Effect of cavity preparation with Er:YAG laser on marginal integrity of resin composite restorations

Takeshi Shinoki, DDS,[a] Junji Kato, DDS, PhD,[a] Masayuki Otsuki, DDS, PhD,[a] and Junji Tagami, DDS, PhD[a,b]

[a]Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School of Medical and Dental Sciences, and [b]Global Center of Excellence (GCOE) Program; International Research Center for Molecular Science in Tooth and Bone Diseases, Tokyo Medical and Dental University, Tokyo, Japan

Purpose: The purpose of this *in vitro* study was to evaluate the effect of cavity preparation with erbium-doped: yttrium-aluminum-garnet (Er:YAG) laser on marginal integrity of resin composite restorations.
Materials and Methods: Twenty-one extracted human molars were divided in three groups and saucer-shaped cavity approximately 1.5 mm in depth and 2 mm in diameter was prepared on the mid-coronal surface of each tooth by Er:YAG laser at 150 mJ/10 pps, 200 mJ/10 pps or a diamond bur. After restoration with a self-etch adhesive and a resin composite, enamel cracks and gap formations at the cavosurface margin were evaluated using a digital microscope on the surface and the crosscut surface of the restoration.
Results: The cavities prepared by a diamond bur caused more enamel cracks and gap formations than lased cavities at 150 mJ/10 pps. There were no statistical differences of crack and gap formation between restored cavities by Er:YAG laser at 150 mJ and 200 mJ.
Conclusion: It was concluded that the preparation by Er:YAG laser at suitable output energy showed the better marginal integrity of resin composite restorations than that by a rotary cutting instrument.
(Asian Pac J Dent 2011; 11: 19-25.)
Key Words: composite resin, laser, marginal integration

Introduction

Since the erbium-doped: yttrium-aluminum-garnet (Er:YAG) laser with a wavelength of 2.94 µm, was introduced in dentistry,[1,2] a lot of basic and clinical studies on Er:YAG laser have been published. The Er:YAG laser is absorbed by water and hydroxyapatite, which partially accounts for its efficiency in cutting enamel and dentin.[3] The Er:YAG laser could remove caries in tooth structures together with sound enamel and dentin with minimal thermal effects in the adjacent hard and soft tissues.[2] The Er:YAG laser appears to be one of the best suited laser types for cavity preparation.[3]

Generally, the cavity preparation using Er:YAG laser takes more time, compared to rotary cutting instruments.[4,5] However, that preparation method advantages include low noise and vibration, eliminating, in most cases, the need for local anesthesia.[6] Clinical studies suggested that the application of the Er:YAG laser system was a more comfortable alternative or adjunctive method than conventional mechanical cavity preparation.[5]

In 1997, the Food and Drug Administration of United States cleared for marketing the first Er:YAG laser for use in preparing human dental cavities.[7] Er:YAG laser was suitable for the caries removal and the cavity preparation based on the minimal intervention dentistry[8] and adhesive restorative dentistry. The Er:YAG laser system is promising as a new technical modality for caries treatment.[4]

There were many *in vitro* researches about bonding of the adhesive materials to Er:YAG laser irradiated enamel and dentin, including micromorphological studies on their interface. However, there were few reports about marginal microleakage of the restoration of the cavity prepared by Er:YAG laser. The purpose of this *in vitro* study was to evaluate the effect of cavity preparation with Er:YAG laser on marginal integrity of resin composite restorations.

Materials and Methods

Cavity preparation and restoration

Twenty-one extracted intact human molars were used in this study. The research design adopted in this experiment, in particular on the use of extracted human teeth, was subjected to the guideline of the Ethics Committee of the Faculty of Dentistry, Tokyo Medical and Dental University. There were no cracks observable on the tested surfaces of the teeth confirmed using a light microscope (x50). The teeth were divided into three experimental groups of each of seven (n=7). Saucer-shaped cavity approximately 1.5 mm in depth and 2 mm in diameter was prepared on the mid-coronal buccal surface of each tooth as follows: Group 1; Each cavity was prepared using an Er:YAG laser (Erwin AdvErL, J. Morita, Kyoto, Japan) with a crystal contact tip (600 µm in diameter, C600F, J. Morita) at 150 mJ and 10 pps under water spray coolant with 2 L/min of air flow and 7 mL/min of water flow. The wavelength of the laser was 2.94 µm and its pulse duration was 300 ms. Group 2; The cavity was prepared with the Er:YAG laser at 200 mJ and 10 pps. The other conditions were same as Group 1. Group 3 (control group); Each cavity was prepared using an air turbine handpiece (Twinpower Turbine P PAR-EX-O D1, J. Morita) and a regular grit round-shape diamond bur (1.3 mm in diameter, #1440, Shofu, Kyoto, Japan) at 400,000 rpm under copious water spray coolant. Then round bevel was placed at cavo-surface margin using same bur.

All margins were placed in enamel. Each cavity was restored with a two-step self-etch adhesive (Clearfil SE Bond, Kuraray Medical, Tokyo, Japan) and a restorative resin composite (Clearfil Majesty, Kuraray Medical) according to the manufacturer's instruction as following procedure. Each cavity was applied with the Primer of Clearfil SE Bond for 20 s and then dried with air. The Bond of Clearfil SE Bond was coated and the excess bonding resin was removed with gentle air stream, then photo-irradiated for 10 s using a blue light emitted diode curing unit (700 mW/cm^2, Pencure, J. Morita). The treated cavity was filled with a restorative resin composite as a bulk and photo-cured for 40 s. Excess composite resin was removed to expose cavosurface margin with an air turbine handpiece and a flame-shaped super-fine diamond bur (SF215, Shofu, Kyoto, Japan), and polished with silicone points (M2 and M3, Shofu) and a micromotor handpiece at low speed under copious water.

Observation of margin and interface

After storage in water for 24 hours, 1.0% acid red propyleneglycol solution (Caries Detector, Kuraray Medical) was applied on the margin of the restorations for 5 s, and then rinsed with water to enable the detection of cracks and gaps. The enamel margin was divided into eight areas and enamel cracks and marginal gaps were observed using a digital microscope (x200, VC3000, Omron, Kyoto, Japan) and scored (present; 1, not present; 0) in each area.

After the evaluation of cavosurface margin, the specimens were cut longitudinally to expose a crosscut surface of the center of the restoration. All the obtained crosscut surfaces were polished carefully using silicon carbide papers. The dye was applied and washed, then observed and scored (present; 1, not present; 0) to determine enamel cracks and gap formation at the occlusal and gingival margins using a digital microscope. The number of cracks and gaps were statistically analyzed using Mann-Whitney U test ($p<0.05$).

Observation of prepared cavity surface

Cavities were prepared as same as those of Groups 1, 2 and 3 using other extracted teeth. These cavity surfaces and margins were observed using a digital microscope and a laser microscope (VK-8500, Keyence, Osaka, Japan).

Results

Typical images of cavosurface margin on the surface of the restoration were shown in Fig. 1. The opaque white line which was called white margin was distributed the margin of the restoration (Fig. 1a). The small gap formation was observed at the cavosurface margin of the restored teeth by digital microscope and small enamel cracks were also found closed to the margin (Fig. 1b and 1c). However, gap formation or enamel crack was not found around the white margin.

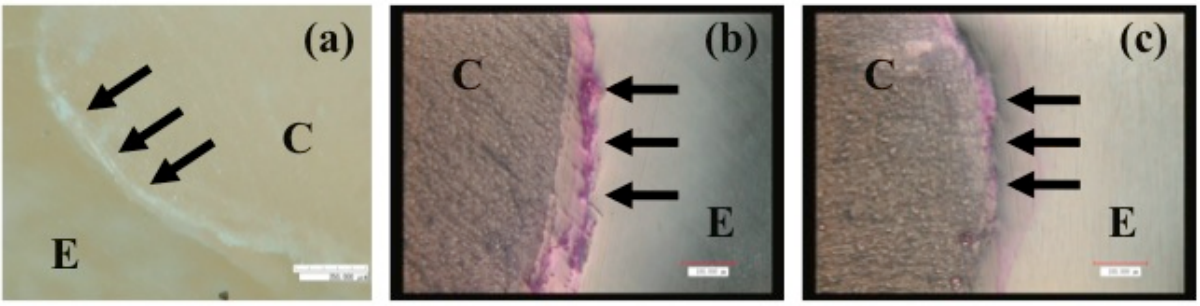

Fig. 1. Typical images of cavosurface margin on the surface of the restoration. Original magnification was x200. E; enamel, C; composite resin. (a) White margin (arrows) was observed (Group 3). (b) Enamel crack (arrows) was observed around the cavosurface margin (Group 2). (c) Gap formation (arrows) was observed at the cavosurface margin (Group 2).

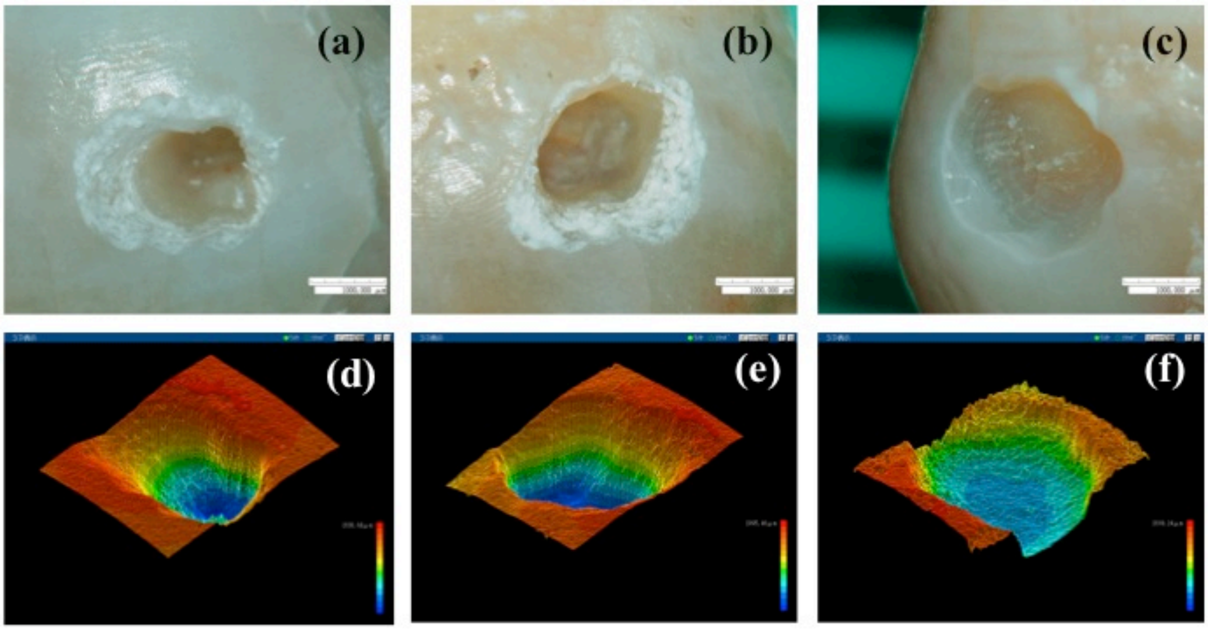

Fig. 2. Typical image of the cavities before restoration. (a), (d) Group 1, (b), (e) Group 2, (c), (f) Group 3. (a)-(c) Image by a digital microscope, (d)-(f) Image by a laser microscope. Marginal enamel was chalky and irregular in Groups 1 and 2. The depth of cavity could be confirmed by a laser microscope.

The score of the enamel crack and gap formation at the cavosurface margin was shown in Table 1. There are more enamel cracks and gap formations in Group 3 than in Groups 1 and 2. The score of enamel crack and gap formation of Group 3 was statistically higher than that of Group 1. There are no statistical difference between the scores of Group 1 and Group 2. The score of the enamel crack and gap formation at the margin on the crosscut surface was shown in Table 2. More enamel cracks and gap formations were observed in Group 3 than Group 1 and Goup2. The score of enamel crack and gap formation of Group 3 was statistically higher than that of Group 1 at occlusal margin. There are no statistical difference between the scores of Group 1 and 2.

Typical images of the cavity before restoration were shown in Fig. 2. Marginal enamel was chalky and irregular in Groups 1 and 2. The marginal enamel in Group 2 seemed to be rougher than that in Group 1.

Table 1. Score of the crack and gap formation at the cavosurface margin

Sample	Group 1		Group 2		Group 3	
	Crack	Gap	Crack	Gap	Crack	Gap
1	1	0	1	1	2	1
2	0	1	1	0	2	2
3	0	0	1	1	1	1
4	1	1	0	0	2	0
5	0	0	0	0	2	1
6	0	0	1	1	2	1
7	0	0	0	0	2	1
Total	2	2	4	3	13	7

Table 2. Score of the crack and gap formation on the crosscut surface

Sample	Group 1				Group 2				Group 3			
	Occlusal		Gingival		Occlusal		Gingival		Occlusal		Gingival	
	Crack	Gap	Crack	Gap	Crackr	Gap	Crack	Gap	Crack	Gap	Crack	Gap
1	0	0	0	0	0	1	0	0	0	0	1	0
2	0	0	0	1	1	0	0	0	0	0	1	1
3	0	0	0	0	0	0	0	0	0	1	0	0
4	0	0	1	0	0	0	0	0	0	0	1	0
5	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	0	0	0	0	1	0	0	1	0	0
7	0	0	0	0	0	0	0	0	1	0	0	1
Total	0	0	1	1	1	1	1	0	2	2	3	2

Discussion

The use of the Er:YAG laser to treat dental hard tissue is both safe and effective for caries removal, cavity preparation and enamel etching.[7] By the investigation of the patients' response to Er:YAG laser preparation of teeth, the application of the Er:YAG laser is a more comfortable alternative or adjunctive method than conventional mechanical cavity preparation.[5,9] The Er:YAG laser is promising as a new technical modality for caries treatment[4] and appears to be one of the best suited laser types for cavity preparation.[3]

The mechanism of dental hard tissues removal by a laser is called "thermomechanical process", "photothermal fragmentation" or "ablation". The energy delivered by Er:YAG laser has one of the highest absorption in water, and has a high affinity for hydroxyapatite. During irradiation, the water heats and evaporates, resulting in a high pressure of steam that causes a micro-explosion of tooth tissue below its melting point. Vaporization of the water within the mineral substrate causes the surrounding material to literally explode away.[3] This mechanism characterizes the morphological aspects of the irradiated enamel and dentin surfaces.

The surface of enamel and dentin after irradiation of Er:YAG laser are specific characteristics which are different from the surface prepared by rotary cutting instruments. The enamel irradiated by the Er:YAG laser shows a characteristic chalky surface. Micromorphology of the Er:YAG laser-treated enamel depicted a retentive pattern similar to acid etched enamel and the anatomical features of enamel rods were preserved.[3]

The dentin surfaces irradiated by Er:YAG laser were irregular, scaly or flaky and dentinal tubules were opened without smear layer.[10] Vaporization of intertubular dentin is greater than that of peritubular dentin, showing a protrusion of the dentinal tubules with a cuff-like appearance.[3] Although the dentin surface irradiated by Er:YAG laser seems to increase restorative material retention,[11] this surface and subsurface contained acid resistant layer and decalcified layer.[10] However, the cavity preparation techniques did not alter the composition[11,12] and microhardness of dentin tissue.[11] These surface characteristics could affect the bonding to restorative materials.

Bond strengths to Er:YAG-lased tooth substrate reported in the literature are often confusing and contradictory.[3] Some studies reported the higher bond strengths to laser-conditioned dentin than to acid-etched dentin.[13,14] Laser irradiated samples improved bond strengths compared with acid-etched and handpiece controls. Er:YAG laser preparation of dentin leaves a suitable surface for strong bonding of an applied composite material. Er:YAG laser might eliminate the need for acid-etching dentin as a pretreatment for composite bonding[14] or was likely to slightly improve the resistance of resin-dentin interface to acid-base challenge.[15] However, others reported significantly lower bond strengths.[16-20] The total-etch adhesive bonded significantly less effectively to lased than to bur-cut enamel and dentin, and laser conditioning was clearly less effective than acid etching. Cavities prepared by laser appear less receptive to adhesive procedures than conventional bur-cut cavities.[16] Er:YAG laser ablation to dentin adversely affected the microtensile bond strength and the sealing ability of Clearfil SE Bond bonded to dentin.[20] On the other hand, bond strength values obtained in bur-prepared samples were similar to Er:YAG laser values in terms of initial periods of evaluation.[21] Because of different experimental conditions, various results might be available.

There are many factors affecting bond of resin to tooth substrates. The conditions of laser irradiation were very effective, such as wavelength, pulse duration, irradiation time, power density, amount of water and air stream, distance between tooth and tip, free-hand vs. uniform irradiation.[22] Other conditions can be also listed as follows, that is, methods of bond tests (shear bond test[14,16,17] vs. tensile bond test[22,23] vs. microtensile bond test),[16,18,20,21] enamel vs. dentin, sound dentin vs. caries affected dentin, adhesive materials, with and without pulpal pressure,[20] superficial dentin vs. deep dentin,[17] with/without thermal stress and long-term storage.[21] Bond strength is strongly related with the occurrence of marginal microlekage and adaptation of cavity wall and restored material. The adhesive resin used in present study is considered to be one of the best materials.

Marginal microleakage of the restoration induces recurrent caries. Improved marginal integrity and adaptation of the resin-cavity interface are essential for the prevention of recurrent caries.[24] In this study, small enamel cracks were detected around interface between enamel and composite resin. The cavosurface margins were located in the enamel, which is brittle. If the bonding is strong enough, the shrinkage stress may lead to crack initiation and propagation within the bonded substrate. Tooth fracture is still a frequently occurring problem caused by induced contraction stresses when the polymerization shrinkage takes place under constrained conditions with the composite bonded between cavity walls.[24-26]

Adaptation at the resin-cavity interface has often been investigated for *in vitro* evaluation of the restorative materials and techniques as well as bond strength. Although microleakage evaluation is one of the most common methods for assessing the sealing efficiency of restorative materials, a gold standard has not been established for this method yet.[27] In this study, surface and crosscut surface of the restoration were observed by a digital microscope.[24,28]

A two-step self-etching adhesive system Clearfil SE Bond was employed in this study. This material has shown acceptable marginal sealing[29] and high bond strength.[30] This material was also used for the evaluation of lased tooth surfaces.[15,18,19,20,23] The self-etch adhesive performed equally to lased as to bur-cut enamel, but significantly less effectively to lased than to bur-cut dentin.[19]

In this study, irradiation with Er:YAG laser caused less enamel cracks and gap formation than rotary cutting instrumentation. Statistical differences were not found between the irradiation with the lower output energy and the higher one for enamel cracks and gap formation. It was concluded that the preparation by Er:YAG laser at suitable output energy showed the better marginal integrity of resin composite restorations than that by a rotary cutting instrument.

Acknowledgments

This work was partially supported by a grant from the Japanese Ministry of Education, Global Center of Excellence (GCOE) Program, "International Research Center for Molecular Science in Tooth and Bone Diseases".

References

1. Hibst R, Keller U. Experimental studies of the application of the Er:YAG laser on dental hard substances: I. Measurement of the ablation rate. Lasers Surg Med 1989; 9: 338-44.
2. Keller U, Hibst R. Experimental studies of the application of the Er:YAG laser on dental hard substances: II. Light microscopic and SEM investigations. Lasers Surg Med 1989; 9: 345-51.
3. De Moor RJ, Delme KI. Laser-assisted cavity preparation and adhesion to erbium-lased tooth structure: Part 1. Laser-assisted cavity preparation. J Adhes Dent 2009; 11: 427-38.
4. Aoki A, Ishikawa I, Yamada T, Otsuki M, Watanabe H, Tagami J, et al. Comparison between Er:YAG laser and conventional technique for root caries treatment in vitro. J Dent Res 1998; 77: 1404-4.
5. Keller U, Hibst R, Geurtsen W, Schilke R, Heidemann D, Klaiber B, et al. Erbium:YAG laser application in caries therapy. Evaluation of patient perception and acceptance. J Dent 1998; 26: 649-56.
6. Liu JF, Lai YL, Shu WY, Lee SY. Acceptance and efficiency of Er:YAG laser for cavity preparation in children. Photomed Laser Surg 2006; 24: 489-93.
7. Cozean C, Arcoria CJ, Pelagalli J, Powell GL. Dentistry for the 21st century? Erbium:YAG laser for teeth. J Am Dent Assoc 1997; 128: 1080-7.
8. Tyas MJ, Anusavice KJ, Frencken JE, Mount GJ. Minimal intervention dentistry--a review. FDI Commission Project 1-97. Int Dent J 2000; 50: 1-12.
9. Keller U, Hibst R. Effects of Er:YAG laser in caries treatment: a clinical pilot study. Lasers Surg Med 1997; 20: 32-8.
10. He Z, Otsuki M, Sadr A, Tagami J. Acid resistance of dentin after erbium: yttrium-aluminum-garnet laser irradiation. Lasers Med Sci 2009; 24: 507-13.
11. Celik EU, Ergucu Z, Turkun LS, Turkun M. Effect of different laser devices on the composition and microhardness of dentin. Oper Dent 2008; 33: 496-501.
12. Bakry AS, Sadr A, Inoue G, Otsuki M, Tagami J. Effect of Er:YAG laser treatment on the microstructure of the dentin/adhesive interface after acid-base challenge. J Adhes Dent 2007; 9: 513-20.
13. Moritz A, Gutknecht N, Schoop U, Goharkhay K, Wernisch J, Sperr W. Alternatives in enamel conditioning: a comparison of conventional and innovative methods. J Clin Laser Med Surg 1996; 14: 133-6.
14. Visuri SR, Gilbert JL, Wright DD, Wigdor HA, Walsh JT Jr. Shear strength of composite bonded to Er:YAG laser-prepared dentin. J Dent Res 1996; 75: 599-605.
15. Bakry AS, Sadr A, Takahashi H, Otsuki M, Tagami J. Analysis of Er:YAG lased dentin using attenuated total reflectance Fourier transform infrared and X-ray diffraction techniques. Dent Mater J 2007; 26: 422-8.
16. De Munck J, Van Meerbeek B, Yudhira R, Lambrechts P, Vanherle G. Micro-tensile bond strength of two adhesives to Erbium:YAG-lased vs. bur-cut enamel and dentin. Eur J Oral Sci 2002; 110: 322-9.
17. Ceballo L, Toledano M, Osorio R, Tay FR, Marshall GW. Bonding to Er-YAG-laser-treated dentin. J Dent Res 2002; 81: 119-22.
18. Van Meerbeek B, De Munck J, Mattar D, Van Landuyt K, Lambrechts P. Microtensile bond strengths of an etch & rinse and self-etch adhesive to enamel and dentin as a function of surface treatment. Oper Dent 2003; 28: 647-60.
19. Dunn WJ, Davis JT, Bush AC. Shear bond strength and SEM evaluation of composite bonded to Er:YAG laser-prepared dentin and enamel. Dent Mater 2005; 21: 616-24.
20. Bakry AS, Nakajima M, Otsuki M, Tagami J. Effect of Er:YAG laser on dentin bonding durability under simulated pulpal pressure. J Adhes Dent 2009; 11: 361-8.
21. do Amaral FL, Colucci V, de Souza-Gabriel AE, Chinelatti MA, Palma-Dibb RG, Corona SA. Adhesion to Er:YAG laser-prepared dentin after long-term water storage and thermocycling. Oper Dent 2008; 33: 51-8.
22. Aizawa K, Kameyama A, Kato J, Oda Y, Hirai Y. Influence of free-hand vs uniform irradiation on tensile bond strength in Er:YAG-lased dentin. J Adhes Dent 2008; 10: 295-9.
23. Kameyama A, Kato J, Aizawa K, Suemori T, Nakazawa Y, Ogata T, et al. Tensile bond strength of one-step self-etch adhesives to Er:YAG laser-irradiated and non-irradiated enamel. Dent Mater J 2008; 27: 386-91.
24. Ikeda I, Otsuki M, Sadr A, Nomura T, Kishikawa R, Tagami J. Effect of filler content of flowable composites on resin-cavity interface. Dent Mater J 2009; 28: 679-85.
25. Jörgensen KD, Asmussen E, Shimokobe H. Enamel damages caused by contracting restorative resins. Scand J Dent Res 1975; 83: 120-2.
26. Causton BE, Miller B, Sefton J. The deformation of cusps by bonded posterior composite restorations: an in vitro study. Br Dent J 1985; 159: 397-400.
27. Yamazaki PC, Bedran-Russo AK, Pereira PN, Wsift EJ Jr. Microleakage evaluation of a new low-shrinkage composite restorative material. Oper Dent 2006; 31: 670-6.

28. Nishimura K, Ikeda M, Yoshikawa T, Otsuki M, Tagami J. Effect of various grit burs on marginal integrity of resin composite restorations. J Med Dent Sci 2005; 52: 9-15.
29. Ernst CP, Galler P, Willershausen B, Haller B. Marginal integrity of class V restorations: SEM versus dye penetration. Dent Mater 2008; 24: 319-27.
30. Omar H, El-Badrawy W, El-Mowafy O, Atta O, Saleem B. Microtensile bond strength of resin composite bonded to caries-affected dentin with three adhesives. Oper Dent 2007; 32: 24-30.

Correspondence to:

Dr. Masayuki Otsuki
Cariology and Operative Dentistry, Tokyo Medical and Dental University
1-5-45 Yushima Bunkyo-ku, Tokyo 113-8549, Japan
Fax: +81-3-5803-0195 E-mail: otsuki.ope@tmd.ac.jp

Accepted January 19, 2011.

 Online ISSN 2185-3487, Print ISSN 2185-3479