A Study of Cavity Preparation by Er:YAG laser —Effects on the Marginal Leakage of Composite Resin Restoration—

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The purpose of this study was to evaluate marginal leakage of composite resin restoration from cavities prepared by Er:YAG laser. The observation of the dentin surface after the application of laser irradiation was performed by LSM, the cutting surface showed a rough surface similar to scales, and exposed dentinal tubules were observed without striations or a smeared layer formation that were observed when using a rotary cutting device. Leakage tests revealed no significant differences in the marginal seal for both enamel and dentin between cavities prepared by Er:YAG laser irradiation and when using an air-turbine. In this study, the usefulness of cavity preparation by Er:YAG laser irradiation in composite resin restoration was suggested.

Key words : Er:YAG laser, Marginal leakage, Cavity preparation

INTRODUCTION

In the treatment of hard tissue diseases such as caries, tooth cutting can not be avoided. The main problem with the conventional caries treatment procedure was the irritation of the patient due to the sound and vibration caused by the rotary cutting device. In addition, there were possibilities of friction heat and cracks during cutting 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.

Since Maiman¹⁾ first developed the ruby laser in 1960, lasers have been applied in many fields. In the dental field, since Stern *et al.*²⁾ and Goldman *et al.*³⁾ irradiated the ruby laser on the teeth in 1964, various lasers have been developed. Cutting of dental hard tissue by laser irradiation has been used in caries treatment. However various problems have been suggested. In particular, the ruby laser^{2,3)}, CO₂ laser⁴⁾, and Nd:YAG laser⁵⁾ have been considered to be inappropriate for cavity preparation because their laser irradiations damage the dental pulp due to heat generation and also form a carbonization layer and cause cracks^{6–8)}. In 1975, Zharikov *et al.*⁹⁾ developed the Er:YAG laser as a new technical modality for caries treatment. The

Er:YAG laser was suggested to be less invasive to surrounding tissue because wavelengths selectively absorbed by water in tissue are used, and tissue destruction occurs by the explosive power at the time of instantaneous water vaporization. Tanabe *et al.*¹⁰⁾ 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 the Er:YAG laser or a conventional drill. In 1988, Hibst *et al.*¹⁰⁾ could perform Er:YAG laser irradiation without causing cracks on the irradiation surface. Clinical trials of the Er:YAG laser for caries treatment have gradually increased¹²⁻¹⁴⁾. However, at present, in cavity preparation by the Er:YAG laser, inlay restoration is difficult because the shape outline form can not be performed by Er:YAG laser irradiation, and composite resin restoration may be appropriate.

As factors affecting the outcome of composite resin restoration, marginal leakage is very important, and many studies and improvements have been performed to prevent this leakage. The marginal sealing of composite resin restorations has been reported to be affected not only by the performance of bonding systems but also by the cavity shape^{15,16)} cavity marginal shape^{17,18)} and the time needed to finish polishing the restorations^{19,20)}.

In cavity preparation by the Er:YAG laser irradiation, evaluation of the sealing on composite resin restoration is important. This study was performed to evaluate marginal leakage after cavity preparation by Er:YAG laser irradiation for the composite resin restoration and to prevent the occurrence of marginal leakage clinically.

MATERIALS AND METHODS

In this study, the used laser apparatus was the Er:YAG laser system (Erwin; Hoya Corp., Tokyo, Japan, and J. Morita Corp., Kyoto, Japan). The cavity was prepared by laser irradiation, using a 0.6 mm diameter tip (FTB-80), and spraying a mixture of air and water. On the other hand, as a control cavities were prepared by an air-turbine hand piece (super ZB, PAR-E Hi, J. Morita Corp., Kyoto, Japan). The used burs were carbide round burs (1.4 mm ϕ , MANI Corp., Tokyo, Japan). Cutting was performed under high-speed water infusion. Cutting conditions are shown in Table 1.

Table 1 Cutting conditions

Er:YAG laser system	
output energy	enamel 200 mJ/pulse dentin 100 mJ/pulse
repetition rate	10 pps
volume of water	5.0 ml/min
contact tip	FTB-80 (0.6 ϕ $\times$ 5.0 mm)
rotary cutting device	
rotary cutting device used	burs used
air-turbine handpiece	carbide bur, round, ISO 014 (1.4 mm ϕ)

Table 2 Filling materials

adhesive system	Batch no.	Manufacture
Mega-bond system	011192	Kuraray, Osaka, Japan
Single-bond system	2000606	3M, St. Paul, MN, USA
Composite resin	Batch no.	Manufacturer
Clearfil AP-X	00436A	Kuraray, Osaka, Japan
Z-100	20001110	3M, St. Paul, MN, USA

Table 3 Experimental groups according to the apparatus and the material used

Group no.	Apparatus used	Material used
A	air-turbine handpiece	Mega-bond system/Clearfil AP-X
B	Er:YAG laser	Mega-bond system/Clearfil AP-X
C	air-turbine handpiece	Single-bond system/Z-100
D	Er:YAG laser	Single-bond system/Z-100

Table 4 Conditions of testing

Group no.	Experimental condition
1	Control (no test)
2	Manual thermal cycle test (100 cycles: 1 to-and-fro cycle: $5\pm 2^{\circ}\text{C}$ for 1 min/ $22\pm 2^{\circ}\text{C}$ for 30 sec/ $60\pm 2^{\circ}\text{C}$ for 1 min)
3	Load cycle test (1.3 kg load for 24 h at a rate of 98 cycles/min)

The materials used in this study were two types of dental adhesive systems and composite resins as restoration materials. Materials are shown in Table 2. By the routine method, pretreatment using Mega-bond system (Kuraray, Osaka, Japan) was performed, followed by restoration using Clearfil AP-X (Kuraray, Osaka, Japan). In addition, pretreatment using Single-bond system (3M, St. Paul, MN, USA) was performed, followed by restoration using Z-100 (3M, Tokyo, Japan.).

The following investigations were conducted:

(I) *Observation by laser scanning microscope (LSM) of the pretreated surface*

Fresh human healthy premolars extracted for orthodontic reasons were used. After removal of soft tissue and dental calculi using a scaler, the premolars were thoroughly washed with distilled water. The class V cavities (about $3.0\times 3.0\times 1.5$ mm) were prepared on the cervical area of enamel and dentin with an Er:YAG laser. As controls, the class V cavities (about $3.0\times 3.0\times 1.5$ mm) were prepared on the cervical area of enamel and dentin with an air-turbine hand piece. The laser irradiated surface and the cutting surface by an air-turbine hand piece were observed using LSM (OLS1100; OLYMPUS OPTICAL Corp., Tokyo, Japan). The cavities were treated with the two-material conditioner (*i.e.* Mega-bond system or Single-bond system). Then, the pretreated surface was observed by LSM.

(II) Marginal leakage tests and evaluation of leakage

Sixty fresh human healthy premolars extracted for orthodontic reasons were used. The teeth were divided randomly into four groups of five teeth each, as shown in Table 3. The class V cavities (about $3.0 \times 3.0 \times 1.5$ mm) were prepared on the cervical area of the enamel and dentin using an Er:YAG laser system or an air-turbine hand piece. Two cavities were prepared for each tooth. The cavity walls and floors were treated with the two-material conditioner (*i.e.* Mega-bond system or Single-bond system). Subsequently, the pre-treated cavities were restored with composite resins (*i.e.* Clearfil AP-X or Z-100). Immediately after filling, the extra-marginal excessive portion was completely removed using carbide burs (#7903, Shoufu Corp., Kyoto, Japan.) for finishing. Then, the specimens were polished using silicone points (R type, Shoufu Corp., Kyoto, Japan.) on the same day. The apical part of the specimens was sealed with utility wax and quick cure resin, and the entire tooth surface was covered with two layers of nail varnish about 1.0 mm from the cavity margin. After the materials had set, the four experimental groups were divided into three subgroups to represent the three experimental conditions: group no. 1 = control, group no. 2 = thermal cycling, group no. 3 = load cycling. As group no. 1, specimens were immersed in the dye under the following conditions; after filling with composite resin, finishing and polishing were performed on the same day. Then the specimens were immersed in the dye and placed in an incubator maintained at a temperature of 37°C for 1 day. As group no. 2 = thermal cycling, specimens were immersed in the dye under the following conditions; after filling with composite resin, finishing and polishing were performed on the same day. After the thermal cycling test, the specimens were immersed in the dye and placed in an incubator maintained at a temperature of 37°C for 1 day. The thermal cycling tests were carried out under the following condition; 100 cycles: 1 to-and-fro cycle: 5 ± 2 °C for 1 minute/ 22 ± 2 °C for 30 seconds/ 60 ± 2 °C for 1 minute. As group no. 3 = load cycling, specimens were immersed in the dye under the following conditions; after filling with composite resin, finishing and polishing were performed on the same day. The load cycling test was then carried out at room temperature with the specimens immersed in the dye. A load was carried out on the occlusal surface side (Fig. 1). The weight at the upper end was adjusted to 1.3 kg. The shape of this force curve resembles one-half of a sine wave, with the time required for 1 cycle being approximately 0.61 seconds, which translates to 98 revolutions per minute or about 1.4×10^5 cycles per day. This cycle is within the range of mastication rates at meals reported by Bates *et al.*²¹⁾. Ishikawa *et al.*²²⁾ reported cyclic loading on marginal leakage of composite restorations under this condition.

All specimens were covered with nail varnish and placed in 0.2 % methylene blue solution and stored in an incubator maintained at a temperature of 37°C for 7 days.

After the termination of marginal leakage tests, the specimens were cross-sectioned longitudinally through the center of the cavities with a low speed diamond micro-cutter (Micro-cutter 201, Maruto, Tokyo, Japan.). At the crown enamel cavity margin and gingival dental cavity margin, the depth of dye entry was measured as

Fig.1 A scheme of load cycle test.

the degree of marginal leakage using a stereoscopic microscope (Measuring microscope model STM, OLYMPUS OPTICAL Corp., Tokyo, Japan).

Results were statistically evaluated using a one-way analysis of variance (ANOVA). The Bonferroni Test ($p < 0.05$) was applied where significant difference was detected.

RESULTS

(I) Observation by laser scanning microscope (LSM) of the pretreated surface

Fig.2 shows LSM images of the enamel and dentin cutting surfaces by an Er:YAG laser system and an air-turbine. The surface of the enamel cut by the Er:YAG laser system was rough, showing micro-cracks, while the surface cut by an air-turbine hand piece was flat and showed cutting scars. The dentinal cutting surface by laser irradiation showed a rough surface similar to scales, and exposed dentinal tubules were observed. Striations were observed on the surface cut by an air-turbine hand piece, and dentinal tubules were covered with a smeared layer. Fig.3 shows LSM images after pretreatment of the enamel and dentin with the Mega-bond system. The enamel surface after laser irradiation was rough, and that cut by an air-turbine hand

Fig. 2 LSM images of the enamel and dentin cutting surface.

I: brightness image, II: three-dimensional image
 E-a: the enamel cutting surface by air-turbine
 E-b: the enamel cutting surface by Er:YAG laser
 D-a: the dentin cutting surface by air-turbine
 D-b: the dentin cutting surface by Er:YAG laser

Fig. 3 LSM images after pretreatment of the enamel and dentin with the Mega-bond system.

E-a: the enamel cutting surface by air-turbine
 E-b: the enamel cutting surface by Er:YAG laser
 D-a: the dentin cutting surface by air-turbine
 D-b: the dentin cutting surface by Er:YAG laser

Fig. 4 LSM images after pretreatment of the enamel and dentin with the Single-bond system.

E-a: the enamel cutting surface by air-turbine

E-b: the enamel cutting surface by Er:YAG laser

D-a: the dentin cutting surface by air-turbine

D-b: the dentin cutting surface by Er:YAG laser

piece showed cutting scars. On the surface of the dentin, the cutting surface by a laser system was similar to that before pretreatment, while that of the air-turbine hand piece showed roughening of the smeared layer, slight outlines of the dentinal tubules, and slight decalcification. Fig. 4 shows LSM images after pretreatment of the enamel and dentin using the Single-bond system. The enamel surface after laser irradiation was rough, and that cut by an air-turbine hand piece showed cutting scars. Surfaces prepared by both systems showed disappearance of cutting scars, wide opening of the dentinal tubules, and the contents in the tubules.

(II) Marginal leakage tests and evaluation of leakage

Fig. 5 shows the results in terms of the degree of marginal leakage. In the enamel, leakage tests showed no significant differences in the degree of leakage between the restoration materials for the laser or the air-turbine hand piece ($p > 0.05$). However, the cavities prepared by Er:YAG laser showed higher marginal sealing than those

Fig. 5 The results in terms of the degree of marginal leakage.

prepared by the air-turbine hand piece in the enamel. In the dentin, leakage tests showed no significant difference between the restoration materials for the laser or the air-turbine hand piece ($p > 0.05$). However, cavities prepared using the laser system showed a higher degree of leakage than those prepared by the air-turbine hand piece.

DISCUSSION

Previous investigations reported the morphological changes that occur in the hard tissue after the application of Er:YAG laser by LSM²³⁾. In the enamel, after laser irradiation the cavity had a deep, dish-like morphology. After 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, after 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. In the enamel, the SEM image showed a bigger crack than the LSM image. In the dentin, several cracks were observed. In addition, the LSM images were less damaged than the SEM images due to pretreatment of the specimens. In this study, laser irradiation surfaces were observed by LSM. Laser irradiation conditions were 200 mJ/pulse for enamel, and 100 mJ/pulse for dentin. The surface of the enamel prepared using the Er:YAG laser system was rough, showing micro-cracks, and that prepared using the air-turbine handpiece was flat, showing cutting scars. The dentinal surface prepared by laser irradiation showed a rough surface similar to scales, and exposed dentinal tubules were observed. Striations were observed on the surface cut using the air-turbine hand piece, and the dentinal tubules were covered with a smeared layer. Regarding the morphological changes by

Er:YAG laser irradiation, Takano²⁴⁾ 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 *et al.*²⁵⁾ confirmed that cracks after Er:YAG laser irradiation were present due to penetration of the bonding agent which was observed under the irradiation area. Aoki *et al.*²⁶⁾ observed the 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. However, they could not determine whether the microcracks developed during laser irradiation. In this study, micro-cracks were observed on the prepared surface of the enamel after the laser irradiation.

In the enamel, leakage tests showed no significant differences in the degree of leakage between the restoration materials for the laser or an air-turbine handpiece ($p>0.05$). The following tendency was recognized from Fig. 5. The cavities prepared by Er:YAG laser showed higher marginal sealing than those prepared by an air-turbine handpiece in the enamel. This difference may be due to the effects of the Er:YAG laser irradiation on the enamel. Keller *et al.*²⁷⁾ suggested that Er:YAG laser irradiation has effects similar to those of pretreatment with a bonding system. Kumazaki *et al.*²⁸⁾ observed the structure of the cavity wall after laser irradiation using an SEM and evaluated the optimal irradiation conditions for laser etching. Kayano *et al.*²⁹⁾ reported improvement in acid resistance of the enamel after laser irradiation. However, in this study, data dispersion was observed at the enamel cavity margin after laser irradiation. This result could be due to unclearness of the cavity margin after cavity preparation by a laser system alone and unfitness of the marginal area after the cavity filling. In addition, the occurrence of micro-cracks after laser irradiation may affect marginal leakage²¹⁻²⁴⁾.

In the dentin, leakage tests showed no significant difference between the restoration materials and among the polishing conditions for the laser or an air-turbine handpiece ($p>0.05$). The following tendency is shown in Fig. 5. The cavities prepared using the laser system showed a higher degree of leakage than those prepared using the air-turbine handpiece. This result may be due to the degeneration layer of the tooth substance after laser irradiation. Takano²⁴⁾ performed linear analysis of the laser-irradiated dentin by Energy Dispersive Spectroscopy and observed decreases in the Ca and P concentrations at a width of about $10\mu\text{m}$ from the cavity surface, suggesting dentin degeneration. Sakakibara *et al.*³⁰⁾ reported that the tensile bond strength of the dentin after laser irradiation is lower than that after cutting using a turbine depending on the bonding system, and the destruction mode is aggregation destruction in the dentin. In addition, they suggested that the decrease in bond strength is associated with the presence of a heat-induced degenerative layer. In the present study, the decrease in the marginal sealing in cavities after laser irradiation also suggested the presence of a degenerative layer. It is suggested that resin components permeated into degenerated dentin but did not reach normal dentin, and the dentin could not resist the polymerization contraction of the composite resin or loading tests and was destroyed, which decreased marginal sealing.

As for the polishing conditions used in present study, polishing was carried out on the same day. Nakamata *et al.*¹⁸⁾ reported that marginal leakage can be prevented by avoiding polishing on the same day and by performing polishing after one week immersion in water or using the resin impregnation method. Torstenson *et al.*²⁹⁾ reported that resin absorbed water and reached saturation after one week of immersion in water and also proposed the resin impregnation method. Composite resin restorations are often applied for cavities where cervical margins are left unetched, resulting in poorer adaptation in this area. They reported that by impregnating gaps with low-viscous resin after the filling has cured, one could obtain an improved seal at unetched margins. Marginal leakage can be readily prevented by the clinical application of this resin impregnation method. However, the polishing was carried out on the same day in this study. The main reason for that is to get a clearer degree of marginal leakage.

When hard tissue restoration is performed using the Er:YAG laser, the laser irradiation surface becomes rough, and the smooth surfaces obtained by the air turbine can not be obtained. Therefore, filling materials such as composite resin should be selected as restoration materials. In this study, marginal sealing in the enamel or dentin did not significantly differ between the Er:YAG laser and turbine ($p>0.05$). Takizawa *et al.*¹⁴⁾ reported that marginal sealing of composite resin restoration is similar for cavity prepared by laser irradiation and that prepared using a rotary cutting device, suggesting the usefulness of laser irradiation. Kusaka *et al.*²⁸⁾ reported that the marginal sealing in cavities prepared by Er:YAG laser irradiation is comparable with that of cavities prepared using the air turbine in all areas except the gingival side of the cervical cavity. Thus, composite resin restoration for cavities prepared by Er:YAG laser irradiation may be useful.

CONCLUSION

In the marginal sealing of the enamel or dentin, there were no significant differences between the Er:YAG laser and the air-turbine hand piece. The results of the present investigation suggest the usefulness of cavity preparation by Er:YAG laser irradiation especially for composite resin restoration.

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