—ORIGINAL ARTICLE—

Study on Microstructure of Adhesive Interface after Caries Removal by Er : YAG laser

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Abstract : The purpose of this study was to evaluate microstructure of adhesive interface after removal caries by Er : YAG laser. Observation of the micromorophology of adhesive interface was performed by Laser Scanning Microscope (LSM), Scanning Electron Microscope (SEM) and WDX type of electron probe X-ray microanalyzer (EPMA) .

The results were as follows :

1 . LSM images on the enamel and dentin cutting surfaces filled by composite resin system
The surface of the enamel cut by the Er : YAG laser system was showing a crack. While surface cut by an air-turbine hand piece was not showing a crack. The dentinal surface by laser irradiation and cut by an air-turbine hand piece did not show a crack.

2 . EPMA Analysis on the enamel or dentin interface filled by composite resin system
In SEM image, the cavity prepared by the laser had crack in the enamel. While the cavity prepared by turbine had hardly any cracks. When observed under an SEM, peripheral irregularities were more marked in the laser cut group than in the turbine cut group. The cavity prepared by the laser and turbine showed no cracks in the dentin. EPMA images showed that the decrease of calcium and phosphorus on the enamel and dentin area irradiated by Er : YAG laser were more remarkable than that on surfaces prepared by air-turbine handpiece.

The results of the present investigation suggested that the subsurface layers of the enamel and dentin area irradiated by Er : YAG laser were mechanically weakened due to the formation of structural defects and denatured layer, leading to considerably lower adhesive properties of resin bonding systems.

抄録：本研究では，レーザー照射歯面におけるコンポジットレジンの接着機構を明らかにすることを目的として，Er：YAGレーザーによるう蝕除去後の接着界面の検討を行った。接着界面の観察は，走査型共焦点レーザー顕微鏡（LSM）およびX線マイクロアナライザー（EPMA）を用いて行われた。

1．コンポジットレジン充填後の歯質切削面のLSMによる観察
エナメル質において，Er：YAGレーザーによる形成窩洞には，クラックが認められたが，タービンを用いた場合には，クラックは認められなかった。象牙質では，Er：YAGレーザーおよびタービンを用いた形成窩洞とも，クラックは認められなかった。

2．コンポジットレジン充填後の接着界面のX線マイクロアナライザーによる観察
SEM像において，Er：YAGレーザーによるエナメル質形成窩洞には，クラックが認められたが，タービンを用いた場合には，クラックは認められなかった。形成窩洞の辺縁は，タービンを用いたものより，レーザーを用いた方が，明らかに不規則であった。象牙質では，Er：YAGレーザーおよびタービンを用いた形成窩洞においては，共に，ク

ラックは認められなかった。EPMA像において，エナメル質および象牙質とも，タービンを用いた形成窩洞よりレーザーを用いた方が，CaとPの濃度の低下を認めた。

以上の結果から，Er：YAGレーザー照射により，エナメル質および象牙質表層に，コンポジットレジンの接着性を阻害する構造の欠陥や変性層が生ずることが示唆された。

INTRODUCTION

The main problem with the conventional caries treatment procedure was the irritation of the patient by the sound and vibration caused by the rotary cutting device. There were also 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[1].

In 1975, Zharikov *et al.*[2] developed the Er : YAG laser as a new technical modality for caries treatment. The Er : YAG laser is considered 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. Furthermore, applying the laser while spraying water reduced the damage caused to non-targeted tissue due to heating, and improved the cutting efficiency. In 1988, Hibst *et al.*[3] indicated that the irradiation of the Er : YAG laser could perform without causing cracks on the irradiation surface. Since then, a number of studies have been conducted on the Er : YAG laser . Clinical trials of the Er : YAG laser for caries treatment have gradually increased. At present, this laser is used clinically not only for the treatment of dental caries, but also for periodontics, endodontics and in other dental disciplines[4-10].

When the Er : YAG laser is used to repair hard tissue affected by caries or other disorders, restorative materials such as composite resin seem to be suitable on the grounds that the surface after laser irradiation is inevitably rough. The surface that Er : YAG laser was irradiated has features favorable for adhesion, e.g., the absence of smears and the presence of a dentinal tubule orifice[11-14]. The surface irregularities created by the laser do not lead to an increase in the bonding area or the formation of smear. These features are expected to favorably affect repair with composite resin, and contribute to improving the bonding strength and border seal. A number of studies have examined the strength of the bonding of composite resin to enamel and dentin laser irradiated[15-17]. Therefore, studying changes in the composition of tooth tissue following application of the Er : YAG laser is useful in developing optimal techniques of restoration following cavity preparation by this laser.

The purpose of this study was to evaluate microstructure of adhesive interface after removal caries by Er : YAG laser. Observation of the micromorophology of adhesive interface was performed by Laser Scanning Microscope (LSM), Scanning Electron Microscope (SEM) and WDX type of electron probe X-ray microanalyzer (EPMA).

MATERIALS AND METHODS

Apparatuses

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 caries was removed by laser irradiation, using a 0.6 mm diameter tip (FTB-80) and a 0.4 mm diameter tip (FTB-60), and spraying a mixture of air and water. On the other hand, as a control the caries was removed by rotary cutting device. The used burs were round-burs. Cutting was performed under high-speed water infusion. Cutting conditions are shown in Table 1. Dental adhesive systems and composite resins as restoration materials were used. Materials used are shown in Table 2. By the routine method, pretreatment using Mega-bond system (Kuraray medical inc., Okayama, Japan.) was performed, followed by restoration using Clearfil AP-X (Kuraray medical inc., Okayama, Japan.).

The following investigations were conducted :

In this study, newly extracted carious teeth that were diagnosed as unpreservable were used. The teeth had caries that extending to the dentin. The caries area of the examined teeth was dyed with the acid red (CARIES DETECTOR; Kuraray medical inc., Okayama, Japan.). The carious teeth were repeatedly dyed till

Table 1 Cutting conditions caries removal

rotary cutting device	
rotary cutting device used	burs used
air-turbine handpiece	carbide bur, round,
	ISO 010 (0.1 mm ϕ), 018 (0.18 mm ϕ)
micro-motor handpiece	steel bur, round,
	ISO 006 (0.06 mm ϕ), 010 (0.1 mm ϕ), 012 (0.12 mm ϕ)
	014 (0.14 mm ϕ), 016 (0.16 mm ϕ), 018 (0.18 mm ϕ)
Er:YAG laser	
output energy	enamel 200 mJ/pulse
	dentin 100 mJ/pulse
repetition rate	10 pps
volume of water	5.0 ml/ 1 min
contact tip	FTB-P60 (0.4 $\phi \times$5.0mm), FTB-80 (0.6 $\phi \times$5.0mm)

Table 2 Filling mterials

adhesive system	Batch no.	Manufacture
Mega-bond system	011192	Kuraray medical inc., Okayama, Japan
Composite resin	Batch no.	Manufacturer
Clearfil AP-X	00436A	Kuraray medical inc., Okayama, Japan

they were not dyed. The cavities were prepared using Er : YAG laser or the rotary cutting device. Prepared cavities were filled by composite resin system. Samples were washed by normal saline after the margins were finished with a fine diamond bur. 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). The micro-structures of cavities filled composite resin were observed using LSM (OLS1100; OLYMPUS OPTICAL Corp., Tokyo, Japan) from the lateral side after sectioning the specimens. And an Electron Probe Microanalyzer (WAX type, EPMA 8705, Shimadzu, Kyoto, Japan) was used to produce the SEM image. Specimens were also viewed with EPMA for elemental distribution of Ca and P on the enamel or dentin interface.

RESULTS

(1) Observation of Microstructure on the irradiated surface by laser scanning microscope (LSM)

Fig. 1 shows the reference specimens of LSM images on the enamel and dentin cutting surfaces after removal caries. The enamel cutting surfaces by laser and an air-turbine hand piece did not show a crack. Also, the dentinal cutting surfaces by laser and an air-turbine hand piece did not show a crack. Fig. 2 shows the reference specimens of LSM images on the enamel and dentin cutting surfaces filled by composite resin system. The surface of the enamel cut by the Er : YAG laser system was showing a big crack. While, the surface cut by an air-turbine hand piece

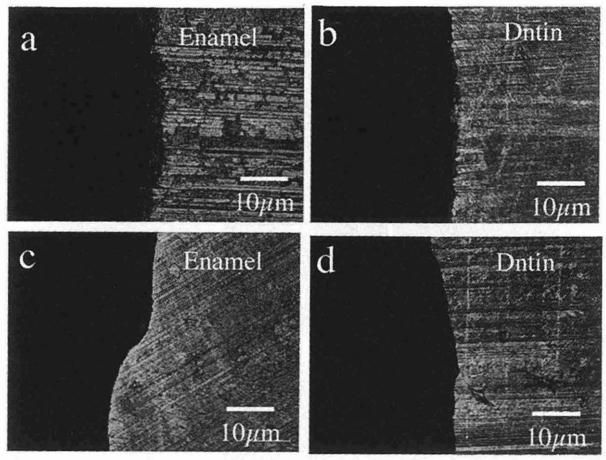

Fig. 1 LSM images of the enamel and dentin cutting surface.

a : the enamel cutting surface by Er:YAG laser
b : the dentin cutting surface by Er:YAG laser
c : the enamel cutting surface by air-turbine
d : the dentin cutting surface by air-turbine

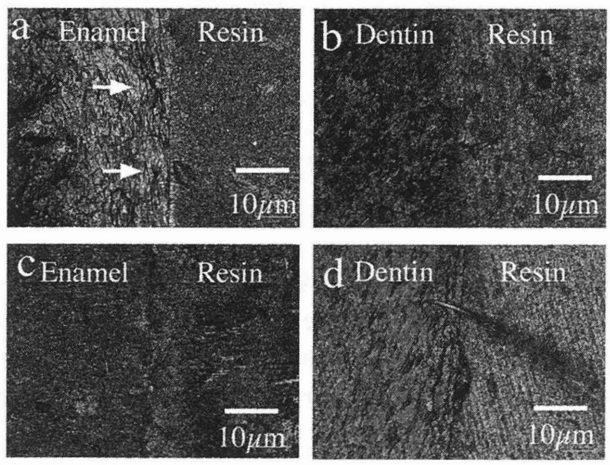

Fig. 2 LSM images of the enamel and dentin cutting surfaces filled by composite resin system.

a : the enamel cutting surface by Er:YAG laser
b : the dentin cutting surface by Er:YAG laser
c : the enamel cutting surface by air-turbine
d : the dentin cutting surface by air-turbine

was not a crack. The dentinal cutting surface by laser irradiation and the surface cut by an air-turbine hand piece did not show a crack.

(2) WDX Analysis on the enamel or dentin interface filled by composite resin system

Fig. 3 shows representations of the SEM and the EPMA images of the enamel after resin filling. In SEM image, the cavity prepared by the laser had crack. While the cavity prepared by turbine had hardly any cracks. When observed under an SEM, peripheral irregularities were more marked in the laser cut group than in the turbine cut group.

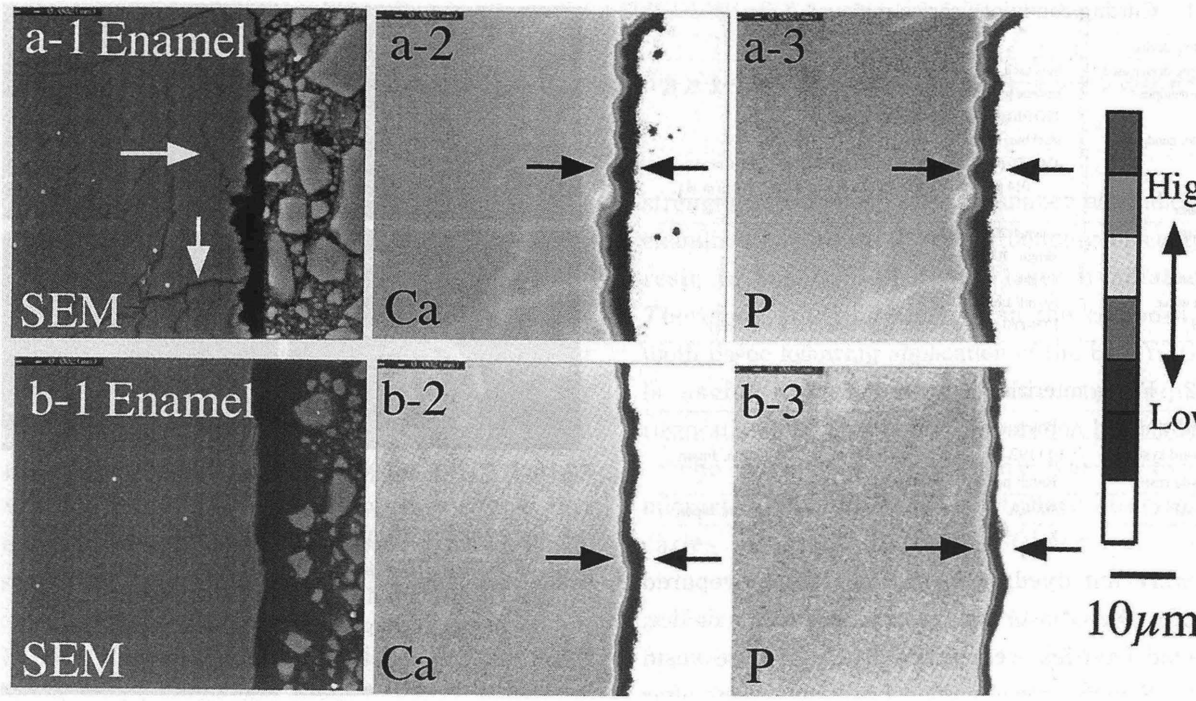

Fig. 3 SEM and WDX images of the enamel after resin filling.
a-1 : SEM image of cavity preparation by Er:YAG laser
a-2 : calcium characteristic density
a-3 : phosphorus characteristic density
b-1 : SEM image of cavity preparation by air-turbine
b-2 : calcium characteristic density
b-3 : phosphorus characteristic density

Decalcified layers, i.e. layers with reduced calcium and phosphorus levels, were seen in the laser cut group. Fig. 4 shows representations of the SEM and EMPA images of the dentin after resin filling. In SEM image, the cavity prepared by the laser and turbine showed no cracks. The laser cut surface had more minute cracks compared to the turbine cut surface. When observed under an SEM, the laser cut surface was poorly demarcated and had more minute cracks compared to the turbine cut surface. Decalcified layers were seen in the laser cut group.

DISCUSSION

Previous investigation showed the morphological changes that occur in the hard tissue after the application of Er : YAG laser by LSM[14]. The surface of the enamel prepared by the Er : YAG laser system was rough, showing micro-cracks, and that prepared by an 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. Regarding the morphological changes by Er : YAG laser irradiation, Takano[11] 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.*[18] 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 *et al.*[12] observed the cervical enamel and root dentin after the removal of root surface caries by Er : YAG laser irradiation, and reported that some thick cracks and a number of minute cracks were seen in the periphery of the enamel. However, they could not determine whether the microcracks developed during laser irradiation. In the present investigation, a crack was seen on the laser-applied surface of the enamel after composite resin filling. It is likely that cracks appeared as a result of tissue destruction that occurred when the tissue could not resist the shrinkage of composite resin due to the presence of laser-induced degeneration of the tissue constituting the cavity wall. These cracks may affect the outcome

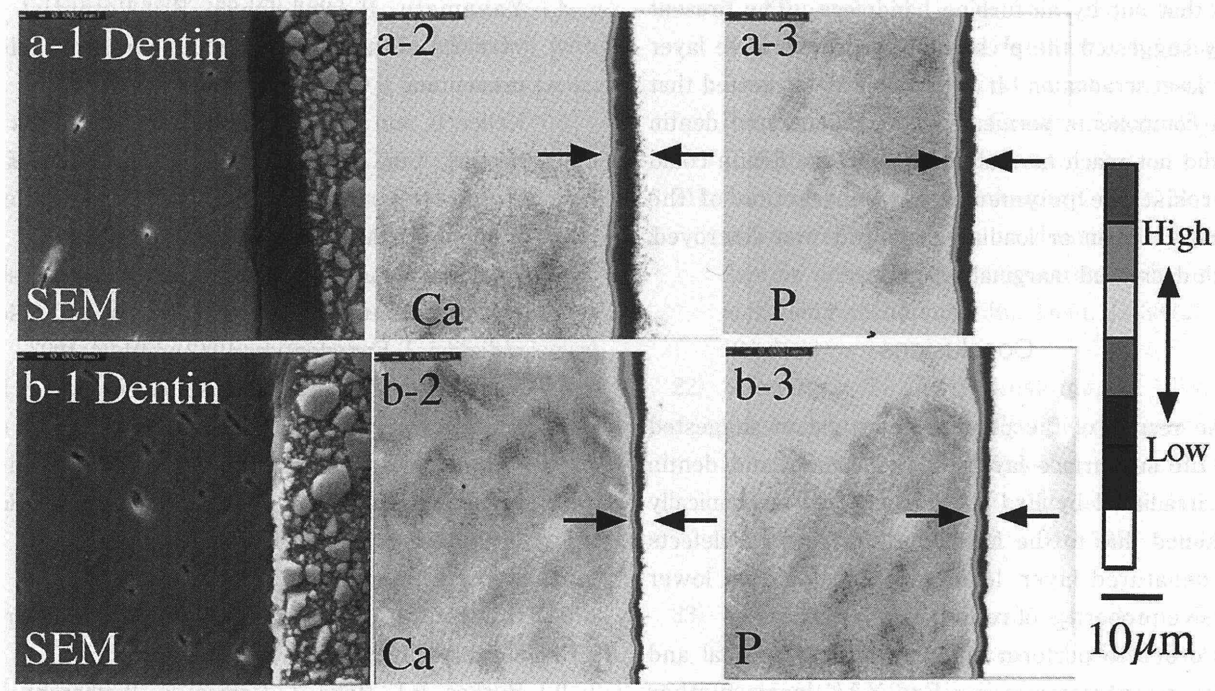

Fig. 4 SEM and WDX images of the dentin after resin filling.
a - 1 : SEM image of cavity preparation by Er:YAG laser
a - 2 : calcium characteristic density
a - 3 : phosphorus characteristic density
b - 1 : SEM image of cavity preparation by air-turbine
b - 2 : calcium characteristic density
b - 3 : phosphorus characteristic density

of composite resin restoration following laser cavity preparation. Previous investigation showed there were no significant differences between the Er : YAG laser and the air-turbine hand piece in the marginal sealing of the enamel or dentin[19]. However, the data was dispersive 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 leakage[20-23]. The Er : YAG laser system uses wavelengths that are selectively absorbed by moisture in tissue. It cuts the tooth by the explosive force created when water evaporates instantaneously. For this reason, the difference in water contents and structure between enamel and dentin can cause differences in the cut plane, possibly leading to the formation of cracks. To prevent cracks, it seems advisable to use pretreated materials with high tooth permeability, to apply the laser at low power levels at the end of laser cavity preparation for the purpose of removing denatured layers, and to perform round beveling.

Takano *et al.*[11] measured changes in calcium and phosphorus levels in the 10-30 μm area showing cracks, using EPMA. In their analysis, the decrease in calcium and phosphorus levels was less marked in the enamel than in the dentin. In the present investigation, the enamel showed sharp changes in both calcium and phosphorus levels following exposure to the laser at a power level of 200 mJ/pps. The dentin, on the other hand, showed no sharp change in calcium or phosphorus level as the laser power was changed. As the laser power was increased, the number of cracks formed in the enamel increased, while hardly any cracks were formed in the dentin. We previously conducted a morphological study using an LSM of teeth following laser application and determined the optimal conditions of laser application[14]. In that study, the optimal laser power was estimated as 200 mJ/pps for the enamel and 100 mJ/pps for the dentin when the cutting efficiency and effects on the pulp during cavity preparation were taken into consideration. EPMA image shows calcium and phosphorus concentration on the enamel and dentin area irradiated by Er : YAG laser were lower than that cut by air-turbine handpiece. The present study suggested the presence of a degenerative layer after laser irradiation. It is particularly 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.

Conclusions

The results of the present investigation suggested that the subsurface layers of the enamel and dentin area irradiated by Er : YAG laser were mechanically weakened due to the formation of structural defects and denatured layer, leading to considerably lower adhesive properties of resin bonding systems.

In order to perform effective caries removal and cavity preparation using Er : YAG laser, further studies are required on the conditioning of the irradiated surface for adhesive restoration. Especially, structural changes and finishing of the margin on the irradiated cavity should be investigated more minutely.

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