A Study of Cavity Preparation by Er:YAG laser—Observation of Hard Tooth Structures by Laser Scanning Microscope and Examination of the Time necessary to Remove Caries—

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The purpose of this study was to observe and measure the morphological changes that occur in the hard tissue after the application of Er:YAG laser. Another objective was to evaluate and compare the duration of application of both the laser apparatus and a conventional cutting device. In this study, sound and newly extracted carious tissues were used. The morphological changes in hard tooth structures produced by Er:YAG laser irradiation were examined by using a laser scanning microscope. Results showed that appropriate laser irradiation was 100 mJ/pulse for dentin, and 200 mJ/pulse for enamel. Also, the laser scanning microscope images were less damaged than the SEM images due to pretreatment of the specimens. The time taken to remove carious enamel by laser irradiation was slightly longer than the compared rotary cutting device; however, no differences between the two methods were observed in case of carious dentin removal.

Key words: Er:YAG laser, Laser scanning microscope, Hard tooth structures

INTRODUCTION

Since Maiman1) first developed the ruby laser in 1960, lasers have been applied in many fields. In the dental field, Goldman et al.2) suggested the possibility of the removal of dental caries by ruby laser. Since then, dental lasers have been used for various applications (i.e. diagnosis of caries3,4), treatment of initial caries5), caries removal6), treatment of dental hypersensitivity7), resin bonding8), and root canal treatment9)). Recently, various laser systems have been developed for caries removal and cavity preparation of teeth.

The main problem with the conventional caries treatment procedure was the irritation to the patient of the sound and vibration caused by the rotary cutting device. In recent studies, it has been suggested that the application of lasers would solve this problem, resulting in a more comfortable treatment procedure for the patient. At first, Nd:YAG- and CO₂ lasers were used for cavity preparations. However, the attempts to use Nd:YAG- and CO₂ laser met with certain difficulties due to the destruction of the dental pulp tissue by the produced heat10,11). As a result, the Er:YAG...
Wigdor et al. prepared dentinal cavities in the teeth of canine subjects, using an Er:YAG laser, the results showing that the device produced minimal damage to pulp tissues, as compared with other types of lasers. Tanabe et al. performed an immunohistochemical study on the dental pulpal response after cavity preparation by Er:YAG laser. They reported that there were no appreciable differences in the manner in which pulp tissue responded to treatment with either Er:YAG laser or a conventional drill. Clinical trials of the Er:YAG laser for caries treatment have gradually increased. Keller et al. suggested that the Er:YAG laser could provide caries removal and cavity preparation in an adequate preparation time with minimal patient discomfort. In other studies, Keller et al. reported that the safety and utility of the cavity preparation by the Er:YAG laser device were confirmed. Kumazaki et al. reported that the Er:YAG laser would probably become widely used for cavity preparation in dental practice. There are several methods currently available to observe morphological changes on the tooth surface; these include scanning microscope, contact stylus tracing laser reflectivity, and non-contact laser stylus metrology. Aoki et al. observed micro-cracks of the irradiation area from the lateral side after sectioning the specimens, and then added that it was uncertain whether those micro-cracks were caused by laser irradiation because of the difference in the methods of the observation and the conditions of laser irradiation. There are several problems with the contact stylus tracing method, which relates to the mass of the measuring stylus and the physical configuration of the contact tip. The non-contact laser uses a contact-free tracing of surfaces that eliminates the possibility of surface damage caused by direct contact with the tip of the mechanical pick-up of the contact stylus type. In this study, a Laser Scanning Microscope (LSM) was used. The LSM could perform under conditions in which specimens were less damaged than with a Scanning Electron Microscope (SEM) because pretreatment such as drying was not necessary. Takizawa et al. reported that the laser was effective for patients with a fear of rotary cutting devices, although the cutting time was longer. However, Aoki et al. reported that caries removal by Er:YAG laser could be completed as fast as by a rotary cutting device.

The purpose of this study was to observe and compare the morphological changes in hard tooth structures caused by Er:YAG laser irradiation, and observe any micro-structural changes on the dentin surface after caries removal. Another objective was the comparison and evaluation of the time taken for the removal of caries by both laser apparatus and rotary cutting device.

**MATERIALS AND METHODS**

*Analysis and observation by LSM of the cavity after Er:YAG laser irradiation*

Premolars extracted for orthodontic treatment were polished with a water-resistant abrasive paper series (#600-1200) until the tooth surface from the enamel on the crown to the dentin on the root was flat. In this study, the laser apparatus was the
Er:YAG laser system (Erwin; Hoya Corp., Tokyo, Japan, and J. Morita Corp., Kyoto, Japan.). Laser irradiation conditions are shown in Table 1. The cavity was prepared by laser irradiation, using a 0.4 mm diameter tip, and spraying a mixture of air and water. Both the laser apparatus and the tooth were fixed, the contact tip at right angles to the polished surface of the enamel and dentin of the specimens. After laser application, the micro-structures of the laser-irradiated surface were observed using LSM (OLS1100; OLYMPUS OPTICAL Corp., Tokyo, Japan). The maximal diameter, depth, and volume of the cavity by laser irradiation were measured. Fig. 1 shows a representative example of the measurement of the diameter, depth, and volume of the cavity by LSM. The micro-structures on the laser-irradiated surface were observed using SEM. An Electron Probe Micronanalyzer (WAX type, EPMA 8705, Shimadzu, Kyoto, Japan) was used to produce the SEM image. Specimens used for surface integrity analysis were the same specimens used in the observation of LSM. After observation by LSM, the same teeth were observed by SEM.

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<th>Condition of Er:YAG laser irradiation</th>
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<td>output energy</td>
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<td>repetition rate</td>
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<td>20, 25, 50, 100, 150, 200, 250 mJ/pulse</td>
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<td>5.0 ml/1 min</td>
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<td>FTB-P60 (0.4 ø x 5.0 mm)</td>
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Fig. 1 Representative example of the measurement of the prepared cavity by LSM.
(dentin; 100 mJ/pulse, 1 pps, 10 sec.) a: diameter, b: depth, c: volume
Examination of the time necessary to remove caries and observation of the micro-
structures on the dentin surface after caries removal

In this study, newly extracted carious teeth that were diagnosed as unpreservable
were used. The teeth had pit and fissure caries or root surface caries that extending
to the dentin. The caries area of the examined teeth was dyed with the acid red
(CARIES DETECTOR; KURARAY Corp., Okayama, Japan.). The carious teeth were
repeatedly dyed till they were not dyed. One half of the caries lesion was removed
by a rotary cutting device (air-turbine handpiece and micro-motor handpiece) and the
other half by Er:YAG laser (Fig. 2). As a rotary cutting device, the enamel caries
lesion was removed by air-turbine handpiece (super ZB, PAR-E Hi, J. Morita Corp.,
Kyoto, Japan.). The burs used were carbide round burs (MANI Corp., Tokyo,
Japan.). The dentin caries lesion was removed by micro-motor handpiece (Torx

Fig. 2 Observation of caries removal.

a: before caries removal, b: after caries removal (b-1: rotary cutting device, b-2:
Er:YAG laser)

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<th>Table 2 Cutting conditions caries removal</th>
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<td>rotary cutting device used</td>
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<td>air-turbine handpiece</td>
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<td>micro-motor handpiece</td>
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<td>Er:YAG laser</td>
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TR-81, J. Morita Corp., Kyoto, Japan.). The burs used were steel round burs (MAILLEFER, Jura hill-country, Swiss.). The caries lesion was removed by laser irradiation, using a 0.4 mm diameter tip or a 0.6 mm diameter tip, and spraying a mixture of air and water. Both the laser apparatus and the tooth were fixed. The cutting conditions are shown in Table 2. The time taken to remove the carious area was recorded. The time during which the caries lesion was dyed was not included. Observation of the micro-structures was conducted by using LSM. Ten teeth were prepared for each study.

The results were statistically evaluated by analysis of variance (ANOVA). The Mann-Whitney U-test (p < 0.05) was applied.

RESULTS

Analysis and observation by LSM of the cavity after Er:YAG laser irradiation
Fig. 3 shows the LSM image of the enamel area and the dentin area after the application of laser irradiation. In the enamel, the cavity after laser irradiation had a deep, dish-like morphology. Under laser irradiation of 200 mJ/pulse (1 pps, 10 sec), micro-cracks and roughening of the surface are observed in the irradiated enamel. In the dentin, under laser irradiation of 100 mJ/pulse (1 pps, 10 sec), a comparatively flat margin was observed, and the profile of the irradiated dentin is a smooth curve. Fig. 4 shows the SEM image of the enamel and the dentin after laser irradiation. In the enamel, the SEM image showed a bigger crack than the LSM image. In the dentin, several cracks were shown.

Figs. 5, 6, and 7 show the diameter, depth, and volume of the cavity after laser irradiation. In each pulse, the increase of output energy is accompanied with an in-

Fig. 3 Observation by LSM of micro-structure in the enamel and dentin.
(enamel, ×150; 200 mJ/pulse, 1 pps, 10 sec)
(dentin, ×150; 100 mJ/pulse, 1 pps, 10 sec)
(a: brightness image, b: height image, c: three-dimensional image, d: profile
crease of removed tooth structure. With an output energy more than 200 mJ/pulse, the amount of enamel removed by laser irradiation increases remarkably. There were significant differences between 150 mJ/pulse and 200 mJ/pulse (p<0.05). With an output energy of more than 100 mJ/pulse, the amount of dentin removed by laser irradiation also increases remarkably. There were significant differences between 50 mJ/pulse and 100 mJ/pulse (p<0.05). Under the conditions of 200 mJ/pulse output energy in this study, the amount of dentin removed by laser irradiation was more than that of enamel.
Examination of the time necessary to remove caries and observation of the microstructures on the dentin surface after caries removal

Fig. 8 shows the time taken to remove caries. The average time to cut enamel by Er:YAG laser was 33.0 sec, the average time by rotary cutting device (air-turbine and micro-motor handpiece) was 23.5 sec. The average time to cut dentin by Er:YAG laser was 35.5 sec, the average time by rotary cutting device was 35.0 sec.
Fig. 8 The time taken to remove caries.

Fig. 9 Observation by LSM of dentin after caries removal.
a: rotary cutting device (×150), b: Er:YAG laser (×150)
In the results, there were no significant differences between the time taken to remove caries by rotary cutting device and the time by Er:YAG laser (p>0.05). In this experiment, the time to cut enamel by Er:YAG laser tended to be slightly longer than that by rotary cutting device; however, the time to cut dentin by Er:YAG laser was almost equal to that by rotary cutting device.

Fig. 9 shows the micro-structures of the dentin surface after caries removal by LSM. Striations were observed on the surface cut by rotary cutting device, and dentinal tubules were covered with a smeared layer. The cutting surface by laser irradiation showed a rough surface similar to scales, and exposed dentinal tubules were observed.

DISCUSSION

Regarding the morphological changes by Er:YAG laser irradiation, Takano\textsuperscript{23} observed sections of the cavity irradiated by Er:YAG laser using SEM, and reported that cracks running parallel along the cavity wall were frequently observed in subsurface areas of enamel specimens. Toyama\textit{ et al.}\textsuperscript{24} confirmed that the occurrence of cracks by Er:YAG laser irradiation was observed due to penetration of the bonding agent which was observed under the irradiation area. Aoki\textit{ et al.}\textsuperscript{21} observed cervical enamel and root dentin after the removal of root surface caries by Er:YAG laser irradiation, and reported that the treated cavity margin tended to be irregular and unclear. Furthermore, Eguro\textsuperscript{25,26} observed the irradiation area from the upper side, and Aoki\textit{ et al.}\textsuperscript{21} observed the irradiation area from the lateral side after sectioning the specimens.

In previous observations, SEM images were mainly used. Although SEM images are useful for the observation of micro-structures, pretreatment such as drying is necessary for observation, and there is a possibility that the pretreatment can cause changes in the tooth structure. Furthermore, line scans by the electron beam were made at right angles to the specimen surface. Aoki\textit{ et al.}\textsuperscript{21} reported that it was uncertain whether those micro-cracks were caused by laser irradiation because of the difference in the methods of observation and the conditions of laser irradiation. In this study, LSM was used, a non-contact laser stylus having the advantage of detecting the texture of comparatively soft surfaces. Another advantage of the non-contact stylus laser is that the contact free tracing of surfaces eliminates the possibility of surface damage caused by direct contact with the tip of a mechanical pick-up of the contact stylus. Regarding the three-dimensional observation of microstructures by LSM, micro-cracks had occurred in the periphery of the enamel, and a comparatively flat margin in the dentin under the conditions of high output energy was also observed. In this study, after observation by LSM, the same teeth were observed by SEM. The SEM image showed a larger crack than the LSM image.

In each pulse, the amount of tooth cut increased in accordance with the increase of output energy. In the amount of enamel, there were significant differences between 150 mJ/pulse and 200 mJ/pulse (p<0.05). In the amount of dentin, there
were significant differences between 50 mJ/pulse and 100 mJ/pulse (p<0.05). Hibst et al.27,28) reported that the cutting amount of dentin was more than that of enamel over the same time, and that of the carious area was more than that of the healthy tooth structures. They also reported that the tissue was very effective both for dentin and enamel. Ishimaru et al.29) reported that effective cavitation is better achieved under a higher energy level. Tanabe et al.30) performed an immunohistochemical study and revealed that pulpal reaction caused by laser irradiation (100 mJ/pulse) was weak during cavity preparation. In a manual, the manufacturer of Er:YAG laser recommends 100 mJ/pulse for dentin, and 200 mJ/pulse for enamel. Considering the cutting efficiency of cavity preparation and the influence on the pulp, appropriate irradiation conditions were thought to be 100 mJ/pulse for dentin, and 200 mJ/pulse for enamel. The wave length of the Er:YAG laser used in this study was 2.94 μm. The Er:YAG laser is selectively absorbed by water and hydroxypatite, and tissular destruction is caused by the explosive power at the time of instantaneous water vaporization.30) As a result, the amount of morphologically change that occurred in the dentin was more than that of enamel, not only due to the differences in the tissular structure, but also the water content, which was higher in dentin than in enamel.

In this study, there were no significant differences between the time taken to remove caries by rotary cutting machine and the time by Er:YAG laser. The time to cut enamel by Er:YAG laser tended to be slightly longer than that by rotary cutting device; however, the time to cut dentin by Er:YAG laser was almost equal to that by rotary cutting device. Aoki et al.21) reported similar results. However Takizawa et al.22) reported that cavity preparation by Er:YAG laser apparatus could reduce the physical pain and mental stress accompanying cavity preparation compared to that by rotary cutting machine, and was thought to be effective for the treatment of pediatric patients or patients with general diseases. These findings suggested that laser was effective for patients with a fear of rotary cutting devices, although the cutting time was longer.

In this study, striations were observed on the surface cut by rotary cutting device, and dentinal tubules were covered with a smeared layer. The cutting surface by laser irradiation showed a rough surface, similar to scales, and exposed dentinal tubules were observed. Aoki et al.21) reported similar results. In future, we need to study the effect of laser irradiation on the bonding strength between resin and tooth structure.

CONCLUSION

As a result of this study, considering the cutting efficiency of cavity preparation and influence on the pulp, appropriate laser irradiation is thought to be 100 mJ/pulse for dentin, and 200 mJ/pulse for enamel.

Comparing the time taken to remove caries between laser irradiation and rotary cutting device, the time taken to remove carious enamel by laser irradiation was
slightly longer than that by rotary cutting device; however, no differences between the two methods were observed in the case of carious dentin removal. It was also reported that laser irradiation caused no smeared layer, and that the obtained cutting surface differed from that by rotary cutting device.

REFERENCES


