetration inside the dentinal tubules which is around five times more when compared to chemical solutions. Diode lasers are sparsely absorbed by hydroxyapatite crystals or water hence allowing it to penetrate deeply into the dentinal tubules [4].

The study conducted by Pradelli et al. showed not only improved removal of the smear layer when using EDTA activated by laser irradiation but also improved sealer penetration in the dentinal tubules [18].

Another study used Er, Cr:YSGG laser (Parameters: wavelength: 2780nm, power: 0.75W, frequency: 5Hz, pulse duration: 60µs) and also showed improved results compared to control groups. The pulsed Er,Cr:YSGG laser using the PIPS technique significantly enhanced sealer penetration in the apical third, especially when combined with NaOCl and EDTA [19].

Nd:YAG lasers also show beneficial effects in enhancing smear layer removal when used for irrigant activation during root canal treatment. In a study the efficacy of Nd:YAG, Er:YAG with photon-induced photoacoustic streaming (PIPS) technique and Er,Cr:YSGG laser activation were evaluated using both distilled water and a combination of 2.5% sodium hypochlorite (NaOCl) and 17% EDTA. The Nd:YAG laser (1064 nm) was operated with a 320-µm fiber optic tip at 1.5 W, 60 mJ pulse energy, and 15 Hz frequency. SEM evaluation revealed that Nd:YAG activation was effective in the removal of the smear layer especially in the coronal and middle thirds of the root canal. The authors also noted that Nd:YAG laser activation produced smear layer removal results comparable to Er,Cr:YSGG laser activation. The Er:YAG laser used with photon-induced photoacoustic streaming (PIPS) achieved the most effective smear layer removal, especially in the apical region. Nevertheless, the study concluded that Nd:YAG laser activation enhances the effectiveness of irrigating solutions and contributes to improved canal cleanliness [17].

Another study compared conventional syringe irrigation (CSI), passive ultrasonic irrigation (PUI), EndoVac apical negative pressure (ANP), diode, Nd:YAG, Er:YAG laser activation and Er:YAG laser activation using with photon-induced photoacoustic streaming (PIPS). The Nd:YAG laser was used with a 300-µm endodontic fiber tip at 10mJ, 15Hz, and 1.5W power settings. The authors reported that Nd:YAG laser activation improved smear layer removal compared with conventional syringe irrigation and diode laser activation. This shows that Nd:YAG laser activation could be used as an adjunctive method for smear layer removal. Irrigant actvation with the PIPS technique showed the highest effectivenes in the apical region [2].

Single-handed laser irradiation has also proven to be effective in the removal of the smear layer. A study showed that combining conventional root canal instrumentation with diode laser irradiation produced cleaner dentinal walls of the root canal. The laser used in this study had a wavelength of 980 nm, and a power of 7W. The irradiation time was 7 sec. The teeth treated with laser irradiation showed cleaner dentinal walls and less apical leakage. The rise of temperature with laser assisted desinfection was below the limit to cause damage to periodontal tissue [24].

The use of CO_2 and Er:YAG lasers for the removal of smear layer has also been investigated. In a study where the root canals of extracted teeth were shaped manually CO_2 and Er:YAG lasers were assessed alongside 17% EDTA, 6% phosphoric acid, 6% citric acid for smear layer removal. The CO_2 laser was operated at a wavelength of 10.6 µm with an output power of 1 W in continuous mode for a total of 23 sec. in each canal. Scanning electron microscopy (SEM) demonstrated that CO_2 laser irradiation effectively removed the smear layer from both the middle and apical thirds of the root canal walls. The smear layer in certain areas of the root canal walls was charred, melted, recrystallized, and glazed. The Er:YAG laser demonstrated superior cleaning ability by producing smear layer-free surfaces with open dentinal tubules and without the melting effects observed after CO_2 laser irradiation [22].

Er,Cr:YSGG lasers demonstrated good opportunity for smear layer removal as well [11, 14, 26].

Optimising laser delivery systems is important for achieving predictable outcomes in endodontic treatment. Advances in fiber tip design have been made to improve disinfection and smear layer removal while reducing the risk of thermal damage to periradicular tissues. Conical laser fiber tips lead to enchanced cleaning of dentine in the apical third by improving laser energy distribution along the canal walls [7]. The use of radial-firing tips along with Er,Cr:YSGG laser showed a decisive disinfectant effect and homogenous removal of the smear layer while the thermal changes were moderate and safe [21].

Studies have raised some disadvantages when using laser assisted disinfection of the root canal and some limitations remain. Laser-activated irrigation can result in smear layer removal from the root canal wall, but also cause extrusion of irrigant through the apex [8]. The use of lasers is associated with the generation of heat. The increase in temperature can cause carbonisation and cracks in the dentinal walls of the root canal [16]. Some clinicians have fears of possible thermal damage to periodontal tissue but most studies show that the temperature increase is within safety limits for the periapical tissues [3,6,20,26]. A lot of the available evidence is derived from in vitro studies so more randomised clinical trials are needed to further improve protocols and specify parameters for the use of lasers in endodontics.

In summary, current evidence strongly supports the use of laser-assisted irrigation as an adjunct to conventional endodontic protocols. Lasers enhance smear layer removal and result in increased dentinal permeability and improved sealer penetration. The integration of laser activation with conventional irrigants such as EDTA and NaClO appears to provide the most effective approach for optimizing root canal cleanliness and improving the adhesion of filling materials. Further high-quality clinical studies are needed to confirm these findings and establish standardized protocols for clinical practice.

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