Change of dentin surface by low-power irradiation of erbium-doped yttrium aluminum garnet laser

Akira Nakane, DDS, Masayuki Otsuki, DDS, PhD, and Junji Tagami, DDS, PhD

Cariology and Operative Dentistry, Department of Restorative Sciences, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan

Purpose: The objective of this study was to evaluate the effect of low output power irradiation of erbium-doped yttrium aluminum garnet (Er:YAG) laser on surface morphology, roughness, and microhardness of the root dentin.
Materials and Methods: Flat root dentin surfaces were prepared from extracted human molars. The surfaces were irradiated by an Er:YAG laser at 10 pps, 30 mJ, sweeping at approximately 2 mm/s by hand. Irradiated power was changed by means of the distance between laser tip and surface kept at 0, 5, 10, 15, 20, 25, 30, 35, and 40 mm. No irradiated surface was employed as control. Those surfaces and crosscut surfaces were observed by a scanning electron microscope (SEM). Specimens of irradiation distance at 0, 5, 10, 20, 30, and 40 mm and control (no irradiation) were further prepared and then, surface roughness (Ra) and microhardness (Vickers hardness) were measured.
Results: Ablation of dentin was observed at distance between 0-15 mm. At 20-30 mm, degenerated layer was observed without ablation. At 35 and 40 mm, ablation and degenerated layer were not found. Ra values of all experimental groups (0-40 mm) showed statistically higher than that of control group ($p < 0.05$). Among the experimental groups, 0 mm group showed statistically higher Ra values than the other groups ($p < 0.05$). For Vickers hardness, no significant difference was found all groups except 0 mm group ($p > 0.05$).
Conclusion: It was concluded that specific low output power Er:YAG laser irradiation produced thin degenerated layer on the root dentin without ablation. This irradiated surfaces showed slight increase of roughness without decrease of microhardness.

(Asian Pac J Dent 2019; 19: 33-37.)

Key Words: Er:YAG laser; low level laser therapy; root dentin

Introduction

The laser was first developed in 1960 [1] and this technology went through a continuous development and an increasing utilization in many fields including medicine. The laser technology was soon introduced for dentistry in 1966 [2]. Recently, various lasers have been used for both soft tissues and hard tissues in clinical dentistry. Among them, erbium-doped yttrium aluminum garnet (Er:YAG) laser can remove caries in tooth structures together with sound enamel and dentin under minimal thermal effects in the adjacent hard and soft tissues [3]. The Er:YAG laser appears to be one of the best suited laser types for cavity preparation [4]. Since Er:YAG laser with wavelength of 2.94 μm was introduced in dentistry [2,5], many basic studies and clinical researches on Er:YAG laser have been reported. The Er:YAG laser is absorbed by water and hydroxyapatite and the reaction of Er:YAG laser and water causes "micro explosion" which ablates enamel and dentin [4]. Generally, the cavity preparation using Er:YAG laser takes more time, compared to rotary cutting instruments [6,7]. However, that preparation method advantages include low noise and vibration, eliminating the need for local anesthesia in most cases [8]. A clinical study suggested that the application of the Er:YAG laser system was a more comfortable alternative or adjunctive method than conventional mechanical cavity preparation [7]. For removing dental hard tissues by Er:YAG laser, high energy (more than approximately 150 mJ) is required. However, effect of low output power irradiation of Er:YAG laser on dentin was not well-known.

In the early time, various dental lasers were used with high output power for incision or removing soft and hard tissues. And later, low level laser therapy (LLLT) was introduced as soft laser therapy or bio-stimulation. The LLLT technique is used for the promotion of wound healing in dentistry including periodontitis [9], temporomandibular disorder [10], denture stomatitis [11], peri-implant mucositis [12], and orthodontic pain [13], expecting soft tissue modulation and neural modulation. The LLLT has been also applied for dentin hypersensitivity [14]. In many case of LLLT for dentin hypersensitivity, diode lasers with several wavelengths and output power of 10-50 mW were used [14]. Also, Er:YAG laser was used for desensitizing of hypersensitive dentin [15]. However, there are few studies on the morphological change of dentin by low output power irradiation of Er:YAG laser. The objective of this study was to evaluate effect of low output power irradiation of Er:YAG laser on surface morphology, roughness, and microhardness of the root dentin.

Materials and Methods

Observation using scanning electron microscope (SEM)

Fifty seven extracted human molars were used for this study. This study was approved by Ethics Committee, Tokyo Medical and Dental University, Faculty of Dentistry (D2013-022). The 5 × 5 mm specimen was obtained from buccal root surface using a diamond bur and an air turbine handpiece under copious water. Obtained specimen was embedded in a plastic tube with an epoxy resin (EpoxiCure2, Buehler, Lake Bluff, IL, USA). After curing the epoxy resin, flat and smooth root dentin surface was obtained by slightly grinding and polishing using silicon carbide papers (#180-2,000, Sankyo Rikagaku, Okegawa, Japan) and diamond paste (6, 3, 1, and 0.25 µm, DP-Paste P, Struers, Ballerup, Denmark).

An Er:YAG laser (λ = 2,940 nm, Erwin AdvErl Evo, J. Morita, Kyoto, Japan) and a quartz contact tip (φ = 600 µm, C600F, J. Morita) were used for this study. The laser was irradiated vertically on the whole of dentin surface uniformly sweeping at approximately 2 mm/s by hand at 10 pps, 30 mJ without water splay for 90 s. During the irradiation, the distance between the dentin surface and the contact tip was kept 0, 5, 10, 15, 20, 25, 30, 35, and 40 mm. At 0 mm, the tip was slightly contact with the surface of the sample. For those distances, power intensity and power density were shown in Table 1. The samples without irradiation were employed as control group. After irradiation, the specimen was cut through the center, and dried and gold-coated routinely. The irradiated surface and crosscut surface of the specimen were observed by a scanning electron microscope (JSM-5310LV, JEOL, Akishima, Japan).

Table 1 Output power and power density of each experimental group and assignment of expedient

Distance (mm)	Output power (mJ)	Power density (mJ/cm^2)	SEM	Surface roughness	Vickers hardness
0	17.3	0.61	○	○	○
5	16.5	0.58	○	○	○
10	14.8	0.52	○	○	○
15	14.1	0.50	○	×	×
20	13.7	0.49	○	○	○
25	12.6	0.44	○	×	×
30	11.9	0.42	○	○	○
35	11.5	0.41	○	×	×
40	10.3	0.37	○	○	○
Control	-	-	○	○	○

○: Experiment was assigned. ×: Experiment was not assigned.

Surface roughness and microhardness tests

Specimens of irradiation distance at 0, 5, 10, 20, 30, and 40 mm and no irradiation (control group) were further prepared and were subjected to the surface roughness test and microhardness test (Table 1). Surface roughness

(Ra) was measured by a profilometer (SJ-210, Mitutoyo, Kawasaki, Japan) with cutoff value λc = 0.8 and λs = 2.5 at 0.5 mm/s. Then, Vickers hardness was measured by a hardness tester (HM-102, Mitutoyo) with 0.49 N of load and 15 s of loading time. The number of samples was five in each group (n = 5). Obtained data was statistically analyzed by one-way ANOVA and Tukey HSD test using a package software (IBM SPSS 23.0, IBM, Armonk, NY, USA). The confidential level was 0.05 (α = 0.05).

Results

SEM observation

Typical SEM images were shown Fig. 1. Although the acquired SEM images were varied among the samples with same distances, following tendencies were recognized. For 0, 5, 10, and 15 mm distances, ablation of dentin and opening of dentinal tubules were apparent. For 20, 25, and 30 mm distances, ablation was not found and the degeneration was found on the surface of irradiated dentin by crosscut images. Some dentinal tubules were occluded. In 35 mm and 40 mm groups, any change in surface was not observed.

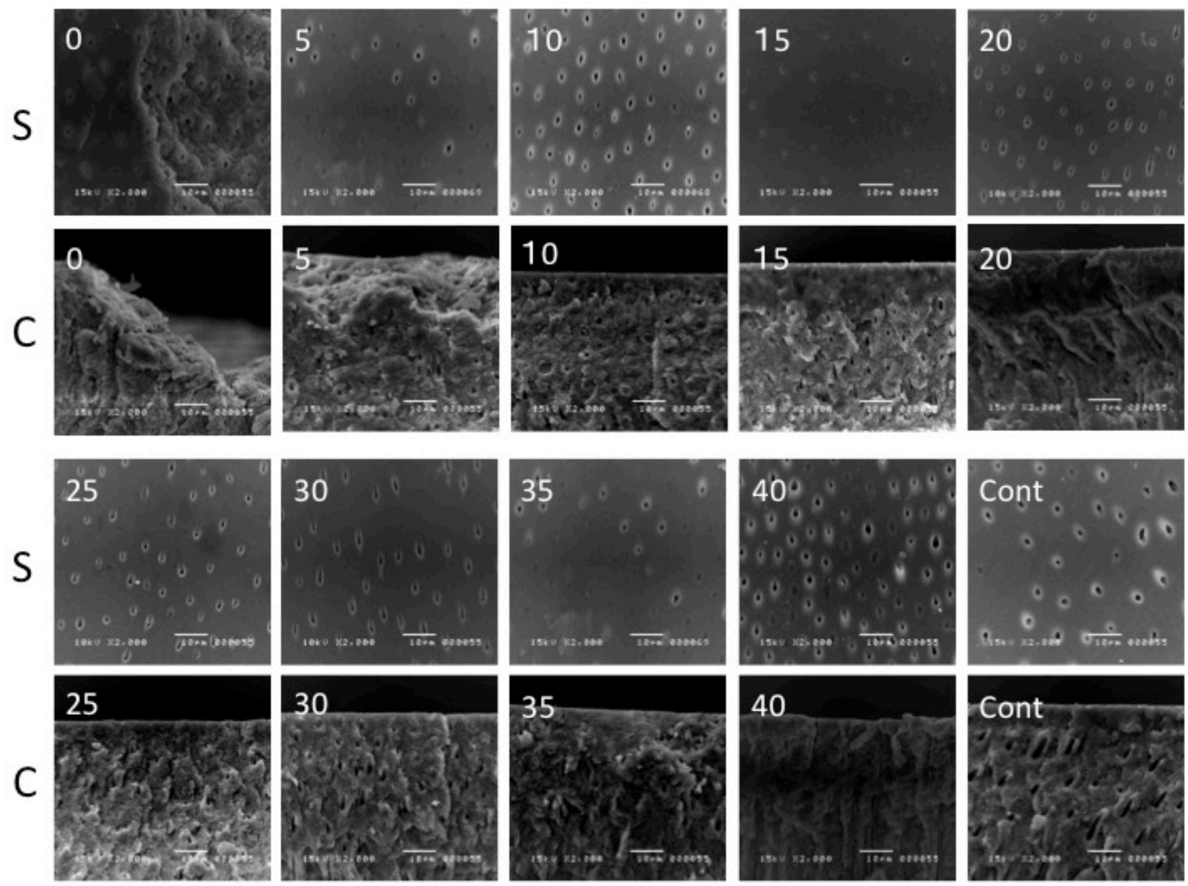

Fig. 1 Typical SEM images after irradiation by each condition of irradiation
S, Surface; C, Crosscut surface; Cont, control group (without irradiation)

Surface roughness and microhardness

The average values and standard deviations of surface roughness (Ra) of each group was shown in Table 2. Ra values of all experimental groups (0-40 mm) showed statistically higher than that of control group ($p < 0.05$). Among the experimental groups, 0-mm-distance group showed statistically higher Ra value than the other groups ($p < 0.05$).

The average values and standard deviations of microhardness (Vickers hardness) of each group are shown in Table 2. For 0 mm group, it was impossible to measure the microhaedness because of rough surface. No significant difference was found for other groups including control group ($p > 0.05$).

Table 2 Surface roughness and microhardness

Distance (mm)	0	5	10	20	30	40	Control
Surface roughness	4.79[a]	0.15[b]	0.11[b]	0.10[b]	0.09[b]	0.09[b]	0.04[c]
(Ra)	-0.07	-0.11	-0.01	0	-0.02	-0.02	-0.03
Microhardness	not available	53.5[a]	58.2[a]	57.5[a]	59.3[a]	60.6[a]	60.4[a]
(Vickers hardness)		-1.2	-1.6	-1.6	-0.6	-2.6	-0.19

Mean values and standard deviations; Identical superscripts indicate no significant differences in a row ($p > 0.05$).

Discussion

Since Er:YAG laser was introduced in dentistry [2,5], many researches were reported. When the Er:YAG laser is irradiated and the molecules of the water in the tooth become superheated, micro explosion is occurred dividing the surrounding tissue into very small pieces and blowing them apart [4]. The dentin surface irradiated by Er:YAG laser was irregular, scaly or flaky and dentinal tubules were opened without smear layer [16,17]. The vaporization of peritubular dentin was greater than that of the intertubular dentin with a cuff-like appearance [4]. For removing dental hard tissues by Er:YAG laser, high energy (more than approximately 150 mJ) is required. In this study, Er:YAG laser was irradiated on the dentin surfaces at much lower output power (10.3-17.3 mJ) as shown in Table 1. At the distance of 0 mm (17.3 mJ) and 15 mm (14.1 mJ), dentin was ablated and irregular and scaly surface with opening dentinal tubules were observed as well as high-power lased dentin. However, at the distance between 20 mm (13.7 mJ) and 30 mm (11.9 mJ), dentin ablation was not found and degenerated layer was still existed.

The desensitizing of hypersensitive dentin with an Er:YAG laser irradiation (80 mJ/pulse, 3 Hz) was effective [15]. Dentin hypersensitivity can be defined as short, sharp pain in response to stimuli by exposed dentin with open dentinal tubules [18]. Dentin hypersensitivity is one of the most common symptomatic condition which causes complaints of discomfort in patients. The hydrodynamic theory was proposed about the mechanism of dentin hypersensitivity [19]. According to this theory, sensitive dentin is caused by thermal, physical or chemical stimuli which induce fluid flow in the dentinal tubules and consequent nociceptor activation in the pulp/dentin border area. This leads to the displacement of the pulp-dentin fluid, which trigger pulpal sensory nervous terminations resulting in the characteristic short and sharp pain of dentin hypersensitivity. The application of an Er:YAG laser would be anticipated to decrease these fluid movements by evaporating the superficial layers of the dentinal fluid [15]. In this study, degenerated layer without ablation could be produced by irradiation at the distance between 20 mm (13.7 mJ) and 30 mm (11.9 mJ) with slight increase of surface roughness. It can be speculated that Er:YAG laser irradiation with this condition may be effective for reducing of dentin hypersensitivity with less morphological change of irradiated surface.

By irradiation at the distance between 20 mm (13.7 mJ) and 30 mm (11.9 mJ), occluded dentinal tables were observed. It may be also effective for dentin hypersensitivity. However, some dentinal tubules were still open. Combination of desensitizing agent and Er:YAG laser irradiation for dentin hypersensitivity seems to be interesting. The occluding effects of Er:YAG laser and dentifrice containing nano-carbonate apatite on the dentinal tubules was reported [20]. For this case, lower output power employed in this study may be also effective and useful. Further study including clinical trial is required to determine the suitable parameter of Er:YAG laser irradiation for the treatment of dentin hypersensitivity.

Within the limitation of this study, it could be concluded that specific low output power Er:YAG laser irradiation produced thin degenerated layer on the root dentin. This irradiated surfaces showed slight increase of roughness without decrease of microhardness.

Conflict of Interest

The authors do not have any financial interest in the companies whose materials are included in this article.

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Correspondence to:

Dr. Masayuki Otsuki
Cariology and Operative Dentistry, Department of Restorative Sciences,
Graduate School of Medical and Dental Sciences, 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 4, 2019.

 Online ISSN 2185-3487, Print ISSN 2185-3479