The inhibitory effect of CW CO₂ laser irradiation on caries like lesion initiation in sound root: an in vitro study

Muthenna Sh. Rajab. BDS, M.Sc*

Abstract:

This study aimed to assess the caries-preventive potential of various CW CO₂ laser parameters, and to explore the effect of the laser power density and the exposure time on the caries inhibition activity.

Roots of extracted human premolar teeth were irradiated with three various power densities (31.83, 63.59, and 127.32) W/cm². The CO₂ laser system emitted laser with 10.6μm in wavelength. All roots were subjected to caries like lesion formation by 3.5 pH lactic acid for 21 days. The roots after that were sectioned into ground cross sections and the lesion depths were measured using a graticule under a polarizing microscope.

CW CO₂ laser preventive treatments inhibited caries like lesion progression up to 79%. This effect was improved with increased power density within the limits of the examined laser parameters.

Conclusion:

1- CW CO₂ laser resulted in a significant inhibition of the root caries like lesion. The inhibitory effect depends upon power density of the laser beam. The optimal chopped CO₂ laser parameters used for caries inhibition purpose are achieved with 127.32 W/cm² power density.

Key words:

CW CO₂ laser, laser irradiation, caries like lesion, caries inhibition.

Introduction:

Possible applications of laser in dentistry have been suggested and studied for more than 30 years. Lasers have become more popular with dentists for soft-tissue surgery in recent years and were approved for limited hard tissue treatment of dental hard tissue to increase their resistance to caries (1-4).

In 1966, Stern et al (1), Sognnaes and Goodman described the effect of high-energy ruby laser on enamel. They report that pulses of 500 μs produced crater that were characterized by

* Assistant lecturer in the Department of Prosthetic Dentistry, College of Dentistry, Al-Mustansiria university
melting and recrystallization of the enamel. This enamel was less permeable than unlosed enamel, resulting in reduced subsurface demineralization by lactic acid. Increased resistance of lased enamel to acid dissolution has also been demonstrated with low energy CO$_2$ and Nd: YAG laser light (1, 3, 5). Yamamoto and Sato suggested that the increased acid resistance was due to a physical alteration in enamel permeability (3). Nelson, Jongebloed and Featherstone suggested that the inhibitory effect was probably due to a combination of laser induced surface sealing, compositional changes in the enamel, and effects on the organic matrix (6).

The inhibitory effect of laser on surface demineralization may be applied in preventive dentistry, for example, the low energy laser irradiation of occlusal surface as a means of preventing fissure caries, and debridement of incipient caries (6-7). In addition, powdered hydroxyapatite and various fluorides have been fused to enamel as potential fissure sealants (8).

In recent years, the effect and interaction of laser with dental hard tissues have been studied carefully. The overall objective of these was to determine optimal laser parameters for clinical caries prevention. These parameters should decrease the enamel susceptibility to caries without jeopardizing the pulp vitality. These studies demonstrated that small changes in these laser treatment parameters could result in significant change in the caries inhibition achieved (9-11).

The aim of this study is to evaluate the CW CO$_2$ laser inhibition of the root artificial caries like lesion within various parameters, and to explore the effect of the power density of this laser on the caries inhibition activity in order to determine the optimal CW CO$_2$ laser parameters used for this purpose.

**Materials and Methods:**

A total of twenty-four extracted newly erupted human premolar teeth were selected for this in vitro study. Following a fluoride-free prophylaxis, these teeth were examined under a light microscope at a magnification of 30X to ensure that they were defect-and caries free. The surface of each root was covered with acid-resistant varnish leaving two circular windows of approximately (4-6) mm in diameter.

These teeth were separated in to 3 groups of 3(A-C) according to which laser parameters were applied, in addition to one group served as a control. In 1st group, the spot diameter is the variable. In 2nd group, the variable is the exposure time. The power is the variable in the 3rd group. Subgroups A1,
A2 and A3 have the same parameters so they were considered as one subgroup. The samples were irradiated using CW CO₂ laser (BLITZ 50 SV, as a medical laser, Vicenza, Italy) with 10.6 μm wavelength (Table 1).

**Table (1): Sample groups and the related chopped CO₂ laser parameters.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Power (W)</th>
<th>Exposure time (s)</th>
<th>Spot Diameter (mm)</th>
<th>Power Density (W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>4</td>
<td>0.8</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B1</td>
<td>4</td>
<td>0.8</td>
<td>2.83</td>
<td>63.59</td>
</tr>
<tr>
<td>C1</td>
<td>4</td>
<td>0.8</td>
<td>4</td>
<td>31.83</td>
</tr>
<tr>
<td>A2</td>
<td>4</td>
<td>0.8</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B2</td>
<td>4</td>
<td>0.4</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>C2</td>
<td>4</td>
<td>0.2</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>A3</td>
<td>4</td>
<td>0.8</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B3</td>
<td>2</td>
<td>0.8</td>
<td>2</td>
<td>63.59</td>
</tr>
<tr>
<td>C3</td>
<td>1</td>
<td>0.8</td>
<td>2</td>
<td>31.83</td>
</tr>
</tbody>
</table>

Caries like lesions were created on all roots by immersing them in lactic acid solution (pH 3.5) at 37°C. following a period of 21 days, cross sections were prepared for polarizing microscope evaluation. Lesion depths were measured using a graticule supplied with the polarizing microscope. The measured lesion depths included the surface zone and the body of the lesion.

**Results:**

Table (2) gives the variation in mean lesion depths and caries inhibition.
A2 and A3 have the same parameters so they were considered as one subgroup. The samples were irradiated using CW CO₂ laser (BLITZ 50 SV, as a medical laser, Vicenza, Italy) with 10.6 μm wavelength (Table 1).

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<tbody>
<tr>
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<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B1</td>
<td>4</td>
<td>0.8</td>
<td>2.83</td>
<td>63.59</td>
</tr>
<tr>
<td>C1</td>
<td>4</td>
<td>0.8</td>
<td>4</td>
<td>31.83</td>
</tr>
<tr>
<td>A2</td>
<td>4</td>
<td>0.8</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B2</td>
<td>4</td>
<td>0.4</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>C2</td>
<td>4</td>
<td>0.2</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>A3</td>
<td>4</td>
<td>0.8</td>
<td>2</td>
<td>127.32</td>
</tr>
<tr>
<td>B3</td>
<td>2</td>
<td>0.8</td>
<td>2</td>
<td>63.59</td>
</tr>
<tr>
<td>C3</td>
<td>1</td>
<td>0.8</td>
<td>2</td>
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</tr>
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Caries like lesions were created on all roots by immersing them in lactic acid solution (pH 3.5) at 37°C, following a period of 21 days, cross sections were prepared for polarizing microscope evaluation. Lesion depths were measured using a graticule supplied with the polarizing microscope. The measured lesion depths included the surface zone and the body of the lesion.

**Results:**

Table (2) gives the variation in mean lesion depths and caries inhibition
percentage by various CW CO\(_2\) laser parameters. The decreased lesions represent up to 79% inhibition of the caries process.

**Table (2): Sample groups and the related caries inhibition percentages.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Lesion Depth ((\mu m))</th>
<th>Caries inhibition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>125</td>
<td>79</td>
</tr>
<tr>
<td>B1</td>
<td>558.33</td>
<td>4</td>
</tr>
<tr>
<td>C1</td>
<td>616.67</td>
<td>-5</td>
</tr>
<tr>
<td>Group II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>125</td>
<td>79</td>
</tr>
<tr>
<td>B2</td>
<td>308.33</td>
<td>47</td>
</tr>
<tr>
<td>C2</td>
<td>335</td>
<td>43</td>
</tr>
<tr>
<td>Group III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>125</td>
<td>79</td>
</tr>
<tr>
<td>B3</td>
<td>433.33</td>
<td>26</td>
</tr>
<tr>
<td>C3</td>
<td>433.33</td>
<td>26</td>
</tr>
<tr>
<td>Control</td>
<td>583.33</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig 1, 2 and 3 represent the behavior of the caries inhibition percentage as a function of the CO\(_2\) power density and the exposure time for the three groups. They show that there is a direct relationship between them. The higher the power density (127.32 W/cm\(^2\)) produces the higher caries inhibition percentage (79%).
Fig (1): The relation between the power densities and the caries inhibition percentages in group I.

Fig (2): The relation between the exposure times and the caries inhibition percentages in group II.
Fig (3): The relation between the energy densities and the caries inhibition percentages in group III.

Discussion:

A single exposure to CW CO₂ laser irradiation of sound root resulted in signified reductions in lesion depth up to 79% inhibition percentage. These findings are in good agreement with those reported for caries like formation in teeth with argon \(^{12-15}\), Nd: YAG \(^2\, ^3\) and CO₂ laser \(^{16-21}\).

The enhanced caries resistance of root surface following laser irradiation may be due to many factors:

1. Alteration in the root surface composition: the organic content, the carbonate and water content of root surface are reduced. Reduction in the amount of carbonate increases root surface resistance to acid. The loss of water, carbonate and organic material reduces the lattice strain in lased root surface. This result in contraction of the a-axis of hydroxyapatite crystal and increases the resistance of hydroxyapatite to acid dissolution \(^{22}\).

2. Increased affinity of lased root surface for fluoride, phosphate and calcium ion uptake: this factor may improve the ability of sound root surface to resist a cariogenic challenge \(^{23}\).

3. Creation of microsieve network within the tooth structure: This may allowed the reprecipitation of
calcium, phosphate and fluoride released during caries formation (24-26).

4. Surface melting and recrystallization: This factor may lead to fusion of smaller root surface crystals into larger ones, thereby reducing the total surface area of the crystals and decreasing the solubility of the root surface to organic acid. In addition, these fused crystals may be composed of apatite with a lower carbonate content, which enhances the resistance to cariogenic challenge (27-29).

5. Decreased root surface permeability: The expanded denaturated proteins reduce micropores within the mineral structure (30, 31).


7. Formation of calcium fluoride surface deposits in the presence of exogenous fluoride. This surface coating may:-
   a. Act as diffusion barriers.
   b. Reduce root surface solubility in acidic condition.
   c. Act as reservoirs for fluoride rich reaction products.
   d. Affect microorganisms in plaque, as well as protein desorping (33-36).

Although the exact mechanism of caries resistance with laser irradiation is not clearly known, it seems to be a combination of the previously listed mechanisms at the same time, according to the depths and temperatures of the root surface layers. At the most inner layer there is a slight increasing in the temperature (60-100°C). The most prominent phenomena in this range of temperatures is the protein denaturation (37). This may lead to decrease the root surface permeability. The second deepest layer is characterized by reaching 100°C, which is the temperature of water evaporation. Therefore water molecules are removed from the root surface (37). Organic materials have been removed and ablated from the third layer when the temperature ranges from 100-650°C. The removal of the water molecules and the organic materials leads to formation of micropores. This gives us the right to suggest the creation of a microsieve network mechanism, when the released fluoride, calcium and phosphate ions reprecipitate within the micropores. The mechanism of increasing affinity of the lased root surface to fluoride, calcium and phosphate ions be applied also. At the same time the ablation of the water molecules and the organic material gives a reason to apply the alteration in the root surface composition mechanism. When the temperature range between 650°-1100°C at the fourth layer, the carbonate content of
the root surface is derived [38]. In this layer and the last two layers (2\textsuperscript{nd} and 3\textsuperscript{rd}), it may be true to suggest the alteration in the root surface composition mechanism. Melting and recrystallization of the hydroxyapatite crystals is the character of the fifth layer, when the temperature exceeds the melting point of the hydroxyapatite (1280°C). Superficial calcium fluoride deposits formation and bactericidal effect and elimination of the dental plaque also characterize the fifth layer, which are two other mechanisms of the caries resistance.

Although the artificial caries system used in this study creates lesions in root surface that are identical histologically to root surface caries formation in vivo, one must consider that this system subjects the root surface to a continuous aggressive, cariogenic challenge without periods of remineralization. In contrast caries formation in vivo is characterized by periods of demineralization interspersed with periods of remineralization with oral fluids. Despite the continuous cariogenic challenge, the lased root surface demonstrated a remarkable resistance to lesion initiation.

It is important to know that the all sets of laser parameters used in this study produce temperature increment less than 5°C at the pulp side [39]. The pulp vitality is not affected [40]. Cooling the surface of the tooth in vitro with water decreased the pulpal temperature change [41, 42]. The assumption is that in vivo, the temperature change would be lower than in vitro because of the effects of the saliva and the blood flow.

Conclusions:

From this in vitro study one can conclude that:

1) Short exposure time of CW CO\textsubscript{2} laser results in a significant inhibition of the enamel artificial caries like lesion.

2) The inhibitory effect depends upon the total power density of the laser beam. The optimal chopped CO\textsubscript{2} laser parameters used for caries inhibition purpose is achieved with approximately 127.32 W/cm\textsuperscript{2} power density.

References:


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