Microleakage of composite resin restoration in cavities prepared by Er,Cr:YSGG laser irradiation and etched bur cavities in primary teeth

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In this in vitro *study, the surface alterations of enamel and dentin in cavities prepared by Er,Cr:YSGG laser irradiation was investigated by scanning electron microscopy and compared to the microleakage degree after composite resin restoration with etched bur cavities in human primary teeth. The results confirmed that laser cavity surface facilitated a good adhesion with the restorative materials; the acid etch step can be easily avoided with the laser treatment.*
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INTRODUCTION

The steps in the carious dentin removal or cavity preparation in a primary teeth often require precise operator control because of some particular characteristics, which include: the pulpal outline follows the dentin-enamel junction more closely than in the case in permanent teeth, and the dentin is not as thick. Therefore, cavity preparation using a less traumatic system such as laser systems may be favorable in pediatric dentistry.

The potential applications of the Er:YAG and Er,Cr:YSG lasers on dental hard tissue treatment such as carious dentin removal or cavity preparation for restorations have been explored by a number of investigators and the application in the dental clinic has been expected. These lasers can ablate enamel and dentin more effectively due to the highly efficient absorption in both water and hydroxyapatite.[1] The ability of Er:YAG laser to remove enamel and dentin was found comparable to that achieved with the conventional dental drill[2-3] and produces minimal thermal damage to the pulp or surrounding tissues, especially when irradiated with continuous water spray.[4-7]

Animal histological studies showed that pulpal response to the Er:YAG laser appears to be similar to the response from high-speed hand piece application.[8-9] 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 soft-tissue surgery as well as for cutting enamel, dentin and bone.[10-11] When dental hard tissues were irradiated by the Er,Cr:YSGG laser accompanied with a water spray, not only could the temperature be suppressed, but cutting efficiency could be increased.[10-11]

Histological studies showed that no pulpal inflammatory responses could be identified in Er,Cr:YSGG laser irradiated with a water spray.[12-13] Studies on surface alterations of the enamel and dentin after Er,Cr:YSGG laser irradiation shows that these surfaces are associated with micro-irregularities and there was also the absence of a smear layer.[11] It is possible that alterations of the surface textures of enamel and dentin after Er,Cr:YSGG laser irradiation may affect microleakage of restorative materials in primary teeth. However, there are no reports regarding this matter.

The purpose of this study was to investigate the surface alterations of enamel and dentin in cavities prepared by Er,Cr:YSGG laser irradiation and compare the microleakage degree after composite resin restoration with etched bur cavities in human primary teeth, *in vitro*.

MATERIALS AND METHODS

Cavity preparation

A total of twenty-five extracted human primary teeth with no carious lesions were used for this study. On the

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buccal and lingual (palatal) surfaces of each tooth, two shallow cavities (diameter; 3 mm, depth; 2 mm) were prepared; one with the laser system and one with a high-speed turbine. From these teeth, 25 lasers and 25 bur cavities were produced.

Laser cavities were prepared using an Er,Cr:YSGG laser system (MillenniumTM, Biolase Technology Inc., San Clemente, CA, USA) emitting photons at a wavelength of 2.78µm, pulsed with a duration between 140 and 200µm, and a pulse repetition rate of 20 pulses per second (20 Hz). The output power could be varied from 0 to 6W. The beam spot size was 0.442 x mm^2 with the use of a 750µm diameter fiber at the distance of 2-3mm.

At the beginning of cavity preparation, we carefully performed laser irradiation in a contact mode to remove enamel with a focused beam of 6W (67.9 J/cm2) at maximum air pressure level and 32% water level. As enamel removal progressed and the treated cavity floor became deeper and closer to the underlying dentin layer, we reduced the power to 3W (33.9 J/cm2) at 70% air level and 20% water level, and cavities were carefully finished by means of the non-contact irradiation mode.

The mechanical cavities were prepared by using a high-speed turbine (Astron Mini α, J. Morita, Tokyo, Japan) with a #3411 diamond bur (Shofu Inc., Kyoto, Japan). The following investigations were performed during and/or after the cavity preparation:

Assessment of cavity preparation

The time required for cavity preparation was determined for each treatment, and the differences in the times required were statistically analyzed by using Mann-Whitney U test; a value of P<0.01 was considered significant. Furthermore, thermal change was measured at the time of each treatment using a thermovision device of 870 system (AGEMA, infrared systems AB, Danderyd, Sweden) linked to a personal computer (PC-AT).

Morphological study of prepared cavities

To verify the surface characteristic, five laser and five bur cavities were examined macroscopically using a stereoscope (SMZ-10, Nikon, Tokyo, Japan). For SEM studies, these cavities were bisected (only bur cavities were acid etched), dehydrated in a grade series of aqueous ethanol (70%, 80%, 90%, 100% ethanol) for 24 hours in each solution, dried by liquid CO_2 using a critical point dryer device (JCPD-3, JEOL, Tokyo, Japan), coated with platinum layer and observed by scanning electron microscopy (SEM) (JSM-T220A, JEOL, Tokyo, Japan) at 20kV.

Microleakage test

The remaining 20 laser and 20 bur cavities were subjected to microleakage test. Bur cavities were acid-etched with a 30% phosphoric acid gel (Clearfil etching agent, Kurary Co., Kurashiki, Japan) for 30 seconds, washed with water spray for another 30 seconds, and dried with air for 20 seconds. None of the laser cavities were acid-etched.

These cavities were filled with a light-curing composite resin (Clearfil Photo Bond, Kurary Co., Kurashiki, Japan) according to the instructions of the manufacturer. First, primer was applied for 30 seconds, dried with an air spray. Next bonding agent was applied, and light activated for 20 seconds, and finally, filled with composite resin and light cured for 40 seconds. All specimens were then polished with white points (Shofu White Points, Shofu Inc., Kyoto, Japan).

The whole tooth surfaces except for the areas of filling cavities and 1mm outside margins of cavities were double-coated with a nail varnish. The specimens were then immersed in a 0.6% rodamine B solution (Muto Chemical Co., Tokyo, Japan) under a thermocycling bath for 48 hours. The temperature was set at 50˚C for 12 hours, followed at 4˚C for another 12 hours; this cycle was repeated again. After rinsing with tap water, the samples were bisected at a bucco-lingual (palatal) plane with a diamond saw disc (Isomet, Buehler, IL).

The degree of microleakage using dye penetration was scored in a blinded manner based on a 4-grade scale (as shown in Table 1) under a stereoscope by a technician, who was not informed of the true nature and purpose of these experiments. Thus, the judgment

Table 1. Criteria for the Microleakage Degree

Scores	Contents
0	No dye penetration
1	Dye penetration through the cavity margin reaching the enamel tissue
2	Dye penetration through the cavity margin reaching the dentin tissue
3	Dye penetration through the cavity margin reaching the cavity floor portion

Table 2. Results of mean time required and thermal change during cavity preparation

	Time Required (sec)	Thermal Change (˚C)
Laser cavity	87.50 ± 3.81*	2.5 ± 0.27
Bur Cavity	18.90 ± 3.06*	1.8 ± 0.21

*Significant difference (P<0.01)

Table 3. Results of Microleakage test in the laser and bur cavities

Scores	0	1	2	3	Mean ± SD
Laser cavity	16	2	1	1	0.35 ± 0.93*
Bur cavity	17	1	1	1	0.30 ± 0.94*

* Not statistically significant (p<0.01)

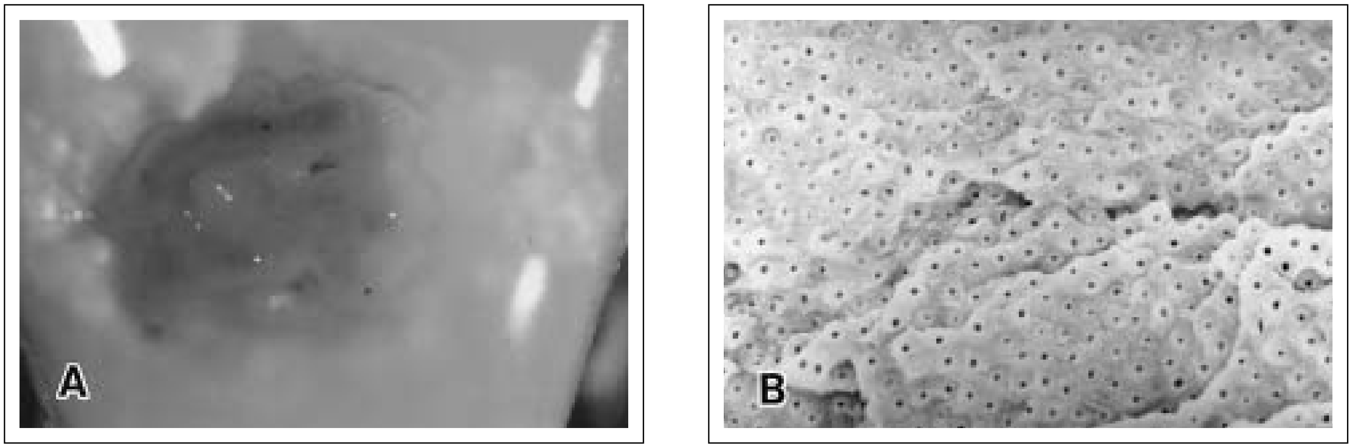

Figure 1. Representative photographs of the cavity prepared by Er,Cr:YSGG laser irradiation. (A). In stereoscopic observation, laser cavity showed an irregular surface with the absence of any charring, carbonization and cracking of the enamel and dentin. (B). In SEM observation, the dentin surface was irregular and there was also an absence of smear layer; the orifices of the dentinal tubules were exposed. (original magnification x1000, bar represents 25μm).

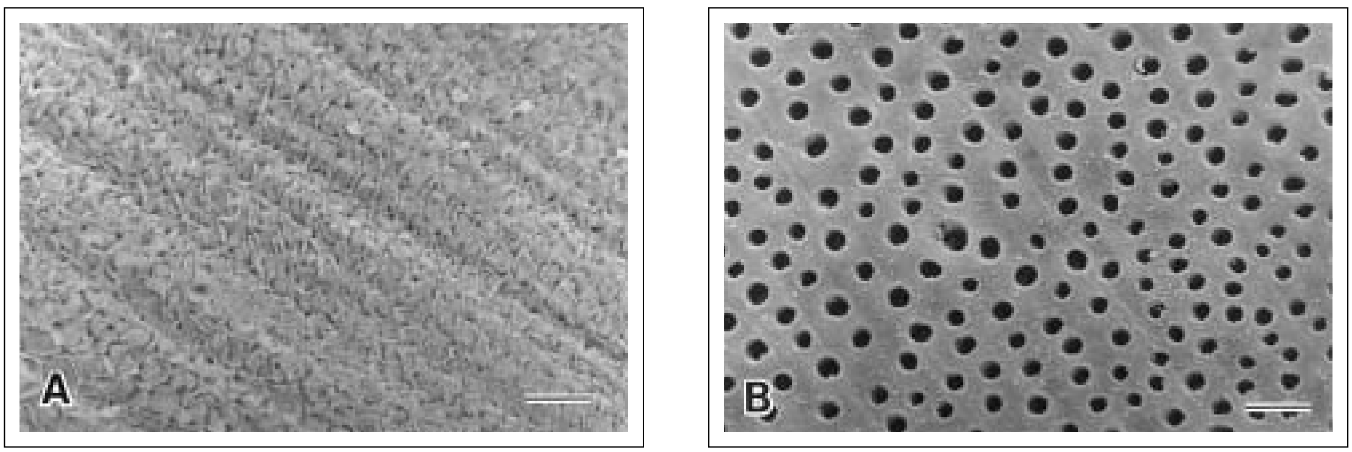

Figure 2. Representative SEM photographs of etched bur cavity. (A). In the enamel, there was an absence of smear layer. Enamel rods were clearly visible, and between the enamel surface and a clearly displayed protruding prism sheath, the body of the prism had been eroded away (original magnification x1000, bar represents 25μm). (B). In the dentin, there was also an absence of smear layer and the orifices of the dentinal tubules were exposed. (original magnification x1000, bar represents 25μm).

of microleakage degree was kept blind. Where the scores were different on both sides, the worse score was used in the evaluation. Statistical analysis was performed using the Mann-Whitney's U test. A value of $p<0.01$ was considered significant.

For further investigation to evaluate the gap between the dental material and dental hard tissues of each sample, cut surfaces were polished with wet silicon carbide paper, and then observed by the SEM.

RESULTS

Assessment of cavity preparation

The mean required time of laser and bur treatment was 87.50 ± 3.81 sec and 18.90 ± 3.06 sec (mean ± SD), respectively (Table 2). The laser irradiation time was longer than the bur treatment, which was statistically significant ($P<0.01$). Furthermore, the mean temperature rise during cavity preparation with the laser and bur treatment was 2.5 ± 0.27 and 1.8 ± 0.21, respectively (Table 2).

Morphological study of prepared cavities

Macroscopically, laser cavity revealed a rough or irregular surface with the absence of any charring, carbonization, or cracking of the enamel and dentin (Figure 1-A).

SEM observation showed a scaly appearance or irregular surface due to micro-irregularities after laser irradiation (Figure 1-B). In addition, there was an absence of a smear layer; enamel rods were found intact, and the orifice of dentinal tubules was exposed. The intertubular dentin had more ablation than the peritubular dentin, showing a protrusion of the tubules.

On the other hand, cavity surfaces prepared by using the bur showed the well-delimited cavity angles, floors and walls, clear margins and relatively smooth cavity floors. SEM observation revealed a relatively flat

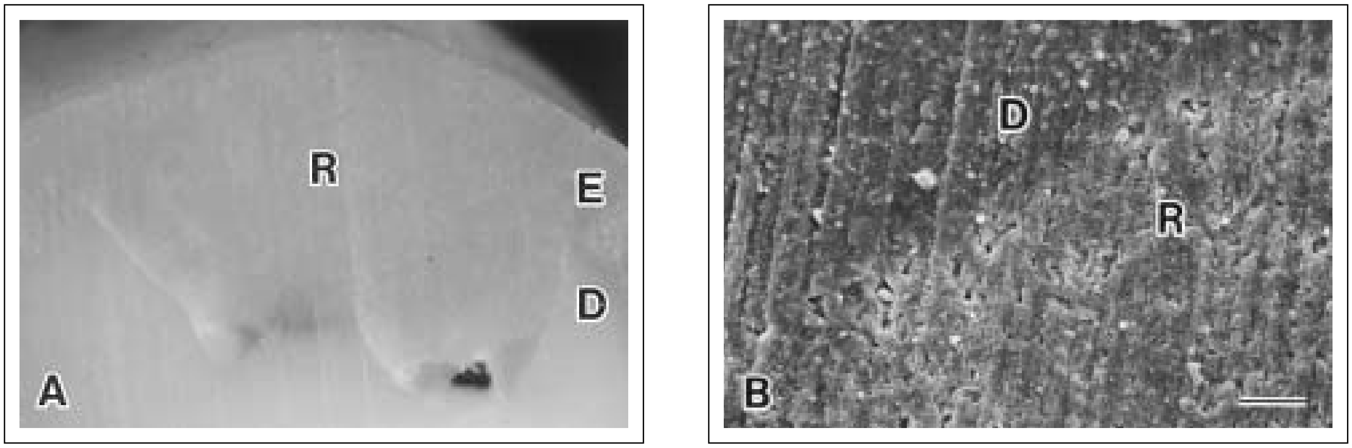

Figure 3. Representative photographs of the cross section of the filled Er,Cr:YSGG laser cavity after microleakage test. (A). In stereoscopic observation, good adaptation was observed between enamel, dentin and resin cement and no microleakage was detected (Score 0) (E: enamel; D: dentin; R: resin). (B). In SEM observation, the resin (R)-dentin (D) interface was also intact. (original magnification x1000, bar represents 25μm).

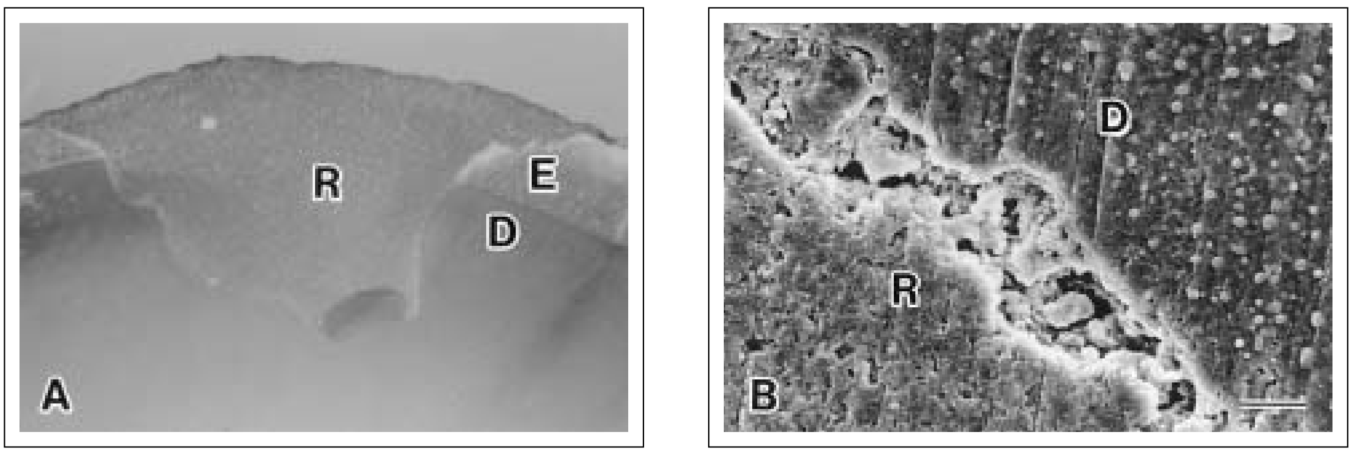

Figure 4. Representative photographs of the cross section of the filled Er,Cr:YSGG laser cavity with complete microleakage (score 3). (A). In stereoscopic observation, loss of adhesion between enamel, dentin and resin cement was seen and dye penetration through the cavity margin reaching the cavity floor (E: enamel; D: dentin; R: resin). (B). In SEM observation, gap formation between the resin cement (R) and dentin (D) was observed. (original magnification x1000, bar represents 25μm).

appearance and was almost covered with a debris-like smear layer; enamel rods were not visible and dentinal tubule orifices were plugged. After acid etching, the smear layer was completely removed and enamel rods or dentinal tubules were clearly visible (Figures 2-A, B). In addition, between the enamel surface and a clearly displayed protruding prism sheath, the body of the prism had been eroded away (Figure 2-B).

Microleakage test

Table 3 shows the result of microleakage scores found in this study. No microleakage (score 0) was detected in 16 lasers (80%) cavities and 17 (85%) etched bur cavities, as seen in stereoscopic observation of the cross cut sections of these cavities. SEM observation also showed no gaps between the composite resin and dental hard tissues (Figures 3-A, B). However, 1 (10%) lasers and 1 (10%) bur cavities showed complete microleakage (score 3) and the remaining cavities were associated with score 1 and 2 degree of microleakage. It seemed that microleakage was due to a gap formation between the resin cement and dental hard tissues as seen in stereoscopic and SEM observation (Figures 4-A, B).

DISCUSSION

Assessment of cavity preparation

In the present study, at the beginning of cavity preparation, irradiation was performed in a contact mode with maximum energy density of 6W (67.9 J/cm^2) because the removal of enamel tissues was more difficult with this laser device. Cutting the enamel by laser has a lower efficiency than cutting the dentin due to less water and organic contents of enamel structures.[11,14] When the treated cavity floor became deeper and closer to the underlying dentin layer, we reduced the power to 3W (33.9 J/cm^2) and cavities were carefully finished by means of the non-contact irradiation mode. This technique might prolong the required time for cavity preparation with the laser device; the required time for use of the laser was several times longer than the high-speed bur treatment which corresponded to the previous studies using the Er:YAG laser.[7] In the clinic, it is possible to reduce the time by increasing the energy densities; in particular, the output power can be increased for cutting the dentin, but it may increase the risk of thermal pulpal damage and was therefore avoided for this study.

The results of thermal change revealed that the surface mean temperature did not exceed 4°C (Table 1), that is believed to be beyond the considered safe limit for pulpal survival.[15] Furthermore, no pulpal inflammatory responses could be identified in Er,Cr:YSGG laser irradiated with a water spray as reported in the previous histological studies.[12-13]

Clinical reports also showed that when compared to the bur treatment, patients feel less pain during cavity preparation with the laser system, and in some cases anesthesia was not needed.[16] Therefore, based on the present study together with previous studies, it can be suggested that under adequate water spray or with a careful irradiation technique, cavities without thermal damage to the dental pulp can be produced; in addition, patients will experience less pain and anxiety with the laser device.

Morphological study of prepared cavities

The result of SEM observation in the laser cavities showed some particular characteristic features. The lased cavity surface was irregular, and there was also the absence of a smear layer; enamel rods were found intact, and the orifices of dentinal tubules were exposed. Typically, these structures were similar to the enamel and dentin surfaces after Er:YAG or Er,Cr:YSGG laser irradiation and have previously been described as scaly or flaky, or as an irregular surface.[2-3,10-13] It is believed that micro-irregularity is associated with the micro-explosion effects proposed as the mechanism of hard tissue ablation with Er:YAG laser or Er,Cr:YSGG laser.[1] On the other hand, the bur cavity surface showed a relatively flat appearance and exhibited a debris-like smear layer (Figure 3), which may interfere with adhesion, wetting, penetration, and hardness of the prepared cavity.[17-18]

After phosphoric acid etching, the smear layer was completely removed; enamel rods and dentinal tubules were clearly visible. In addition, enamel surface clearly displayed protruding prism sheath, between which the body of the prism had been eroded away. Chemical changes may also produce modification of the fraction of organic matter and decalcification of the inorganic component.[19-21] Laser technique might perform better because it leaves an etching behavior and does not damage the underlying tissues and dental pulp. The use of laser therapy also shows promise from the current research. Laser therapy induced surface roughness comparable to that of acid etching, and facilitated or even improved bond strength or decreased marginal microleakage.[22-30] Therefore, the acid etch step can be easily avoided with laser treatment and can decrease the total treatment time.

Microleakage test

The results of microleakage test confirmed that Er,Cr:YSGG laser cavity surfaces facilitated good adhesion with the restorative materials. No significant differences between the laser and etched bur cavities were found. These results corresponded to previous studies using the Er:YAG laser in permanent teeth.[31-33] Sixteen laser (85%) and 17 (85%) etched bur cavities showed no microleakage between the restoration and cavity surfaces. When cross cut sections of these cavities were examined by SEM, good adhesion between the restorative material and dental hard tissues were noted, there was also no gap at the interface. The highly irregular surfaces without a smear layer could provide a suitable surface for good adhesion or strong bonding with restorative materials as reported in the previous studies using the Er:YAG laser.[28-30] It was thought that openings of dentinal tubules after laser treatment might facilitate the formation of a hybrid zone, since primer and adhesive can penetrate the surface better when the smear layer is removed. However, one laser and one bur cavity showed complete microleakage.

SEM observation of the interfaces at cross sections of these samples showed that the microleakage was due to a gap formation. Gaps can be produced due to loss of adaptation of the resin cement with dental hard tissues, less penetration of the resin cement into the dentinal tubules, insufficient curing of the composite resin or due to entrapped air at the time of placing the restorative materials. Surface treatment can use in large restorations as suggested in a previous study using the Er,Cr:YSGG laser in Class II cavities of the permanent teeth[34], or an improvement of the resin cement especially resin cement having good flow is required for the laser cavities in large restorations.

CONCLUSION

From the above results, it can be concluded that Er,Cr:YSGG laser irradiation is favorable to remove carious dental hard tissues or cavity preparation in pediatric dentistry because it does not damage the surrounding tissues. Furthermore, the need for an acid etch step could be easily avoided in laser cavities, especially in shallow cavities. Further investigations regarding using greater sample sizes or large restorations as well as clinical evaluations are required to confirm these results.

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