A comparative evaluation of the efficacy of erbium: yttrium–aluminum–garnet and diode lasers in smear layer removal and dentin permeability of root canal after biomechanical preparation – A scanning electron microscopy study

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ABSTRACT

Introduction: The chemomechanical preparation of root canal dentin with hand or rotary instruments creates debris and a smear layer. Root canal preparation (RCP) along with irrigants is not effective in cleaning apical portions, and hence, different laser activation systems were used for better cleaning in the apical third. Aim: The aim of this study is to compare the efficacy of erbium: yttrium–aluminum–garnet (Er:YAG) and diode laser irradiation in smear layer removal and dentin permeability after biomechanical preparation using scanning electron microscopic investigation. Material and Methods: Thirty sound single-rooted human teeth were distributed randomly and equally into three groups (n = 10 each) based upon the type of laser irradiation after RCP: Group I (control group) – RCP with ProTaper rotary system using the standard irrigating protocol; Group II – RCP with ProTaper rotary system using the standard irrigating protocol followed by diode laser irradiation; and Group III – RCP with ProTaper rotary system using the standard irrigating protocol followed by Er:YAG laser irradiation. After root sectioning, specimens were dehydrated, then gold plated and observed using a scanning electron microscopy. Then, the smear layer scores were recorded and performed using the statistical analysis. Results: Smear layer removal efficacy of Er:YAG laser was more at coronal, middle, and apical third when compared to Group I and Group II. Debris removal score of Group III (Er:YAG) was better than Group I (17% ethylenediaminetetraacetic acid) and Group II (diode). Conclusion: Er:YAG laser-activated RCP was comparatively efficient in cleaning the smear layer and dentinal tubules opening.

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KEYWORDS: 17% ethylenediaminetetraacetic acid, diode laser, erbium:yttrium–aluminum–garnet laser, hand and rotary instruments, root canal preparation, scanning electron microscope, smear layer

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Introduction

During root canal preparation (RCP), instrumentation produces a layer of organic and mineral debris called the smear layer which cannot be completely removed by sodium hypochlorite (NaOCl) irrigation. Many researchers considered smear layer as a negative factor in root canal adhesion because it may prevent sealer adaptation to the canal walls\(^\text{[1]}\) and favoring the occurrence of marginal leakage.\(^\text{[2]}\) However, some reported that it might be beneficial because it reduces the permeability of dentin and prevents or slows the penetration of bacteria into dentinal tubules.\(^\text{[3]}\) Despite the research-based evidence shows smoother RCP with NiTi instruments, they are not as much as effective for cleaning flattened root canals or those in which the canal shape does not permit instrumentation of all dentin walls.\(^\text{[4]}\) In these cases, irrigating solutions may have fundamental importance. The most widely used irrigant for root canal treatment is NaOCl at concentrations of 0.5%–5.25%. The tissue dissolving capacity and microbicidal activity of NaOCl are excellent, but it has a limited effect on the dissolution of the smear layer.\(^\text{[5]}\) Acid solutions have been recommended for removing the smear layer, including sodium salt of ethylenediaminetetraacetic acid (EDTA), most active at a concentration of 15%–17% and pH of 7–8; citric acid solutions, used at concentrations of 10, 25, and 50%; and orthophosphoric acid at concentrations of 10, 32, and 37%.\(^\text{[6]}\) These irrigants dramatically improve the cleaning ability of root canals. On the other hand, studies have shown that a combination of NaOCL and EDTA removed the smear layer only partially\(^\text{[7]}\) and unable to clean in the apical portion of the root canals, and hence, to improve that in apical portion laser-activated systems were used in this study.

With regard to the laser application in endodontics, its effects have been investigated previously. Laser systems such as neodymium: yttrium–aluminum–garnet (Nd:YAG) and carbon dioxide (CO\(_2\)) lasers have proved effective in cleaning and disinfecting the root canal and lateral dentinal tubules\(^\text{[8,9]}\) when combined with hand filling and showed a general absence of smear layer and tissue remnants on the root canal wall. The diode laser is recommended\(^\text{[10]}\) for endodontic treatment because its wavelength is within the infrared range and its thin and flexible fibers helps to remove the smear layer. With the development of laser beams and accessories capable of delivering light into the root canal, researchers are creating new techniques to apply this device in dentistry.

Cozean C\textit{et al.}, 1997 reported the use of erbium:yttrium–aluminum–garnet (Er:YAG) laser, with a wavelength of 2.94 mm, that specifically removes the enamel and dentin.\(^\text{[11]}\) It has been observed in a study by Takeda \textit{et al.}, in 1999, that Er:YAG laser irradiation led to the removal of debris and smear layer from the root canal wall. The evaluation of these fine debris and the presence of the smear layer require higher magnification levels that are achievable only through the use of scanning electron microscopy (SEM).\(^\text{[12]}\) The aim of the present study was to compare the efficacy of Er:YAG laser and diode laser in smear layer and debris removal and dentin permeability of root canal walls after biomechanical preparation with ProTaper rotary instrumentation technique using SEM.

Materials and Methods

After obtaining clearance from the Research and Ethical Committee of the Institute, the study was carried out in the Department of Pedodontics and Preventive Dentistry, Genesis Institute of Dental Sciences and Research, Ferozepur, under the Baba Farid University of Health Sciences, Faridkot (Punjab).

Collection of teeth

Thirty sound single-rooted human teeth extracted due to periodontal reasons were selected based on the inclusion criteria.

Sample selection criteria

\textit{Inclusion criteria}

The inclusion criteria were as follows:

1. Caries-free teeth
2. Teeth without cracks or any fracture
3. Teeth without restorations
4. Devoid of any developmental defects
5. Fully developed teeth with closed apex.

\textit{Exclusion criteria}

The exclusion criteria were as follows:

1. Teeth with curvature
2. Teeth with dilaceration
3. Teeth with a fractured root
4. Teeth with resorbed root
5. Teeth with cervical and root caries
6. Partially developed teeth with an open apex.

Preparation of teeth before forming groups

The samples were prophylactically cleaned with an ultrasonic scaler and periodontal curette to remove the debris and periodontal soft tissue. The specimens were stored in 0.9% normal saline solution at room temperature.

Root canal preparation

First, 30 sound single-rooted incisors were sectioned at the cemento-enamel junction using a bur and root canal was prepared with ProTaper rotary system, and standard irrigating protocol (5 ml of 17% EDTA for 1 min followed by 5 ml of 5.25% NaOCl and finally with 2.5 ml of...
distilled water) was followed to remove the debris from the root canal. The samples were distributed randomly and equally into three groups (n = 10 each) based on the type of laser irradiation after RCP. Group I (n = 10): control group - RCP not followed by laser irradiation, Group II (n = 10): RCP followed by diode laser irradiation ([elexxion, claros pico], 200 μm, 808 ± 10 nm, 5 W CW) was activated gently at the coronal region of the root canal with a helicoid movement for a total laser irradiation cycle of 20 s, and in Group III (n = 10): RCP followed by Er:YAG laser irradiation ([Syneron], a wavelength of 2940 nm, energy of 1.8 W, pulse rate of 100 mJ, frequency of 18 Hz, with a 0.8 mm × 14 mm fiber-optic tip) was activated from the orifice of each root canal with continuous rotational movement for 30 s.

The root sectioning was done by making two parallel longitudinal grooves along the outer surfaces of the roots that were not deep enough to penetrate the root canal.

The specimens were then dehydrated using a series of graded ethanol solution (50%, 80%, 90%, and 100%) for 1 h and each. The samples were then gold plated with a 15–20 nm gold-palladium layer and observed using an SEM. In each group, images from the coronal, middle, and apical part of the root canal were obtained at ×1000. The photographs [Figure 1a-f] were then analyzed using the three specific criteria:

Criteria to score smear layer removal
• Score 1: No smear layer; orifice of dentinal tubules patent
• Score 2: Small amount of smear layer and some dentinal tubules open
• Score 3: Homogeneous smear layer along almost the entire canal wall; only very few dentinal tubules open
• Score 4: Entire root canal wall covered with a homogeneous smear layer; no open dentinal tubules
• Score 5: A thick, homogeneous smear layer covering the entire root canal wall.

Criteria to score debris removal
• Score 1: Clean canal wall; only very few debris particles
• Score 2: Few small conglomerations
• Score 3: Many conglomerations: <50% of canal wall covered
• Score 4: >50% of canal wall covered
• Score 5: Complete or nearly complete covering of the canal wall by debris.

The degree of evaluation was scored in a blind manner based on an Five-Grade Scale by a technician who was not informed of the true nature and purpose of these experiments. Then, the smear layer scores recorded were performed using the statistical analysis.

Results

The data recorded from the scanning electron microscopic pictures were statistically analyzed using the Kruskal-Wallis test and Mann-Whitney U-test.

The results of the study showed a statistically significant difference in the mean smear layer values between Group I, II, and III at the coronal, middle, and apical third. The intergroup comparison of mean smear score at the coronal level was significantly more among Group I (17% EDTA) as compared to Group II (diode) and Group III (Er:YAG) with (P = 0.027 and 0.008), respectively. The intergroup comparison of mean smear score at the middle level was significantly more among Group I (17% EDTA) compared to Group II (diode) and Group III (Er:YAG) with (P = 0.041 and 0.008), respectively. The intergroup comparison of mean smear removal score at apical level was significantly more among Group I (17% EDTA) compared to Group II (diode) and Group III (Er:YAG) with (P = 0.032 and 0.008), respectively.

The photographs [Figure 1a-f] were then analyzed using the three specific criteria:
(Er:YAG) with P value (0.004 and <0.001, respectively). The intergroup comparison of mean smear removal score at an apical level among Group II (diode) and Group III (Er:YAG) was statistically significant with a value of \( P = 0.727 \) [Tables 1, 2 and Graph 1].

There was no statistically significant difference in the debris score at coronal and middle third between the three groups, but at the apical third, there was a statistically significant difference in the mean debris score. The intergroup comparison of mean debris removal score at apical third was significantly more among Group I (17% EDTA) compared to Group II (diode) and Group III (Er:YAG) with \( P = 0.009 \) and 0.002, respectively. The intergroup comparison of mean debris removal score at apical third among Group II (diode) and Group III (Er:YAG) was significant with \( P \) value (1.000) [Tables 3, 4 and Graph 2].

### Discussion

The smear layer containing bacteria and bacterial products produced by instrumentation in infected root canals might provide a reservoir of irritants.\[^{13}\] This layer constitutes a negative influence on the sealing ability of obturated canals since it is a porous and weakly adherent interface between the obturation material and the dentin wall. Thus, the complete removal of the smear layer will be consistent with the elimination of irritants from the pulp space. Moreover, rotary instruments may pack debris further into the dentinal tubules, thus, making it more difficult to remove with irrigation. Therefore, it is recommended by several clinicians that irrigants with antibacterial effects/or chelating agents to remove debris as well as the smear layer be used.

To date, NaOCl is the most accepted root canal irrigant due to its antibacterial efficacy and its tissue dissolving capabilities. Different studies have indicated that NaOCl is not an efficient smear layer remover. The regimens of NaOCl and EDTA solutions have been advocated to effectively remove soft-tissue remnants as well as organic and inorganic smear layer. Bekir Öğuz Aktener and Ugur Bilkay.\[^{14}\] evaluated the efficacy of smear layer removal after irrigation with 10 ml of 15% EDTA followed by 10 ml of 3% NaOCl solutions.

### Table 1: Smear layer removal score of Group I, II, and III at coronal, middle, and apical third using the Kruskal-Wallis test

| Smear layer score | Mean±SD | \( P \) |
|-------------------|---------|-------|
|                   | Group I (17% EDTA) | Group II (diode) | Group III (Er:YAG) |
| Coronal level     | 1.80±0.63       | 2.00±0.42       | 1.10±0.32          | 0.006* |
| Middle level      | 2.00±0.67       | 1.40±0.52       | 1.20±0.42          | 0.008* |
| Apical level      | 2.40±0.70       | 1.50±0.53       | 1.20±0.42          | <0.001* |

*Significant difference. SD=Standard deviation; EDTA=Ethylenediaminetetraacetic acid; Er:YAG=Erbium: yttrium-aluminum-garnet

### Table 2: Intergroup comparison of mean smear layer removal score at coronal, middle, and apical third using the Mann-Whitney U-test

| Inter group comparison | Smear layer (P) |
|------------------------|-----------------|
|                        | Coronal | Middle | Apical |
| Group I (17% EDTA)     | Group II (diode) | 0.027* | 0.041* | 0.004* |
| Group I (17% EDTA)     | Group III (Er:YAG) | 0.008* | 0.008* | <0.001* |
| Group II (diode)       | Group III (Er:YAG) | 1.000  | 1.000  | 0.727  |

Mann-Whitney U-test. *Significant difference. EDTA=Ethylenediaminetetraacetic acid; Er:YAG=Erbium: yttrium-aluminum-garnet

### Table 3: Debris removal score of Group I, II, and III at coronal, middle, and apical third using the Kruskal-Wallis test

| Debris score | Mean±SD | \( P \) |
|--------------|---------|-------|
|              | Group I (17% EDTA) | Group II (diode) | Group III (Er:YAG) |
| Coronal level | 1.50±0.53       | 1.20±0.42       | 1.10±0.32          | 0.116 |
| Middle level  | 1.70±0.48       | 1.40±0.52       | 1.20±0.42          | 0.078 |
| Apical level  | 1.90±0.32       | 1.30±0.48       | 1.20±0.42          | 0.001* |

*Significant difference. SD=Standard deviation; EDTA=Ethylenediaminetetraacetic acid; Er:YAG=Erbium: yttrium-aluminum-garnet

### Table 4: Intergroup comparison of mean debris removal score at coronal, middle, and apical third using the Mann-Whitney U-test

| Groups          | Debris removal (P) |
|-----------------|--------------------|
|                 | Coronal | Middle | Apical |
| Group I (17% EDTA) | Group II (diode) | 0.392  | 0.509  | 0.009* |
| Group I (17% EDTA) | Group III (Er:YAG) | 0.142  | 0.079  | 0.002* |
| Group II (diode)  | Group III (Er:YAG) | 1.000  | 1.000  | 1.000  |

Mann-Whitney U-test. *Significant difference. EDTA=Ethylenediaminetetraacetic acid; Er:YAG=Erbium: yttrium-aluminum-garnet

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Graph 1: Graphical representation of mean smear layer removal score of Group I, II, and III at coronal, middle, and apical third
The ability to effectively clean the endodontic space is dependent on both instruments and irrigation. Endodontic instruments in themselves vary in their debris removal efficacy due to their specific flute design. Takeda et al. observed inadequate volume and/or penetration of the solution into the apical portion of the canal during irrigation may be because of root canal complexity and the presence of tortuous canals. Thus, showing that the cleaning action of the EDTA solution was less efficient near the apex leading to increased smear scores. Crompton et al. showed that the smear layer was effectively removed with a final rinse of 1 mL of 17% EDTA for 1 min followed by 3 mL of 5.25% NaOCl. Chopra et al. also showed that the smear layer was not completely removed from all of the instrumented root canals by using 17% EDTA according to this protocol, particularly in the apical third of the root because the smaller size of the apical third compared with the other thirds impedes the circulation and action of the irrigating solutions. Consequently, it is important to use these new methods, such as ultrasonic devices, laser activation, and irrigation for improving the efficiency of low-volume chelating agents. Laser therapy has shown a great promise in removing the smear layer in endodontics: Argon, CO₂, Nd:YAG, Er:YAG, and erbium, chromium-doped yttrium, scandium, gallium and garnet lasers have been reported to be effective. Laser applications that use different wavelengths have also been proposed as adjuncts to conventional endodontic cleaning procedures. In the present study, evaluation by SEM revealed that all the laser treatments utilized had the ability to remove the smear layer. The samples that were laser activated while using EDTA as irrigating solution produced the smear-free surfaces even in the apical one-third of the canals. This can be attributed to the ability of the laser-driven irrigation used in this investigation to create cavitation. Cavitation is defined as the formation of vapor or a cavity that contains bubbles inside a fluid. This process allowed the irrigants to access the apical third of the canal more easily. In addition, the cavitation bubbles expand, become unstable, and then collapse which is termed as implosion. The implosion will have an impact on the surfaces of the root canal, causing shear forces, surface deformation, and the removal of surface material. Ebeling and Lauterborn observed that the laser-generated pressure waves move at high speed and appear to enhance the action of endodontic irrigants in terms of removal of the smear layer.

In Moon et al.’s study, activation with a 1320 nm Nd:YAG laser with NaOCl or EDTA was found to be much better than NaOCl for sealer penetration into dentinal tubules. In the present study, an 808 nm diode laser was used with 17% EDTA. Interestingly, in the middle and apical thirds of root canals, the highest number of open dentinal tubules was observed in the group with 20 s of agitation using the laser. In another study, a diode laser of 980 nm wavelength was used, and the results obtained were similar. Compared with a conventionally instrumented root canal wall, a canal wall prepared by mechanical instrumentation combined with a diode laser was significantly cleaner. Furthermore, the apical third of the root canal wall was cleaner than the middle third. This can be attributed to the narrower canal in the apical third (i.e., the narrower the root canal was, the closer the laser tip to the canal), thus melting and evaporating the smear layer easily. However, unlike the findings reported by Moritz et al., notable dentin fusion or the closure of dentinal tubules was not observed in the present study. Many different laser wavelengths have been investigated for use in the field of endodontics. Among them, Nd:YAG laser is the most frequently used and accepted one. The diode laser is portable, compact, and efficient for practical applications. Moreover, its thin and flexible fiber benefits access into the narrow and curved root canals. It was also verified in the present study that RCP combined with 808-nm wavelength laser was able to clean the canal walls and open dentinal tubules as well as reduce the apical leakage. As the penetration depth by this laser is lower than that of Nd:YAG laser (wavelength 1064 nm), the risk of thermal side effects seems to be lower. Therefore, the encouraging results of the present study suggest that the diode laser is potentially a valid and safe tool for endodontic treatment.

The Er:YAG laser irradiation has produced melted and sealed dentinal tubules, accompanied by the removal of the organic matrix, resulting in the reduction of fluid permeability, sterilization of the contaminated root apex, and increased resistance to root resorption. These two types of lasers (CO₂ and Er:YAG) showed the ability to remove the smear layer, and the surfaces presented a specific characteristic in each of the laser types. The time used in a study by Paghdwala was 23 s for CO₂ laser and 30 s for Er:YAG laser, which were the minimum times to obtain the most effective result for each laser. When comparing the different lasers (CO₂, Nd:YAG, and Er:YAG lasers) for irradiating teeth, it has been demonstrated that the Er:YAG laser...
caused less thermal damage than either the Nd:YAG or CO2 laser. Moshonov et al.[26] demonstrated that argon laser irradiation removed debris more effectively than NaOCl. Khan et al.[27] reported that laser energy could vaporize debris but it could create crater and carbonization areas on the root canal. Arslan et al.[28] confirmed that Er:YAG laser removed more superficial debris in all thirds and diode laser in the middle and apical thirds than NaOCl and citric acid. It is well established that the irradiation by the Nd:YAG laser is absorbed by the mineral structures. Er:YAG laser irradiation is absorbed by the water, and it ablates the hard tissues. However, the irradiation by the diode laser irradiation is poorly absorbed by the hard tissues. Kivanç et al.[29] found that Er:YAG and Nd:YAG lasers were not effective in removing the debris and smear layer. In the present study, it was found that Er:YAG and diode laser systems are efficient for the removal of debris. This finding is harmonious with those of the study by Takeda et al.

From the present study, it can be concluded that laser treatment along with the irrigating solution is effective in cleaning the root canal system. However, a variety of factors affect the cleaning ability of root canal walls such as the type of laser wavelength, pulse duration, exposure time, laser power, type of instrumentation, amount of water and air steam created, type of irrigants, and the distance from the tooth surface to laser tip. The undesirable side effects that occur with the use of lasers are moderate, and within limits, this technique is regarded to be safe.[29] In the present study to avoid some of the side effects associated with the use of a laser, laser-driven irrigation was performed by hovering the laser tip around the orifice of the root canal system instead of placing the tip within the canal itself. During laser irradiation, the root canal was irrigated continuously to maintain the hydration level.

Further studies should be carried out to improve the effects of lasers and its combination with different irrigating solutions in removing the smear layer from the root canal walls. Further research on diode laser for the practical use in endodontics is needed before it is clinically applied.

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**Conflicts of interest**
There are no conflicts of interest.

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