A Study on Acquired Acid Resistance of Enamel and Dentin Irradiated by Er,Cr:YSGG Laser


ABSTRACT

Objective: This investigation was performed to evaluate the acid resistance of lased enamel and dentin by Er,Cr:YSGG laser to artificial caries-like lesions by spectrophotometry, and the ultrastructure of lased areas was investigated by scanning electron microscopy (SEM) in vitro. Background Data: In recent years, many studies have been performed to evaluate the effects of Er,Cr:YSGG laser on dental hard tissues. However, there have been only a few studies to determine if this laser is suitable for caries preventive treatments. Methods: An Er,Cr: YSGG laser was used to irradiate the enamel or dentin samples from 30 extracted human molars at 6 W (67.9 J/cm²) or 5 W (56.6 J/cm²) pulse energy, respectively, with or without water mist. Samples were subjected to 2 µl of 0.1 M lactic acid solution (pH 4.8) for 24 h at 36°C. The parts per million (ppm) of calcium ion (Ca²⁺) dissolved in each solution was determined by atomic absorption spectrophotometry, and the morphological changes were investigated by SEM. Results: The lowest mean Ca²⁺ ppm was recorded in the lased samples. SEM observation showed that the lased areas were melted and seemed to be thermally degenerated. After acid demineralization, the thermally degenerated enamel or dentin surfaces were almost unchanged. Conclusions: The results of this study suggested that Er,Cr:YSGG laser irradiation with and without water mist appears to be effective for increasing acid resistance.

INTRODUCTION

In recent years, many investigations related to the applications of lasers in the area of preventive dentistry have been performed. Westerman et al.¹ and Powell et al.² found that enamel and dentin surfaces treated with argon laser appeared to be more resistant to artificial caries than control surfaces. Regarding the Nd:YAG laser, it has been reported that human enamel irradiated by this laser, especially with black ink as an initiator, was more resistant to acid decalcification than unlased enamel.³⁻⁴ The effect of CO₂ laser irradiation on the enhanced resistance to artificial caries formation of lased enamel or dentin has already been performed.⁵⁻⁷ However, laser irradiation at some specific parameters cause an increase in the pulpal temperature,⁸⁻⁹ that might lead to injury to the dental pulp. Recently developed Er:YAG and Er,Cr:YSGG lasers have been reported to ablate dental hard tissues with minimum injury to the pulp and surrounding tissues. The Er:YAG laser has been reported to ablate enamel and dentin effectively, because of its highly efficient absorption in both water and hydroxyapatite.¹⁰⁻¹² On the other hand, the Er,Cr:YSGG laser, which uses a pulsed-beam system, fiber delivery, and a sapphire tip bathed in a mixture of air and water vapor, has been shown to be effective for cutting enamel, dentin, and bone.¹³⁻¹⁵ Regarding the caries prevention effect of these lasers, Fried et al.¹⁶ in a previous study, reported that there was marked caries inhibition in the enamel. However, there are still a limited number of papers concerning acid resistance of enamel and dentin, to determine if this laser is suitable for caries preventive treatments.

In this study, the effect of Er,Cr:YSGG laser irradiation on the acid resistance of sound enamel and dentin to artificial caries formation was evaluated by spectrophotometry, and the ultrastructure of lased areas was investigated by scanning electron microscopy (SEM) in vitro.
MATERIALS AND METHODS

Sample preparation

Thirty extracted, non-caries human molar teeth were used. The experimental procedure used in this study was based on the method by Sterrett et al. For the enamel study, three cavities (3 x 3 x 1 mm) were prepared on the buccal and lingual (palatal) surfaces of each tooth at equal height from the cemento-enamel junction with a high-speed turbine. For the dentin study, three cavities (2 x 2 x 2 mm) were produced with a high-speed turbine on each polished with a 1000-grit paper (Marumoto Kogyo, Tokyo, Japan) dentin disk prepared by horizontal cutting at the middle of tooth crown. In each enamel or dentin sample, one cavity served as control and the other cavities were used for laser irradiation.

Laser irradiation

A Millennium™ Er,Cr:YSGG laser system (Biolase™ Technology Inc., San Clemente, CA) was used. This laser system emitted photons at a wavelength of 2.78 μm, pulsed with a duration between 140 and 200 μm and a repetition rate of 20 Hz. The beam spot size was 0.442 mm² with the use of a 750-μm diameter fiber at the distance of 2–3 mm.

For the enamel study, irradiation was performed with a focused beam of 6 W with maximum air pressure level and 32% water level or with no water for 6 sec at the cavity floor and for another 6 sec at the cavity walls (67.9 J/cm²). For the dentin study, irradiation was performed with a focused beam of 5 W with maximum air pressure level and 32% water level or with no water for 6 sec at the cavity floor and for another 6 sec at the cavity walls (56.6 J/cm²). The distance between the sample surfaces and the tip was kept at 2 cm.

Lactic acid demineralization and calcium atomic measurement

The demineralization solution contained 0.1 M lactic acid, 0.2 mM methylene diphosphonic acid (MDHP) at pH 4.8, and 0.01% thymol. A 2-μl solution was pipetted into the control, and laser-irradiated cavities and samples were stored at 36°C in 100% humidity for 24 h. Then 2 μl of solution was transferred into 5 ml of distilled water, and cavities were washed with this water. The parts per million (ppm) of calcium ion (Ca²⁺) dissolved in each 5-ml solution was determined using an atomic absorption spectrophotometer (AA-6400F, Shimazu, Kyoto, Japan). Statistical analysis of the data was performed using the Mann-Whitney's U test between two groups, and a value of p < 0.01 was considered significant.

SEM observation

To observe the ultrastructure of control and laser-irradiated surfaces of enamel and dentin, specimens were dehydrated with a graded series of ethanol, dried to a critical point with CO₂, and mounted on aluminum stubs. All specimens were sputter-coated with platinum at the thickness of 15 μm for SEM (JSM-T220A, JEOL, Tokyo, Japan) examination at 20 kV.

RESULTS

Atomic absorption spectrophotometric analysis

Table 1 shows the mean Ca²⁺ ppm for each lactic acid solution (pH 4.8) of lased and unlased (control) samples. In the enamel and dentin samples, the lowest mean Ca²⁺ ppm was recorded in the samples irradiated without water mist, in those irradiated with water mist, and in the unlased samples (control). There was a statistically significant difference between the mean Ca²⁺ ppm of samples irradiated with or without water mist and unlased (control) samples (p < 0.01).

![FIG. 1. Representative SEM photograph of enamel surface that was lased at 6 W pulse energy with water mist and then demineralized with 0.1 M lactic acid for 24 h. At x1000 magnification, the thermally degenerated enamel surface was unchanged. (Bar represents 16 μm.)](image-url)
Acid Resistance by Er,Cr:YSGG Laser Irradiation

FIG. 2. Representative SEM photograph of dentin surface that was lased at 5 W pulse energy with water mist and then demineralized with 0.1 M lactic acid for 24 h. At \( \times1000 \) magnification, the thermally degenerated enamel surface was unchanged. (Bar represents 16 \( \mu \)m.)

**SEM observation**

SEM observation showed that the unlased enamel or dentin cavity surfaces (control) featured a relatively flat appearance that was covered with a smear layer. After demineralization with 0.1 M lactic acid, the smear layer was removed and thus the enamel rods or the dentinal tubules could be recognized. It seemed that the continued acid exposure might further attack the enamel rods or the dentinal tubules and could result in further dissolution of calcium. However, the lased enamel and dentin surfaces with or without water mist showed some different characteristic features.

The water mist enamel or dentin surfaces showed multiple circular patterns with a scaly appearance. In contrast to the relatively flat appearance of the control surface, the lased surfaces lacked a smear layer and showed various patterns of micro-irregularity, often accompanied by microfissure propagation. In addition, the enamel rods or the openings of dentinal tubules were clearly visible. Slight melting was observed and the surfaces seemed to be degenerated thermally. However, no thermal damage was observed at the bottom and margin of the cavities. After acid demineralization, the thermally degenerated enamel or dentin surfaces were unchanged (Figs. 1 and 2).

The enamel or dentin surfaces lased without the use of water mist presented a molten lava-like appearance and, as a whole, an irregular structure with many microholes. The floors and walls of the cavities showed severe carbonization or seemed to be thermally degenerated. Enamel rods or the dentinal tubules were not clearly visible, and might be sealed by the melted smear layer. After acid demineralization, the thermally degenerated enamel or dentin surfaces were almost unchanged (Figs. 3 and 4).

**DISCUSSION**

**Atomic absorption spectrophotometry analysis**

In our study, the lowest mean Ca\(^{2+}\) ppm was recorded for the tooth samples irradiated without water mist, followed by those irradiated with water mist. The unlased samples showed the highest Ca\(^{2+}\) ppm (Table 1). There was a statistically significant difference between the mean Ca\(^{2+}\) ppm of samples irradiated with or without water mist and the unlased samples. This result corresponds with the previous studies by Nd:YAG or CO\(_2\) lasers. Regarding the Nd:YAG laser irradiation, Yamamoto and Ooya reported that the greatest degree of demineralization occurred with the unlased normal enamel surface, whereas the least demineralization was seen with the lased enamel measured by atomic absorption spectrometry. Similar reports on the decrease in the mean Ca\(^{2+}\) ppm of dental hard tissues subjected to acid demineralization using the CO\(_2\) laser irradiation have been published. However, at some specific parameters the irradiation of these lasers caused significant heat, that might lead to injury to the dental pulp. Compared to Nd:YAG or CO\(_2\) laser irradiation, Er,Cr:YSGG ablates the den-

FIG. 3. Representative SEM photograph of enamel surface that was lased at 6 W pulse energy without water mist and then demineralized with 0.1 M lactic acid for 24 h. At \( \times3500 \) magnification, molten lava-like appearance or the thermally degenerated enamel was unchanged. (Bar represents 4.5 \( \mu \)m.)

FIG. 4. Representative SEM photograph of dentin surface that was lased at 5 W pulse energy without water mist and then demineralized with 0.1 M lactic acid for 24 h. At \( \times1000 \) magnification, molten lava-like appearance or the thermally degenerated enamel or dentin surface was unchanged. (Bar represents 16 \( \mu \)m.)
that laser irradiation with and without a water mist degenerates occlusal or root surfaces. Clinical significance

Our results have shown that pretreatment of dental hard tissues with Er, Cr:YSGG laser can markedly reduce acid dissolution. This laser treatment could be useful for inhibition of decay in the mouth. On the basis of the above discussions, this laser system can be used for the prevention of dental caries or secondary caries prevention in cavity preparation, removing dental caries, and the treatment of early enamel or dentin lesions in the occlusal or root surfaces.

CONCLUSIONS

Irradiation with or without a water mist reduced the mean Ca²⁺ ppm significantly (p < 0.01). SEM observation revealed that laser irradiation with and without a water mist degenerates the enamel or dentin, and thus makes it highly resistant to acid demineralization. It can be concluded that Er,Cr:YSGG laser irradiation with or without water mist is effective for increasing acid resistance of dental hard tissues.

ACKNOWLEDGMENTS

This work was supported by funding from Grant-in-Aid for Scientific Research from the Ministry of Education, Science, and Culture of Japan. We are grateful to the Japan Society for the Promotion of Science (JSPS) for supporting the author Mozammal Hossain.

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