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ASSESSMENT OF MODIFICATION APPROACH OF LASER FIBER OPTIC TIP DESIGNED TO ACHIEVE EFFECTIVE LATERAL EMISSION CAPABILITIES

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ABSTRACT

Objective: During root canal or periodontal treatment, directing laser energy onto the walls of the root canal is essential for effective disinfection. This study assessed the performance of three designs of fiber modifications that modified to allow the laser beam skip in lateral direction to be used in endodontic applications and investigated the irradiation effects on the walls on root canal using scanning electron microscope in comparison to that irradiation using the endodontic fiber optic provided by manufacturer. **Material and Methods:** Twenty fiber optic subdivide into two main groups as conventional endodontic 200 μ tips and the second group was 400μ fiber optic that modified into 3 design of modification as one, two and three windows. All fiber optics was used in irradiation of endodontically cleaned natural teeth and scanned by SEM. **Result:** There was a significant difference between the irradiated teeth by the proposed modified fiber optics in comparison to that irradiated by the conventional endodontic fiber optic tips. **Conclusion:** Fiber designs with lateral emission capabilities may be useful for various endodontic applications.

KEY WORDS: Endodontic, Fiber optics, Laser, Lateral emission, Side firing.

INTRODUCTION

The elimination of microorganisms and remnants from the root canal space is one of the most challenging problems in endodontic treatment process. This problem based mainly on the limitations of the conventional chemo-mechanical techniques, therefore there were many attempts to find new techniques that have the promising potential for higher levels in disinfection efficiency as the usage of laser.

Laser light can penetrate areas of canals where irrigating and disinfecting solutions cannot reach, such as fins, deltas, and lateral canals. (1) Selective photo thermolysis occurs when laser energy is applied into the root canal system. For water-absorbing laser wavelengths, rapid expansion of water contained within microorganisms leads to their rupture, while for the visible and near-infrared wavelengths, primary absorption of laser energy into porphyrins, melanin, and other pigments occurs. The increase in temperature then denatures proteins and this renders the organisms unviable (2).

When lasers are used in endodontics or periodontics, the same issue of controlling the forward effect arises because most current fibers employ plain forward emitting ends. Placing such fiber tips close to the apical construction of the root canal increases the risk of perforations or

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transportation of the canal and also increases the likelihood of deleterious thermal changes in the adjacent periapical tissues. [(3)] To further complicate the issue, plan ended fibers suffer problems in delivering adequate levels of laser energy due to the modifying effects of water film or dentinal morphology within the root canal. These factors explain in part why different energy settings are recommended for the same procedure when water irrigation or water spray is used while lasing within the root canal [(4-6)].

Ideally, lasers to be used in endodontics for smear layer removal, canal shaping, and disinfection should employ fiber-optic tips which are side-firing so that they can deliver laser energy laterally onto the canal walls. The tip design should also prevent unwanted effects of the laser past the apical foramen. Spherical and cylindrical tips with a near-360-degree emission profile (isotropic tips) have been used for photoactivated disinfection of root canals using low-intensity visible red light, but the designs are not suited to delivering high-intensity pulses in the near (780-1400 nm) and mid-infrared (1400-3000 nm) range. An alternative method of achieving a 360-degree emission profile is using embedded titanium dioxide which can disperse near-infrared laser energy laterally along the length of the fiber tip, however such tips are expensive and are too large (0.6 mm) for clinical use in endodontics [(7, 8)].

Therefore, there's still a great need for a modified fiber optic that has the capability of emitting the laser beam toward the walls of the endodontic canals as the one we proposed in this study to overcome the drawbacks of the available models of endodontic tips that are in use now a days.

MATERIAL AND METHODS

The materials used in this study were: two different types of fiber optics were selected for this study, namely:

a. BIOLASE® Diode laser tip (E4-9 EZ) with diameter of 400μ and length 9mm

b. BIOLASE® Diode laser tip (E2-20 EZ) with diameter of 200μ and length 20mm.

The fiber optics were grouped in two main groups according to type and modification as shown in table (1).

Fiber Optic Modification Sequence:

In this study we made a modification on diode laser tip (BIOLASE® E4-9 EZ, BIOLASE, Inc. USA) by creating a side window with (5mm x 0.4mm) dimensions to allow the lateral emission of laser beam. This modification was designed on 3D software and executed in successive steps aiming to create a window on the side of the fiber optic to allow for the skipping of the laser light beam from the side of the fiber optic. This modification was made by creating a window in the jacket cover followed by the cladding removal form the area underneath the window.

TABLE (1) Number of teeth, fiber optic tips and laser irradiation technique grouping for this experiment

Variable	Unlased sample	Lased by 200µ endodontic tip	Lased by 400 µ endodontic tip		
Tip type		Conventional endodontic tips	Modified tip to 1 window design	Modified tip to 2 window design	Modified Tip to 3 window design
Technique		0.1W, speed of 1mm/ sec	1W for 10 sec.	1W for 10 sec.	1W for 10 sec.
No. of teeth	5 teeth	5 teeth	5 teeth	5 teeth	5 teeth

The creation of this window in the jacket covering, started with marking the points of guidance in cutting through jacket covering around the fiber optic, this marking points was made by fixing the fiber optic on an endometer and created small grooves on each mm of jacket covering using surgical blade (No.11) under 600x magnification using digital microscope (Mustool© G600, China), and the creation of window was made by connecting the grooves into the design dimensions.

The cladding removal was made by the combination of three cladding removal techniques started by surface etching using 37% Phosphoric Acid Etchant Gel (Meta Etchant©, META BIOMED CO. LTD. Korea) applied over the area of window creation for 1 minute. The second step was submersion of the fiber in a solution mix 40/60 acetone/methanol inside a plastic syringe help in upright position for 7.2 minutes. The third step was Fiber window surface roughness with finishing bur (Mani TR-13EF D.S ISO 198/ 018) on high-speed contra-angle handpiece.

In this experiment we aimed to find the microscopic changes on dentinal tubules and smear layer on the surface of the inner wall of the endodontic canal after laser irradiation by modified fiber optics in comparison to that founded after irradiation using the conventional endodontic tips provided by the manufacturer.

Tooth preparation:

Six Maxillary single rooted anterior teeth freshly extracted, were selected. Each sample was numbered sequentially from 1 to 6. All the teeth were cleaned from any deposits or calculus were on the root surface and stored in 0.1% thymol at 4°C in the refrigerator until used.

All the teeth were checked radiographically for standardization to fulfill following characteristics: straight roots at least 15 mm long, single canal with no resorption or calcification and completely formed apex.

All the sample teeth were washed thoroughly using normal saline to remove any residual thymol and endodontically cleaned and shaped in the same sequence of the second experiment. The smear layer was removed by a 1 min application of 18% ethylenediaminetetraacetic acid (EDTA). Teeth were rinsed with distilled water and immediately irradiated with laser.

Laser Irradiation:

The diode laser was attached to the modified 400μm fibers which had had 1 window, 2windows, or 3 windows tips. The fibers were fixed in position so that the fiber end was positioned to make the modification area of the fiber facing middle third of the internal wall of the root canal. Laser exposure parameters were 1W in continuous wave mode for 10 seconds. And control sample irradiated using endodontic tips following the manufacturer protocol (0.1 W power and 1 mm in each seconds)

SEM Examination:

The samples were dried for 24 hours and then sputter-coated with gold-palladium alloy to prevent charging of the surface, to promote the emission of secondary electrons so that the specimen conducts evenly, and to provide a homogeneous surface for analysis and imaging. All samples observed by SEM with electron prompt head at 30 kV. The entire area 5 mm in the middle third was examined in each sample. The magnification used for analysis was 2500x representative SEM images at this magnifications was recorded as a control at a fixed distance of 2 mm from the working length for each sample. Images were recorded digitally in lossless jpeg format and enhanced into high resolution using ImageJ software to enhance local contrast for the best resolution possible from the images.

RESULTS

The main purpose of this experiment was the evaluation of dentin surface of the root canal structural changes caused by laser irradiation by the conventional endodontic tips and the modified tips in comparison to the normal unlased one.

In this experiment we made the SEM of the dentinal wall of the root canal in the targeted area and scans was made in magnifications (2500x) for clear investigation of the laser irradiation effects.

The main findings on the SEM were focused on the following:

1. Narrowing of dentinal tubules.
2. Areas of melting of the dentin and a total occlusion of tubules.
3. Areas of dentinal ablation and formation of dentin cuts.
4. Dentinal destruction and surface cracks formation.

a- SEM of Unlased group:

In the SEM in 2500x magnification of the nonirradiated control group presented open tubules, absence of the smear layer, and a regular aspect, which is a standard pattern of dentin treated with EDTA as shown in figure (1).

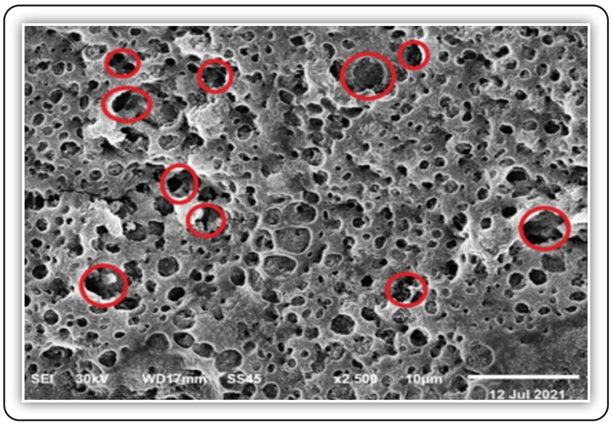

FIG (1) The non-irradiated control group presented open tubules (red circles), absence of the smear layer, and a regular aspect, which is a standard pattern of dentin treated with EDTA.

b- SEM of irradiated dentin by endodontic radial firing tips:

In the SEM in 2500x magnification of the irradiated dentin surface using the endodontic fibers following the manufacturer protocol, it was founded surface structural changes caused by laser irradiation was a narrowing and some signs of occlusion of the dentinal tubules, and there was no areas of dentinal ablation and formation of dentin cuts or dentinal destruction, or surface cracks formation as shown in figures (2).

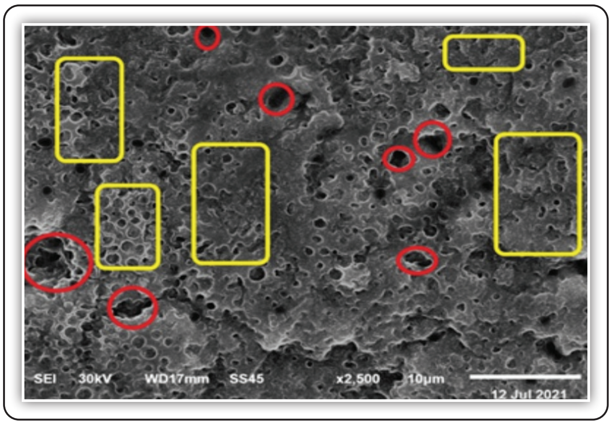

FIG (2) The irradiated dentin surface endodontic fibers following the manufacturer protocol showed surface structural changes caused by laser irradiation. A narrowing and some signs of obliteration of the dentinal tubules (yellow squares) was observed but there was many of dentinal tubules still open (red circles) at delivered output power recommended by manufacturer.

c- SEM of irradiated dentin by modified fiber optic tips one-window design

In the SEM in magnification 1000x, 1500x, 2000x and 2500x magnification of the irradiated dentin surface using the modified one-window design fibers, it was founded surface structural changes caused by laser irradiation was some signs of occlusion of the dentinal tubules, and there was areas of dentinal ablation and formation of dentin cuts, dentinal destruction, and surface cracks formation as shown in figure (3).

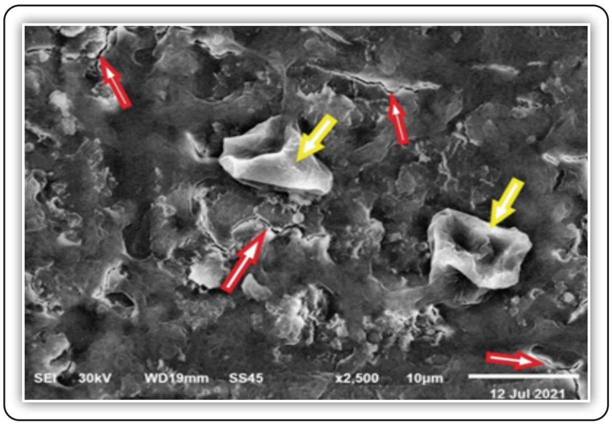

FIG (3) SEM analysis of the irradiated dentin with the one-window design modified fiber. The dentin showed melting areas and a total occlusion of tubules and provoked some areas of dentinal ablation (yellow arrows) and destruction in form of surface cracks (red arrows).

d- SEM of irradiated dentin by modified fiber optic tips two-windows design:

In the SEM in 2500x magnification of the irradiated dentin surface using the modified two-windows design fibers, it was founded surface structural changes caused by laser irradiation was some signs of occlusion of the dentinal tubules, and there was areas of dentinal ablation and formation of dentin cuts larger than that founded in one-window design and the abled dentin cuts aggregate and fussed in clusters, and also there was a dentinal destruction, and surface cracks formation as shown in figure (4).

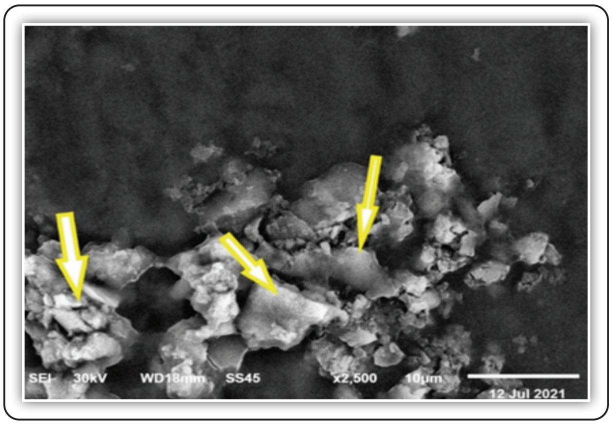

FIG (4) SEM analysis of the irradiated dentin with the two-window design modified fiber. The dentin showed melting areas and a total occlusion of tubules and provoked some areas of dentinal ablation and destruction. The abled dentin cuts aggregate and fussed in clusters (yellow arrows).

e- SEM of irradiated dentin by modified fiber optic tips three-windows design:

In the SEM in magnification 1000x, 1500x, 2000x and 2500x magnification of the irradiated dentin surface using the modified three-windows design fibers, it was founded surface structural changes caused by laser irradiation was some signs of occlusion of the dentinal, and there was areas of dentinal ablation and formation of dentin cuts tubules smaller than that founded in two-windows design and the abled dentin cuts aggregate and fussed in clusters, and also there was a dentinal destruction, and surface cracks formation as shown in figure (5).

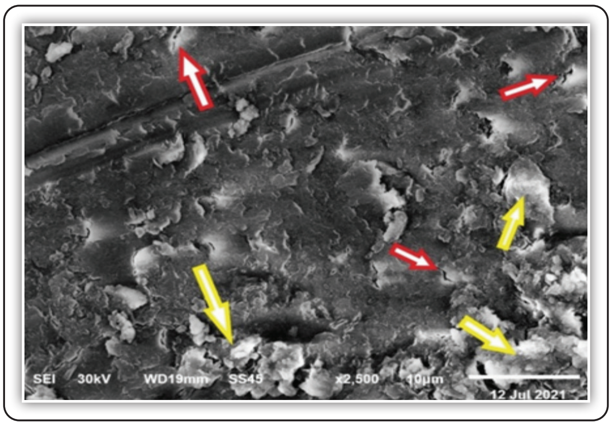

FIG (5) SEM analysis of the irradiated dentin with the three-window design modified fiber, The dentin showed melting areas and a total occlusion of tubules and provoked some areas of dentinal ablation and destruction (red arrows). the abled dentin cuts aggregate and fussed in clusters (yellow arrows)

DISCUSSION

Design concept of fiber modification:

Modification of fiber optic by removal of side cladding to allow for skipping path for the laser beam from the side of the fiber optic is not a new concept originated by us, but we followed the previous attempts, and we add our designs of modifications to this concept to provide more effective and controllable models, that we hope to be as good as what is the endodontist needs to achieve by optimum cleaning and sealing of the root canal without ledging, perforation or endangering the apical periodontium by the forward emission of laser beam like what is usually happening with the traditional forward emitting laser fiber optics available to date.[9]

Previous attempts to produce side firing tips with a safe tip, have used optical fiber, with the terminus polished at an angle of 45 degrees, [10] also, it was described that the surface modification to optical fibers increases the lateral energy emissions along the length of the fiber tip, to facilitate endodontic laser applications. [11] While these fibers are suitable for directly delivering laser energy on the walls of the canal, they also have forward emissions. Thus, some of the shockwaves produced are directed in a forward direction. Tips with side firing capabilities and with a "safe tip" design also reported to be useful for a number of dental applications as in endodontics, such tips could preferentially ablate the walls of the root canal, with little or no energy apically directed, without risk of laser energy or shock waves passing toward the apical constriction at the end of the root. [12]

We built upon this previous attempt to make the modification of the of the fiber optic to be more controlled by specific dimensions rather than the complete removal of the cladding from the entire sides of the fiber optic, and we made just windows to let the light to skip through small area directly to the targeted zoon. The window we created on the side of the fiber optic was designed in on large window with the dimensions of 0.4 x 5 mm to get will defined exposure areas with specific dimensions to help in further upcoming research in modifications of the fiber optics for the usage in endodontics.

The concept of chemical removal of the cladding:

The most of the previous attempts to make chemical etching of the fiber optic was mainly depends on the use of solution of hydrofluoric acid (HF) in different concentrations, but we founded that the effect of HF on the selected type of the fiber optic for this study was very aggressive so we decided to use the phosphoric acid gel instead, and followed by chemical etching by a mixture of acetone/methanol, and the final step was mechanical roughness using finishing bur to ensure the proper removal of the cladding from the windows areas on the fiber optic. [13, 14]

1- Scanning electron microscope scanning:

This step of the study was the concluding and the most related to the direct effect of the modifications we mad in the fiber optics to the irradiated dentin in the root canal, so the main purpose of this experiment was the evaluation of dentin surface of the root canal structural changes caused by laser irradiation by the conventional endodontic tips and the modified tips in comparison to the normal unlased one.

The SEM could be regarded as the point of the final proof and the concrete evidence for what we really got from the modification of the fiber optic, so we had to make this investigation as clear as possible through the following points:

a. All tooth samples were cleaned with EDTA to remove the smear layer just before the laser irradiation process to make it clear that, any changes would happen to the dentin would be as a result of the laser irradiation.

b. The SEM images provided us with a lot of details, so we had to specify the criteria that we would looking for in all SEM images to make the analysis more specific and into the points. This points were summarized in the following:

1. Narrowing of dentinal tubules.
2. Areas of melting of the dentin and a total occlusion of tubules.
3. Areas of dentinal ablation and formation of dentin cuts.
4. Dentinal destruction and surface cracks formation.

The results of the SEM images showed that the endodontic tips provided by the manufacturer done a nice job in narrowing the dentinal tubules and some levels of sealing of dentinal tubules, but it was not a huge step forward or a great add value to the traditional endodontic results since the SEM images showed that there was still decent amount of open dentinal tubules and lateral canals that may leads to the expected drawbacks that we already found in the traditional endodontic cleaning without the use of laser at all.

In the other hand the SEM images of the irradiated dentin with the modified fiber optics show a dramatic changes in the amount of the dentinal tubules sealing, but there was some drawback as the formation of smear layer resulted from dentinal ablation and formation of dentin cuts, and the dentinal destruction and surface cracks formation and this drawbacks could be resulted from the high power level of the laser beam we used in this experiment that will lead us to make more studies in the future to find the optimum amount of power that we can use with the modified tips to get the advantage of good dentinal tubules seal without drawback as dentinal ablation and surface cracks.

CONCLUSIONS

Within the limitations of this study the following conclusions might be drawn:

1. The creation of side windows on the lateral wall of the laser fiber optic by removal of cladding creating a skip way for the laser beam can be regarded as an effective way for modification of fiber optics to be used in endodontic irradiation for disinfection and sealing of the dentin of the root canal.
2. The proposed designs in this study have the ability to produce a thermal effect that can rise the temperature of the targeted area by irradiation.
3. If the irradiation period was longer than 10 seconds in 1W power using the proposed designs in this study will leads to increase of the temperature to levels higher than 40°C that may endanger the surrounding tissue around the root.

The irradiation by the proposed designs for 10 seconds in 1W power may leads to dentin ablation and surface cracks in the dentin.

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