Formation of re-solidified layer on the surface of dental hard tissue by Er:YAG laser irradiation

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Abstract:
This paper deals with the formation of re-solidified layer on dental hard tissue by irradiation of a pulse Er:YAG laser beam. Extracted human enamel is used as a specimen, and titanium dioxide powder is applied to the surface of dental hard tissue as the absorbent. Er:YAG laser beam is led to the specimen with an optical fiber. The influence of powder thickness and laser condition on re-solidified layer is investigated experimentally. The result showed that the re-solidified layer was formed on the surface of dental hard tissue by irradiation of Er:YAG laser beam, and the sufficient layer thickness of titanium dioxide powder is 10-15 µm for formation of re-solidified layer.

Keywords: Er:YAG laser, re-solidified layer, titanium dioxide powder, dental hard tissue, layer thickness

1. Introduction

In dental treatment, Er:YAG laser beam with a wavelength of 2940 nm is generally used to remove the hard tissue for the cavity preparation and periodontal root canal. Additionally, Er:YAG laser beam has high absorption characteristic to the dental hard tissue which is including a crystallization water inside[1]. Hence, Er:YAG laser beam is possible to prepare the cavity without the significant thermal influence[2]. On the other hand, Nd:YAG laser beam with a wavelength of 1064 nm has a high transmittance characteristic to the hard tissue, and an absorbent is applied to the tissue surface to absorb the Nd:YAG laser effectively[3]. The cavity by Nd:YAG laser irradiation is prepared with heating of hard tissue. In the present dental treatment, re-solidified layer is generally formed on the surface of dental hard tissue by Nd:YAG laser beam irradiation. It is advocated that formation of re-solidified layer can add the acid resistance to enamel surface[4]. Figure 1 shows the prepared cavity by Er:YAG laser and Nd:YAG laser. When Nd:YAG laser was irradiated to the dental hard tissue, the titanium dioxide powder was applied to the surface. As was obvious from the image, the dental hard tissue was removed by irradiation of Er:YAG laser beam, although re-solidified layer was formed by irradiation of Nd:YAG laser beam.

In this study, it is aimed that re-solidified layer is formed on the surface of dental hard tissue by Er:YAG laser irradiation. And it is the final goal of this study to add the acid resistance to enamel surface by Er:YAG laser irradiation. If possible, cavity preparation and formation of re-solidified layer can be controlled by only Er:YAG laser irradiation. In order to form the re-solidified layer by Er:YAG laser irradiation, the titanium dioxide powder is applied to the surface of dental hard tissue and Er:YAG laser beam is irradiated to its surface. After the Er:YAG laser irradiation, the prepared surface is evaluated by the observation with a scanning electron microscope (SEM) and the measurement with a three-dimensional surface profiling system.

2. Experimental method

2.1 Laser equipment

Figure 2 shows a pulsed Er:YAG laser equipment (Morita Manufacturing Corp, Erwin AdvErL) used in this study. The irradiation energy per pulse is changed from 30 mJ/pulse to 350 mJ/pulse and pulse duration is kept constant to τ =200 µs. Optical system of Er:YAG laser equipment is composed of contact tip (Morita Manufacturing Corp.: C600F) and optical fiber. The
Er:YAG laser beam was passing through the optical fiber and it is radiated from the contact tip which is attached on the tip of optical fiber. The contact tip is made of quartz glass, therefore the irradiated laser beam was absorbed to the contact tip. The laser beam which was passing through the contact tip was 60%[5].

Figure 3 shows the experimental setup for the measurement of laser beam profile which is radiated from the contact tip. The radiated laser beam is passing through a pin hole and detected with the PbSe photosensor (Hamamatsu Photonics K.K.:P3984). The output value was measured from the PbSe photosensor when the laser beam passes through a pin hole. The measured position was scanned in the laser irradiated area. The laser energy was calibrated in each position and the beam diameter was calculated from these results. Figure 4 shows the result of measurement of laser beam profile. The laser beam possesses a Gaussian distribution. When the distance from the contact tip to the surface of dental hard tissue was 0.5 mm, the beam diameter at the point where the intensity falls to $1/e^2$ times from the maximum value was 530 µm.

2.2 Deposition of titanium dioxide powder on dental tissue

The layer thickness of titanium dioxide powder was measured to evaluate the amount of titanium dioxide powder applied to the surface of dental hard tissue. The specification of the titanium dioxide powder used in this experiment is shown in Table 1. The titanium dioxide solution of different concentration was made. After that, the titanium dioxide powder was deposited on the dental hard tissue by drying the solution which was spread on the surface. The thickness of deposition of titanium dioxide powder was measured by three-dimensional surface profiling system (Tokyo Seimitsu Co.: SURFCOM 2000DX2).

Figure 5 shows the variation of layer thickness with concentration of titanium dioxide solution. As was obvious of the graph, it was found that the layer thickness of titanium dioxide powder increases as the concentration of titanium dioxide solution increases. In the case of 10 w% in titanium dioxide solution, the layer thickness is 5-10 µm. From this result, the layer thickness of titanium dioxide powder was controlled by changing the concentration of the solution.

Table 1: Specification of titanium dioxide powder

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>79.9</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>4240</td>
</tr>
<tr>
<td>Melting point [K]</td>
<td>2143</td>
</tr>
<tr>
<td>Boiling point [K]</td>
<td>3200</td>
</tr>
<tr>
<td>Specific heat [J/(kg・K)]</td>
<td>697</td>
</tr>
<tr>
<td>Thermal conductivity [W/(m・K)]</td>
<td>6.54</td>
</tr>
<tr>
<td>Average particle size [µm]</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Figure 5: Variation of layer thickness with concentration of TiO₂ solution
2.3 Laser irradiation conditions

Laser irradiation conditions are shown in Table 2, and Figure 6 shows the enlargement of laser irradiation area. Laser energy is kept constant to 100 mJ/pulse. The specimen used is an extracted human enamel and its surface is smoothed with diamond abrasive paper (#150). The distance from the surface of human enamel to contact tip is 0.5 mm. The layer thickness of titanium dioxide powder is 5-20 µm. After the laser beam irradiation, the irradiated surface was observed with a SEM and the aspect of hard tissue surface was evaluated. Additionally, the volume of system prepared cavity was measured with a three dimensional surface profiling system.

3. Experimental result and discussion

3.1 Observation of the re-solidified layer

The surface of hard tissue after laser beam irradiation was shown in Figure 7. Here, the layer thickness is changed from 5 µm to 20 µm, and pulsed number of laser beam irradiation was kept constant to 10 times. As the layer thickness of titanium dioxide powder is 5-10 µm, re-solidified layer was not formed at all and the dental hard tissue was removed. This was the reason why Er:YAG laser beam was directly radiated to the dental hard tissue, because the layer thickness of titanium dioxide powder is too thin.

When the layer thickness of titanium dioxide powder was 10-15 µm, re-solidified layer could be formed on the surface of dental hard tissue. On the other hand, as the layer thickness of titanium dioxide powder is 15-20 µm, the quantity of formed re-solidified layer became small. This was the reason why the layer thickness is too thick to heat the surface of the dental hard tissue sufficiently. Therefore, \( t = 10-15 \mu m \) is the most sufficient layer thickness of titanium dioxide powder to form the re-solidified layer by Er:YAG laser thickness.

Additionally, it was not found the influence of variation of pulse number to the formation of re-solidified layer. In the case of 1 pulse irradiated pulse number, when the layer thickness of titanium dioxide powder was 10-20 µm, re-solidified layer was not formed and dental hard tissue was not removed. This was the reason why the only surface of titanium dioxide powder was removed by irradiation of Er:YAG laser beam and the surface of dental hard tissue was not sufficiently heated.

As a result, it is found that 4 or more pulses are needed to form re-solidified layer. In the case of only 1 pulse, Er:YAG laser beam remove the only surface of layer of titanium dioxide powder and can’t transmit sufficient heat to the surface of dental hard tissue.

3.2 The measurement with a three-dimensional surface profiling system

Figure 8 shows variation of volume of prepared cavity with pulse number. In the condition of no titanium
dioxide powder, much volume of prepared cavity was removed. The eliminated volume increased with the increase of pulse number. Because, Er:YAG laser beam is directly irradiated to the surface of dental hard tissue and absorbed by the crystalization water inside the hard tissue. When the layer thickness was \( t = 10-15 \mu m \), the re-solidified layer was formed on the surface, therefore, hard tissue was not removed at all. On the other hand, when re-solidified layer was formed in the condition of \( t = 5-10 \) and \( 15-20 \mu m \), the dental hard tissue was removed. However the volume of prepared cavity is smaller than in the condition of no titanium dioxide powder.

4. Conclusion

In this paper, re-solidified layer on the surface of hard dental tissue by Er:YAG laser beam irradiation is observed by a scanning electron microscope and the volume of prepared cavity is measured with a three-dimensional surface profiling system. The main results obtained are as follow.

(1) The deposition of titanium dioxide powder on the dental hard tissue made it possible to form the re-solidified layer on the surface by Er:YAG laser irradiation.

(2) When the layer thickness of titanium dioxide powder is 10-15 \( \mu m \), re-solidified layer was formed. It was not found the influence of variation of pulse number to the formation of re-solidified layer.

(3) When titanium dioxide powder was applied to the surface of dental hard tissue, the dental hard tissue was not removed almost. However, in the condition of no titanium dioxide powder, the dental hard tissue was removed by Er:YAG laser beam is absorbed by the hydroxyapatite crystal in the tooth.