Microleakage of composite resin restoration in cavities prepared by Er:YAG laser irradiation in primary teeth

Y. YAMADA, M. HOSSAIN, Y. NAKAMURA, Y. MURAKAMI, K. MATSUMOTO

ABSTRACT. Aim The purposes of this study were to investigate the surface morphology of cavities prepared by Er:YAG laser irradiation and to compare the microleakage degree after composite resin restoration with etched bar cavities in primary teeth, in vitro. Materials and methods On the buccal (facial) and lingual (palatal) surfaces of 25 primary teeth, a round cavity was prepared with the Er:YAG laser system and with a high-speed diamond bur, respectively. Five cavities from each group were investigated by scanning electron microscopy (SEM). The remaining cavities were filled with a composite resin and subjected to a microleakage test (0.6% rodamine B solution) under thermocycling. Only bur cavities were acid-etched before filling. Statistical analysis was performed using the Mann-Whitney’s U test; a value of p <0.01 was considered significant. Results SEM observation of the laser and etched bar cavities revealed an absence of a smear layer; enamel rods and opening of dentinal tubules were recognized. No statistically significant differences were noted between microleakage of composite resin restorations of the laser and the etched bar cavities. Crosscut sections of the cavities with no microleakage showed good adhesion between the restorative material and dental hard tissues; there was also no gap at the interface. Discussion The highly irregular surface or the removal of the debris-like smear layer after laser irradiation may facilitate good adhesion of composite resin with enamel or dentine, and these surfaces might play a major role in decreasing microleakage of laser cavities. Conclusion It can be concluded that cavities prepared by Er:YAG laser are capable of decreasing microleakage of composite resin restorations in primary teeth, and the efficiency is similar to etched bar cavities.

KEY WORDS: Cavity preparation, Primary teeth, Er:YAG laser, Composite resin restoration, Microleakage

Introduction

The potential applications of the Er:YAG laser on dental hard tissue treatment, such as the removal of carious dentine or cavity preparation for restorations, have been studied by a number of investigators. The ability of this laser to remove dentine and enamel was found comparable to that achieved with the conventional dental drill [Hibst and Keller, 1989; Keller and Hibst, 1989]. The Er:YAG laser ablates dental hard tissues effectively, due to its highly efficient absorption in both water and hydroxyapatite [Wigdor et al., 1995] and produces minimal thermal damage to the pulp or surrounding tissues, especially when irradiated with continuous water spray [Li et al., 1992; Burkes et al., 1992; Wigdor et al., 1993; Visuri et al., 1996a; Hossain et al., 1999]. When dental hard tissues were irradiated by the Er:YAG laser accompanied with fine water mist, not only could the temperature be suppressed, but cutting efficiency could be increased [Burkes et al., 1992; Visuri et al., 1996a]. An animal histological study showed that pulp response to the Er:YAG laser appears to be similar to the response from high-speed hand piece application [Sonntag et al., 1996]. It can be considered that Er:YAG laser irradiation is favourable to carious tissue removal or cavity preparation in the primary tooth because it does not damage the pulp and surrounding tissues. It is possible that alterations of the surface textures of enamel and dentine after Er:YAG laser irradiation may affect microleakage of restorative materials in primary teeth. However, there are no reports regarding this matter.

The purposes of this study were to investigate the surface morphology of cavities prepared by
Er:YAG 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 25 extracted human primary teeth with no carious lesions were used for this study. On the buccal surface of each tooth, one round cavity (diameter: 3 mm, depth: 3 mm, about 2 mm occlusally to the cement-enamel junction) was prepared with the laser system and one cavity on the lingual surface, with a high-speed turbine (Fig. 1a, b). From these teeth, 25 laser and 25 bur cavities were prepared.

The laser cavity was prepared using an Er:YAG laser system (Key Laser 1242, KaVo Dental GmbH, Jena, Germany) emitting photons at a wavelength of 2.94 µm. The output power and pulse repetition rate of this laser device can be varied from 60 to 500 mJ and 1 to 15 pulses per second (pps), respectively. At the beginning of cavity preparation, we carefully performed laser irradiation in a non-contact mode to remove enamel with a focused beam of 400 mJ (50.9 J/cm²) energy density with a pulse repetition rate of 2 pulses per second (2 Hz) under continuous water mist (1 mL/min). As enamel removal progressed and the treated cavity floor became deeper and closer to the underlying dentin layer, we reduced the energy density to 200 mJ (25.5 J/cm²). The beam spot size was maintained at 1 mm from the distance of 2-3 mm.

The mechanical cavities were prepared 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 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 using Mann-Whitney’s 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 an 870 system (AGEMA, infrared systems AB, Danderyd, Sweden) linked to a personal computer (PC-AT).

**Morphological study of prepared cavities.** To verify the surface characteristics, five lasers and five bur cavities were examined macroscopically using a stereoscope (SMZ-10, Nikon, Tokyo, Japan). In further 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. They were then dried with liquid CO₂ using a critical point dryer device (J CPD-3, J E O L , Tokyo, Japan), coated with a platinum layer and observed by scanning electron microscopy (SEM) (JSM-T220A, J E O L , Tokyo, Japan) at 15 or 20 kV.

**Microleakage test.** The remaining 20 lasers and 20 bur cavities were subjected to the microleakage test. Bur cavities were acid etched with a 30% phosphoric acid gel (Clearfil, 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 then filled with a light-curing composite resin (Clearfil Photo Bond, Kurary Co., Kurashiki, Japan) according to the manufacturer’s instructions. First, the primer was applied for 30 seconds, dried with an air spray and, secondly, the bonding agent was applied and light activated for 20 seconds. Finally, the cavities were 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 filled cavities and 1 mm outside the margins of the cavities, were double-coated with 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 by 4°C for another 12 hours; this cycle was repeated. After rinsing with tap water, the samples were bisected at a buccolingual plane with a diamond saw disc (Isomet, Buehler, IL, USA). The degree of microleakage using dye penetration was scored in a blinded manner based on a 4-grade scale (Table 1).

<table>
<thead>
<tr>
<th>Scores</th>
<th>Contents</th>
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<tbody>
<tr>
<td>0</td>
<td>No dye penetration</td>
</tr>
<tr>
<td>1</td>
<td>Dye penetration through the cavity margin reaching the enamel tissue</td>
</tr>
<tr>
<td>2</td>
<td>Dye penetration through the cavity margin reaching the dentine tissue</td>
</tr>
<tr>
<td>3</td>
<td>Dye penetration through the cavity margin reaching the cavity floor</td>
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</table>

**Table 1 - Criteria for assessing the degree of microleakage in composite resin restorations in lased or bur cut cavities in primary teeth.**
under a stereoscope by a technician who was not informed of the true nature and purpose of these experiments. Thus, the judgment of the degree of microleakage was kept blind. Where the scores were different at both sides, the worse score was used in the evaluation. Statistical analysis was performed using the Mann-Whitney's U test and 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 SEM.

**Results**

Assessment of cavity preparation. The mean time required for bur and laser treatment was 18.9±2.09 sec and 107.5±5.65 sec (mean±SD), respectively. The laser irradiation time was several times longer than the bur treatment, which was statistically significant ($p < 0.01$). Furthermore, the mean temperature rise during cavity preparation with the bur and laser treatment was 1.2±0.13 and 2.5±0.35, respectively.

Morphological study of prepared cavities. Macroscopically, cavity surfaces using the bur showed well-delimited cavity angles, floors and walls, clear margins and relatively smooth cavity floors (Fig. 1a). On the other hand, laser cavities revealed a rough or irregular surface with the absence of any charring, carbonization, or cracking of the enamel and dentine (Fig. 1b).

SEM observation showed that cavity surfaces prepared with the bur revealed a relatively flat appearance and were 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 (Fig. 2a). In addition, between the enamel surface and a clearly displayed protruding prism sheath, the body of the prism had been eroded away. On the other hand, laser cavities revealed a rough or irregular surface with the absence of any charring, carbonization, or cracking of the enamel and dentine (Fig. 1b).
hand, a scaly appearance or irregular surface due to micro-irregularities was noted after laser irradiation (Fig. 2b). 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 dentine had more ablation than the peritubular dentine showing a protrusion of the tubules.

**Microleakage test.** Table 2 shows the result of microleakage scores found in this study. Due to good adaptation of the resin cement with enamel and dentine, no microleakage (score 0) was detected in 16 (80%) etched bur cavities and 15 lasers (75%) cavities, as seen in stereoscopic observation (Fig. 3a). SEM observation of the cross cut sections also showed no gaps between the composite resin and dental hard tissues (Fig. 3b). However, 2 (10%) lasers and 2 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 (Fig. 4a, 4b).

<table>
<thead>
<tr>
<th>Group</th>
<th>Microleakage Scores</th>
<th>Mean ± SD</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Bur</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Laser</td>
<td>15</td>
<td>2</td>
</tr>
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No significant difference was found between bur and laser cavities (p < 0.01)

**TABLE 2** - Results of microleakage tests on composite resin restorations in primary teeth.

**Fig 3** - Representative photographs of the cross section of the filled Er:YAG laser cavities after microleakage test. In stereoscopic observation, good adaptation was observed between enamel, dentine and resin cement and no microleakage was detected (Score 0) (E: enamel; D: dentine; R: resin) (a). In SEM observation, the resin-dentine interface was also intact (b) (original magnification x1000, bar represents 20 µm).

**Fig. 4** - Representative photographs of the cross section of the filled Er:YAG laser cavities with complete microleakage (score 3). In stereoscopic observation, loss of adhesion between enamel, dentine and resin cement was seen and dye penetration through the cavity margin reaching the cavity floor (E: enamel; D: dentine; R: resin) (a). In SEM observation, gap formation between the resin cement and dental hard tissues was observed (b) (original magnification x1000, bar represents 20 µm).
**Discussion**

Assessment of cavity preparation. The steps in cavity preparation in a primary tooth often require precise operator control because they have some particular characteristics; their pulpal outline follows the dentine-enamel junction more closely than in the case of permanent teeth, and the dentine is not as thick. Mechanical preparation often induces pain, and local anesthesia is therefore needed. It is often difficult to establish exactly how much tooth material should be removed, which often leads to overextended cavities [Cederlund et al., 1999]. On the other hand, the time needed for cavity preparation with the laser system is long compared with traditional techniques. There are also thermal side effects such as melting, cracking of enamel or dentine, and an increase in the pulpal temperature has been a major problem with the laser device [Aoki et al., 1988; Wigdor et al., 1993; Wigdor, 1995].

As some degree of heat generation is inevitable with the Er:YAG laser, we performed a careful irradiation technique. At the beginning of cavity preparation, irradiation was performed at a high energy density of 400 mJ with a repetition rate of 2 pulses per second for enamel cutting, because the removal of enamel tissues was more difficult with this laser device [Li et al., 1992; Hossain et al., 1999]. When the treated cavity floor became deeper and closer to the underlying dentine layer, we reduced the power to 200 mJ and cavities were finished by means of the non-contact irradiation mode. This might prolong the required time for cavity preparation, which was several times longer than the high speed bur treatment corresponding to a previous study using the Er:YAG laser [Aoki et al., 1998]. In the dental clinic, it is possible to improve the cutting efficiency by changing the energy densities. In particular, the repetition rate can be increased for cutting enamel or dentine, but it may raise the risk of thermal pulp damage, and, therefore, it was 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 pulp survival [Zach and Cohen, 1965]. Furthermore, animal histological studies showed that the pulp response to the Er:YAG laser would appear to be similar to that from a high speed hand piece application [Sonntag et al., 1996]. Clinical reports of cavity preparation with this laser device showed that, when compared with the bur treatment, patients feel less pain during cavity preparation with the laser system, and in some cases anesthesia was not needed [Keller et al., 1998]. Therefore, based on the present study together with previous ones, it can be suggested that cavity preparations with a less traumatic technique such as a laser system may be favourable in paediatric dentistry. 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, so the dentist can offer this service to children as an alternative to needles and drills.

Morphological study of prepared cavities. The results of SEM observation showed that the lased cavity surface was irregular, and there was also the absence of a smear layer; enamel rods were found intact, and the orifice of dentinal tubules was exposed (Fig. 2b). Typically, these surfaces have previously been described as scaly or flaky, or as irregular surfaces [Hibst and Keller, 1989; Keller and Hibst, 1989; Burkes et al., 1992; Aoki et al., 1998; Hossain et al., 1999]. It is believed that microirregularity is associated with the microexplosion effects proposed as the mechanism of hard tissue ablation with the Er:YAG laser [Hibst and Keller, 1989; Keller and Hibst, 1989]. On the other hand, the bur cavity surface showed a relatively flat appearance and exhibited a debris-like smear layer, which may interfere with adhesion, wetting, penetration, and hardness of the prepared cavity [Smith, 1982].

After phosphoric acid etching, the smear layer was completely removed; enamel rods and dentinal tubules were clearly visible (Fig. 2a). In addition, the enamel surface clearly displayed a 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 [Pashley, 1992; Bertolotti, 1992]. The laser technique might perform better because it leaves out an etching application and does not damage the underlying tissues and dental pulp. The use of laser therapy also seems promising from current research. Laser therapy induces surface roughness comparable to that of acid etching, and facilitates or even improves bond strength or decreases marginal microleakage [Cooper et al., 1988; Powell, 1992; Arcoria et al., 1993; Keller and Hibst, 1993; Visuri
et al., 1996b]. Therefore, the acid etch step can easily be avoided with laser treatment and can decrease the total treatment time.

Microleakage test. The results of the microleakage test confirmed that Er:YAG laser cavity surfaces facilitated good adhesion with the restorative materials. No significant differences between the laser and bur cavities were found and these results corresponded to a previous study using the Er:YAG laser [Wright et al., 1993]. Of the total, 15 laser (75%) and 16 (80%) etched bur cavities showed no microleakage between 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 was 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 previous studies using the Er:YAG laser [Keller and Hibst, 1993; Visuri et al., 1996b]. It has been thought that openings of dentinal tubules after laser treatment might facilitate the formation of a hybrid zone, as a primer and an adhesive can penetrate the surface better when the smear layer is removed. However, two laser and two bur cavities showed complete microleakage (score 3). 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. There may also be air entrapped when placing the restorative materials. It can be suggested that an improvement of the resin cement is often required for laser cavities especially. Resin cement having a good flow might perform better to decrease microleakage in laser cavities or a surface treatment can be used before placing a restoration into the laser cavities for better wetting and penetration.

Conclusion
It can be concluded that cavities prepared by Er:YAG laser are capable of decreasing microleakage of composite resin restorations in primary teeth, and its efficiency is similar to etched bur cavities. Further investigations on larger sample sizes or bigger restorations, as well as clinical evaluations, are required to confirm these results.

References


