Influence of Er:YAG Laser Beam Angle, Working Distance, and Energy Density on Dentin Morphology: An SEM Investigation

Rubens C. R. de Carvalho[a], Patricia M. de Freitas[b], Masayuki Otsuki[c], Carlos de P. Eduardo[d], Junji Tagami[e]

[a] *Associate Professor, Department of Restorative Dentistry, School of Dentistry of São Paulo, University of São Paulo (USP), São Paulo, SP, Brazil.*
[b] *PhD Student, Department of Restorative Dentistry, School of Dentistry of São Paulo, University of São Paulo (USP), São Paulo, SP, Brazil.*
[c] *Associate Professor, Cariology and Operative Dentistry, Graduate School of Dentistry, Tokyo Medical and Dental University, Tokyo, Japan.*
[d] *Professor, Department of Restorative Dentistry, School of Dentistry, University of São Paulo (USP), São Paulo, SP, Brazil.*
[e] *Professor and Chairman, Department of Restorative Sciences, Tokyo Medical and Dental University, Tokyo, Japan.*

Purpose: To evaluate the morphological aspects of dentin surfaces irradiated with different parameters (energy, contact or noncontact, incidence angle) of the Er:YAG laser and determine whether dentin morphology is adversely affected by these parameters.

Materials and Methods: Forty-five dentin disks were obtained from extracted third molars. An area of 6 x 9 mm^2 was delimited on the dentin surface of each specimen. After that, specimens were randomly divided into 9 groups: G1 – control; G2 – Er:YAG laser at 150 mJ, 90-degree angle, contact mode (38.8 J/cm^2); G3 – Er:YAG laser at 70 mJ, 90-degree angle, contact (18.1 J/cm^2); G4 – Er:YAG laser at 150 mJ, 90-degree angle, noncontact mode (1.44 J/cm^2); G5 – Er:YAG laser at 70 mJ, 90-degree angle, noncontact mode (0.67 J/cm^2); G6 – Er:YAG laser at 150 mJ, 45-degree angle, contact mode (37.5 J/cm^2); G7- Er:YAG laser at 70 mJ, 45-degree angle, contact mode (17.5 J/cm^2); G8 - Er:YAG laser at 150 mJ, 45-degree angle, noncontact (1.55 J/cm^2); G9 - Er:YAG laser at 70 mJ, 45-degree angle, noncontact mode (0.72 J/cm^2). After irradiation, dentin surfaces were analyzed under scanning electron microscopy (SEM).

Results: SEM analysis revealed different surface morphology within the groups evaluated. The contact mode of irradiation and higher energy densities (G2 and G6) produced greater changes on dentin surfaces.

Conclusions: Different energy densities and contact/noncontact mode irradiation cause different morphological changes on dentin surfaces. Operators should be aware of the best irradiation settings for a specific clinical application.

Keywords: dentin, energy, Er:YAG laser, incidence angle, morphology.

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Er:YAG lasers are widely used for the removal of dental hard tissues prior to the application of restorative materials.[1,2] During the last decade, there has been a great improvement in the use of these lasers in clinical practice, based on increased research in this field.[3-5]

Er:YAG lasers emit a wavelength of 2.94 µm, which coincides generally with the absorption band of water. The emitted energy is also well absorbed by hydroxyapatite and has been reported to ablate enamel and dentin more effectively than other lasers systems.[6]

The use of lasers for hard tissue removal is a dynamic process that can affect dentin properties. Besides the absorption characteristics of the tissue, the chemical/morphological alterations are also dependent on laser characteristics, such as wavelength specificity, energy density, and pulse repetition rate.[7,8] Depending on the parameters used for laser irradiation, the energy applied to the dentin surface can increase the temperature both in the irradiated area and in the surrounding tissues, producing different morphological changes.[5,7] The use of either contact or noncontact mode of irradiation and different incidence angles also seem to be very important when considering dentin morphological changes. However, there are still no reports in the literature regarding their importance during the irradiation of this hard tissue. In vitro studies have been carried out with standardized incidence angles which do not necessarily represent the clinical condition. The articulated arm can be handled well for preparing anterior teeth, but removal of caries on posterior teeth is more difficult.

The present in vitro study evaluated the influence of different Er:YAG laser irradation parameters (energy, fiber contact angle, and contact/noncontact mode) on the dentin morphology and discusses their influence on clinical procedures.

MATERIALS AND METHODS

Preparation of the Specimens

Forty-five freshly extracted third molars, free of both caries and restorations, were cleaned with pumice and a rotary brush, and stored in physiological saline at 4°C until the beginning of the experiment. The teeth were fixed with cyanoacrylate adhesive (Zapit Base Dental Ventures of America, Corona, CA, USA) on a metal disk. Forty-five dentin slabs of approximately 2 mm thickness (buccal or lingual dentin surface) were obtained by slow-speed sectioning with a diamond saw (Isomet-Buehler, Lake Buff, IL, USA). The dentin disks were polished with 600-grit silicon carbide papers (Struers, Tokyo, Japan). An area of approximately 6 x 9 mm^2 was delimited on the surface of each specimen, in which the laser irradiation was performed.

Laser Irradiation

The dentin disks were randomly assigned into 9 groups of 10 specimens each. The samples from the experimental groups (G2-G9) were irradiated with the Er:YAG laser (OSADA Electric, Tokyo, Japan) with different parameters (energies, contact or noncontact mode, and incidence angles), as shown in Table 1. The Er:YAG laser works with a wavelength of 2.94 µm. The output power and repetition rate of this equipment range from 10 to 400 mJ and 1 to 25 Hz, respectively. When using the handpiece (HPER-S, OSADA Electric, Tokyo, Japan) in a noncontact mode of irradiation, the laser beam was delivered at a working distance of 10 mm from the tooth surface. The laser irradiation was performed on the dentin surface for 52 s, scanning the surface in both directions, under water cooling (5.0 ml/min). The beam diameters at the focal area for the handpiece in the noncontact and contact mode were 0.63 mm and 0.32 mm, respectively. The handpiece used in the present study presented a 30% loss of energy at the end of the tip. The energy delivered at the end of the tip was measured with a power meter (FieldMaster, Coherent, USA) before irradiation. The energies of 70 mJ and 150 mJ depicted on the equipment display were actually 49 mJ and 105 mJ, respectively.

The parameters used for the irradiation of the dentin samples are shown in Table 1.

Morphological Analysis

Following laser irradiation, all dentin surfaces were examined under a scanning electron microscope (JXA-840, JEOL, Tokyo, Japan). The specimens were subsequently dehydrated in an ascending ethanol series of 20 min at 25%, 20 min at 50%, 20 min at 70%, 30 min at 90%, and 60 min at 100%. Then, they were placed on blotting paper to air dry under a vacuum hood for 2 days. At this point, samples were sputter coated using a carbon coating device and were submitted to SEM analysis.

RESULTS

The control group (G1) revealed a dentin surface with a small number of exposed dentinal tubules and intact peritubular and intertubular dentin (Fig 1). It was also possible to verify an intact smear layer.

For the noncontact mode of irradiation, dentin showed a smooth surface with obliterated dentinal

Table 1 Parameters used for the irradiation of the dentin specimens

Group	Energy (mJ)	Repetition rate (Hz)	Incidence angle	Laser beam delivery	Energy density (J/cm^2)
G1			control – without laser irradiation		
G2	150	20	90°	contact	38.8
G3	70	20	90°	contact	18.1
G4	150	20	90°	noncontact	1.44
G5	70	20	90°	noncontact	0.67
G6	150	20	45°	contact	37.5
G7	70	20	45°	contact	17.5
G8	150	20	45°	noncontact	1.55
G9	70	20	45°	noncontact	0.72

tubules (Figs 2a to 2d). The maintenance of the intertubular and peritubular dentin structures was observed, similar to those found in the control group.

On the other hand, the irradiation performed in contact mode (Figs 2e to 2h) resulted in more pronounced morphological changes than those observed in the noncontact groups for the same parameters (energy and beam angle). Dentin showed a rough surface with opened dentinal tubules. The intertubular dentin suffered more ablation than the peritubular dentin, making the tubules protrude (cuff-like appearance). In these groups, there was no smear layer discernible.

Within the contact-mode groups, the dentin irradiated with an incidence angle of 90 degrees (G2 and G3) revealed morphological alterations similar to those from the other experimental groups (G6 and G7). Higher energy densities showed a tendency to induce greater dentin ablation, forming microholes. Furthermore, it was observed that the use of an angle of incidence of 90 degrees induced greater changes compared to the same energies used with the laser set for an angle of incidence of 45 degrees (lower energy densities).

DISCUSSION

Dentin morphology following cavity preparation plays an important role in bonding procedures. Some authors[9,10] reported that the surface topography interferes with bonding procedures and that the degree of surface roughness seems to indicate the degree of mechanical anchorage in the bonding process. Considering

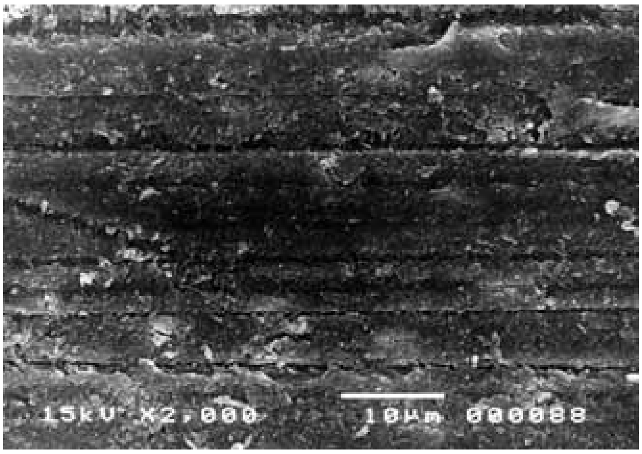

Fig 1 Representative micrograph of the control group showing the nonirradiated dentin surface with a small number of exposed dentinal tubules and an intact peritubular and intertubular dentin.

the increasing use of laser systems for this application,[11] the influence of different parameters of irradiation on the dentin morphology seems to be of extreme clinical relevance.

Regarding the energies used in the study, when applying either 70 mJ or 150 mJ (49 mJ and 105 mJ, respectively) with water/air spray, neither carbonization nor melting was observed. These findings are in agreement with previous studies with the Er:YAG laser, in which minimal thermal damage was observed when the irradiation was performed with water cooling.[5,12]

In the current study, dentin surfaces treated with the handpiece in contact mode (high energy densities –

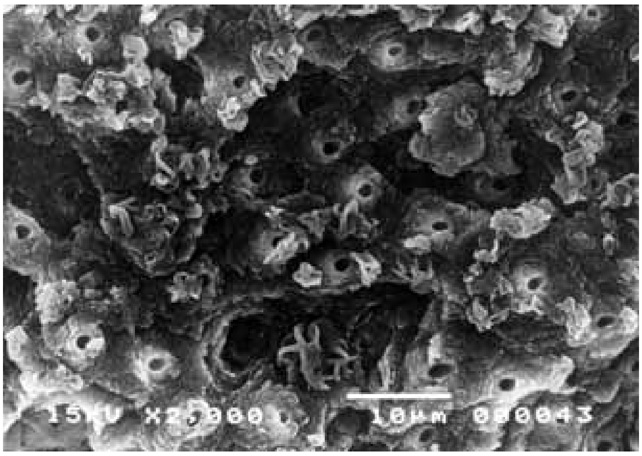

Fig 2a Group 4, noncontact mode.

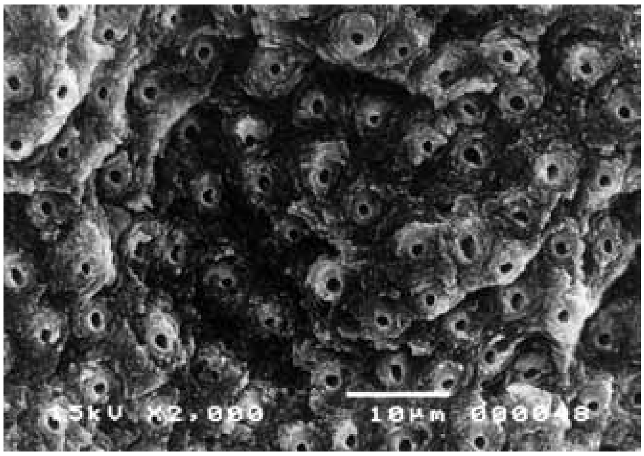

Fig 2b Group 5, noncontact mode.

Fig 2 Representative micrographs of the experimental groups. The ablation pattern of the Er:YAG laser with different parameters of irradiation shows significant morphological differences within the experimental groups, mainly for the contact irradiated samples

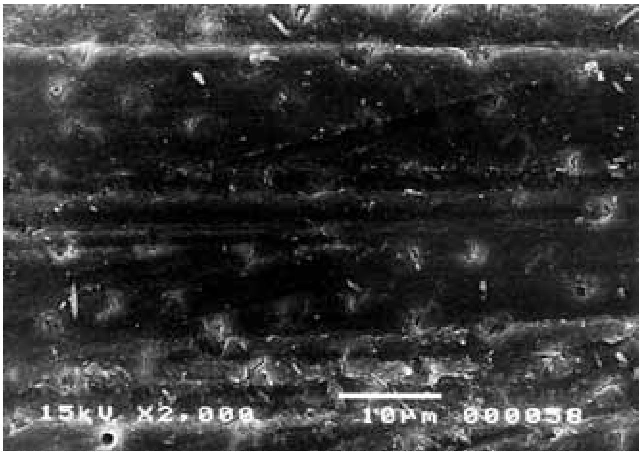

Fig 2c Group 8, noncontact mode.

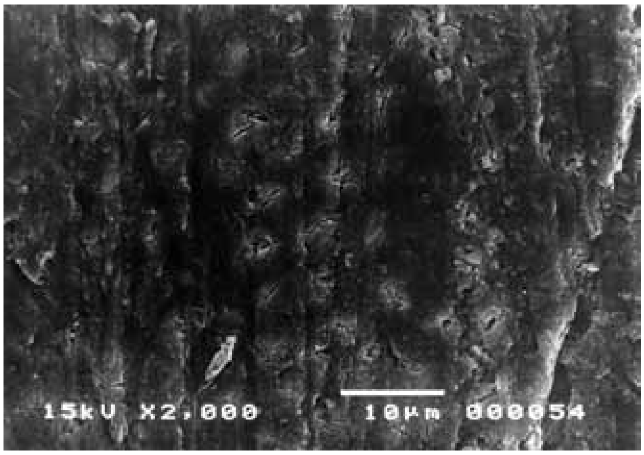

Fig 2d Group 9, noncontact mode.

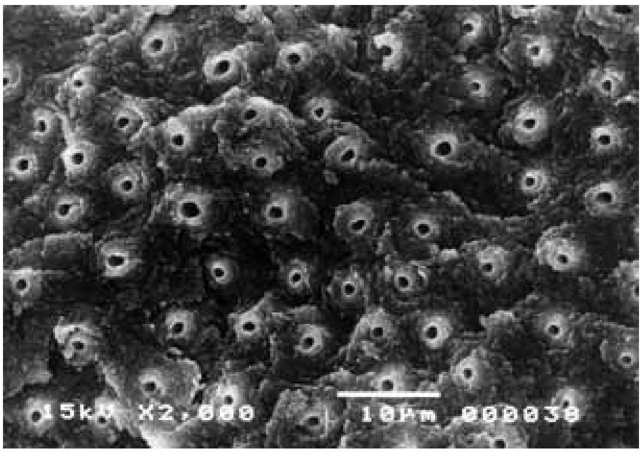

Fig 2e Group 2, contact mode.

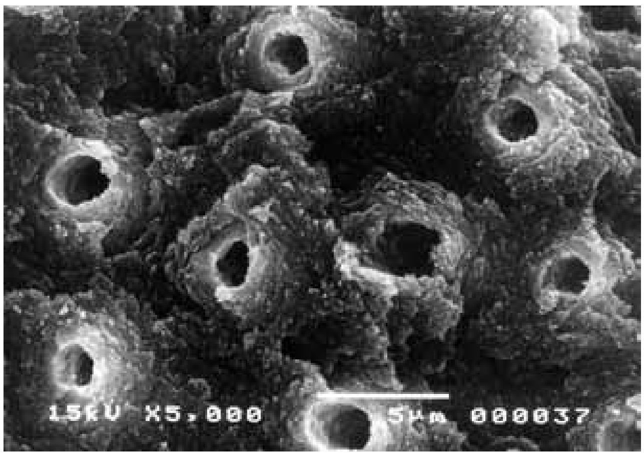

Fig 2f Group 3, contact mode.

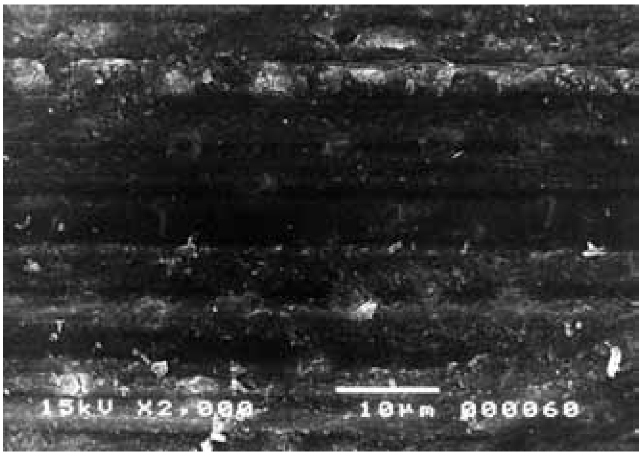

Fig 2g Group 6, contact mode.

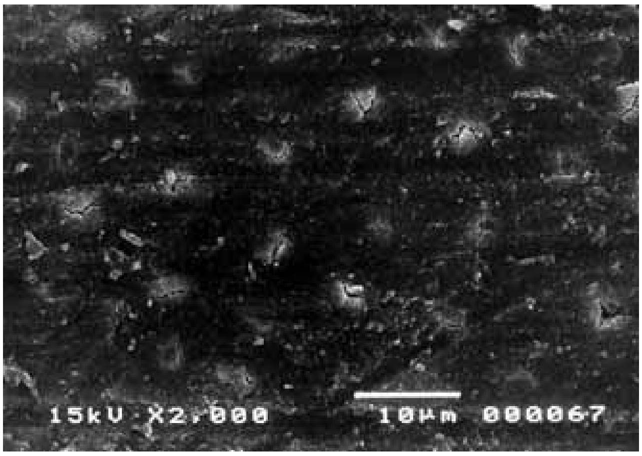

Fig 2h Group 7, contact mode.

groups 2, 3, 6, and 7) revealed dentinal tubules with opened orifices and a scaly or irregular surface with the absence of a smear layer.[5,13-17] The surface irregularity results from the microexplosions through rapid water evaporation, which is the main mechanism of hard tissue ablation with the Er:YAG laser.[8] In these groups, it was also observed that the intertubular dentin suffered more ablation than the peritubular dentin, making the tubules protrude.[5] This can be explained by the great amount of water and lower mineral content of the intertubular dentin, which is selectively ablated more than the peritubular dentin, leaving dentinal tubules with a cuff-like appearance.[4,5,18]

Although there were no striking differences in the laser-treated dentin pattern within the groups with same irradiation mode (contact or noncontact), there seemed to be a tendency toward greater ablation of the intertubular dentin when using higher energies (150 mJ) and an angle of incidence of 90 degrees (ie, higher energy densities), leading to a more irregular surface with microholes. In both group 2 and group 3 (contact mode and incidence angle of 90 degrees), microfragment-like structures scattered on small areas of the surface were observed. Clinically, the rough surface can possibly contribute to the adhesion of resin to dentin,[13,14,18,19] but the presence of fragments was reported to contribute to an adverse effect on the adhesion of resin, decreasing the bonding quality.[5]

These dentin characteristics following the contact-mode irradiation are expected to provide a suitable surface for physical bonding mechanisms of composite materials.[18,19] However, there are still contradictions in the literature,[4,20-22] despite numerous studies which reported that patent tubules and the absence of smear layer are additional factors that may enhance bonding to laser-treated dentin.[13,14,18,19]

According to Ceballos et al,[22] when Er:YAG laser is used to treat dentin, there is no demineralization of its surface and no collagen matrix is exposed, both of which are necessary for the formation of hybrid layer. Therefore, bonding procedures can be compromised. Using SEM, Eguro et al[16] found scaly, flaky dentin surfaces that had opened dentinal tubules. However, the bond strength test revealed that such surfaces achieve lower bond strength values than those on dentin treated with phosphoric acid or air abrasion. Findings in the literature also point to the possibility of collagen denaturation after Er:YAG laser irradiation.[23]

Different surface changes were observed when the handpiece was employed in noncontact mode. These groups (G4, G5, G8, and G9) presented a smooth and homogeneous layer, with an aspect of melted collagen,[24] similar to the findings from the control group (G1, untreated dentin). It also seems that there was practically no ablation of the dentin as a result of the low energy densities at the tissue surface. With low energy densities, the temperature for evaporation is not reached and ablation does not occur.[7] The SEM analysis showed a dentin surface with occluded dentinal tubules and an intact smear layer. Considering that these characteristics were similar to those of the untreated control, it is possible that this dentin surface is favorable for the adhesion of composite materials, achieving a suitable bonding quality after acid etching.

Changes on dentin surfaces seem to be related to both the increase of energy densities and to incidence angles close to 90 degrees. Folwaczny et al[25] reported that besides the physical radiation parameters, the parameters of clinical handling, in particular the laser tip position (beam incidence angle), have a strong influence on the amount of dentin substance removal using Er:YAG laser. This has been shown to be greater with the laser tip at 90 degrees.[25] However, in our study, the laser beam incidence angle revealed a slight difference in morphological changes for the same applied energy. On the other hand, the use of a handpiece either in a noncontact or contact mode of irradiation showed different aspects of the irradiated dentin. Operators must be aware that during hard tissue removal (irradiation procedures), the distance from the end of the laser tip and the tooth surface can change. This seems to be more relevant for adhesive procedures, and can possibly justify their use for different clinical applications.

CONCLUSIONS

Under the conditions of this study, the following conclusions can be drawn:

1. Regarding the same energy and mode of irradiation, the laser beam incidence angle (45 or 90 degrees) does not significantly affect the morphological changes on dentin.
2. Higher energies (150 mJ) tended to induce a greater ablation of the intertubular dentin.
3. The distance from the irradiated surface (contact or noncontact mode of irradiation) greatly affects the morphological changes on dentin.
4. The Er:YAG laser can be used as an alternative tool for dentin ablation. However, correct parameters of irradiation are required and it is advisable that professionals strictly follow them in clinical procedures.

Understanding how the Er:YAG laser energy, fiber contact angle, and contact mode influence the appearance and topography/morphology of the irradiated dentin may help dentists to select the best irradiation technique for different procedures in restorative dentistry. This understanding is important to clinical success, where expertise in the use of recent technologies should parallel oral health maintenance.

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Contact address: Dr. Rubens Corte Real de Carvalho, Departamento de Dentística - Faculdade de Odontologia de São Paulo – USP, Av. Prof. Lineu Prestes, 2227, Cidade Universitária - São Paulo - SP – Brazil. Tel: +55-11-3091-7839, Fax: +55-11-3091-7839. e-mail: rcorte@terra.com.br