Effect of Er:YAG and Diode Laser Irradiation on the Root Surface: Morphological and Thermal Analysis

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Background: The aim of the present study was to compare the effects of Er:YAG and diode laser treatments of the root surface on intrapulpal temperature after scaling and root planing with hand instruments.

Methods: Fifteen extracted single-rooted teeth were scaled and root planed with hand instruments. The teeth were divided into 3 groups of 5 each and irradiated on their buccal and lingual surfaces: group A: Er:YAG laser, 2.94 µm/100 mJ/10 Hz/30 seconds; group B: diode laser, 810 nm/1.0 W/0.05 ms/30 seconds; group C: diode laser, 810 nm/1.4 W/0.05 ms/30 seconds. The temperature was monitored by means of a type T thermocouple (copper-constantan) positioned in the pulp chamber to assess pulpal temperature during and before irradiation. Afterwards, the specimens were longitudinally sectioned, and the buccal and lingual surfaces of each root were analyzed by scanning electron microscopy.

Results: In the Er:YAG laser group, the thermal analysis revealed an average temperature of –2.2 ± 1.5°C, while in the diode laser groups, temperatures were 1.6 ± 0.8°C at 1.0 W and 3.3 ± 1.0°C at 1.4 W. Electronic micrographs revealed that there were no significant morphological changes, such as charring, melting, or fusion, in any group, although the specimens were found to be more irregular in the Er:YAG laser group.

Conclusions: The application of Er:YAG and diode lasers at the utilized parameters did not induce high pulpal temperatures. Root surface irregularities were more pronounced after irradiation with an Er:YAG laser than with a diode laser. *J Periodontol 2003;74:838-843.*

KEY WORDS

Comparison studies; dental pulp; lasers/therapeutic use; periodontal diseases/therapy; planing; scaling; temperature.

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A primary goal in treating periodontitis is to remove bacterial deposits and halt the progression of the disease.[1] To achieve this goal, a complete removal of adhered plaque and calculus, as well as infected cementum, is necessary, although complete removal is rare.[2,3] Despite visual appearances, scaling does not successfully render root surfaces free of plaque and calculus; additionally, locations such as furcations are barely accessible to instruments.[4] Conditioning of the root surface by topical application of solutions has been introduced as a regenerative procedure to dissolve the smear layer produced by root instrumentation, to aid in detoxification of the root surface, and to expose embedded collagen fibers.[5,6]

Attention has been paid to the clinical applicability of the Er:YAG laser with a 2.94 µm wavelength in the near infrared spectrum. This wavelength is well absorbed by water because the peak is close to the absorption coefficient of water. The Er:YAG laser also enables the removal of subgingival calculus and superficial layers of infected cementum. Its effects on periodontally involved root surfaces have been examined in vitro[7-10] and in vivo.[11] On the other hand, the effect of the diode laser with a wavelength of 810 nm on root surfaces has not yet been thoroughly investigated.[12] Thermal and photodisruptive laser effects result in the elimination of periodontopathogenic bacteria[13-16] and might be beneficial in the treatment of periodontitis.

While some studies have demonstrated that when applied to root surfaces, some Er:YAG lasers do not promote an undesirable increase in pulpal temperature,[7,8,17,18] high intensity lasers, which are not as strongly absorbed by tissues, might spread and cause an undesirable temperature increase due to the sub-ablation effect.

However, to our knowledge, there are no studies examining the thermal alterations induced by the utilization of a diode laser on root surfaces. The aim of this study was to evaluate the effects of Er:YAG and diode lasers on intrapulpal temperature when used as adjuncts to conventional periodontal therapy, as well as to analyze the resulting morphological alterations by means of scanning electron microscopy (SEM).

MATERIALS AND METHODS

Specimens

Fifteen extracted, non-carious, single-rooted, periodontally diseased human teeth with probing depths >6 mm were used in this study. After extraction, the teeth were stored in phosphate buffered saline (PBS, pH 7.4) at 37°C until treatment was carried out. The teeth were treated with scaling and root planing (SRP) with hand instruments (Gracey curets[‖] No. 1/2 and 3/4) in order to remove calculus completely. SRP was performed by the same experienced operator with hand instruments, and the teeth were stored in PBS to avoid dehydration. These measures were taken because the thickness of the cementum, dehydration, and characteristics of the teeth could influence thermal diffusion. The teeth were divided into 3 groups of 5 specimens each: group A was irradiated with an Er:YAG laser; group B was irradiated with a diode laser at 1.0 W; and group C was irradiated with a diode laser at 1.4 W.

Lasers

The laser equipment used in this study was an Er:YAG laser[¶] device with a wavelength of 2.94 µm, energy of 100 mJ/pulse, and pulse repetition of 10 Hz, tip diameter of 1.3 mm, focused and in contact, with water cooling, for 30 seconds, with fluency of 10 J/cm^2; and a GaAlAs diode laser[#] device with a wavelength of 810 nm, in the repeat wave mode (0.05 ms), used at power outputs of 1.0 W (group A) and 1.4 W (group B), for 30 seconds. Laser light was delivered through a 320 µm contact optical fiber.

Laser Irradiation and Thermal Analysis

After SRP, the teeth were prepared to receive a thermocouple inside their pulp chambers. The optical fiber was positioned perpendicularly to the surface of the specimens. Each surface (buccal and lingual) was irradiated for 30 seconds, with scanning movements along the cervical third of the root. Thirty-second intervals took place between irradiations. The temperature was measured 10 times. Thermal changes were monitored by means of a copper-constantan (Type T) thermocouple;[**] the 130 µm thick tip was put in contact with the dentinal tissue inside the pulp chamber. A thermal paste was utilized to enable good thermal contact between the thermocouple tip and the internal pulp wall. Data were obtained during laser irradiation, and temperature increase was determined by calculating the difference between the maximum and initial temperature values. Comparisons between the groups were carried out and tested with analysis of variance (ANOVA). The alpha error was set at 0.01.

SEM Observations

After laser irradiation, the teeth were horizontally sectioned using a thin saw so that crowns were removed. The remaining roots were then longitudinally sectioned so that 30 specimens were obtained (15 buccal and 15 lingual root surfaces). For SEM observations, the samples were fixed in 2.5% glutaraldehyde in phosphate buffer (pH 7.3) for 24 hours at 4°C, and washed 3 times for 10 minutes each in phosphate buffer. The specimens were then dehydrated in a series of aqueous ethanol solutions with ascending strengths up to 100%. They were dried overnight in a desiccator jar and mounted with silver paint on SEM stubs. Afterwards, the samples were sputter-coated with gold and palladium and examined with a scanning electron microscope.[††] Photomicrographs from the root surfaces were taken at a magnification of ×2,000 to obtain representative images of each group.

RESULTS

Thermal Alterations

Figure 1 presents the results of the thermal measurements carried out in the pulp chamber during Er:YAG laser irradiation. The final temperatures were lower than the temperature registered before irradiation. During diode laser irradiation, the temperature rose gradually, according to the progress of the treatment (Figs. 2 and 3). Thermal variation registered in the pulp chamber during Er:YAG laser irradiation with water spray ranged from –4.0°C to 0.5°C. The average thermal alteration was –2.2 ± 1.5°C for the Er:YAG laser. For the diode laser, it was 1.6 ± 0.8°C in group B and 3.3 ± 1.0°C in group C (Table 1). A significant difference was observed between the 3 groups at $P < 0.01$.

SEM Analysis

SEM analysis of the irradiated specimens revealed various degrees of alterations on the root surface. The Er:YAG laser-treated specimens revealed different

‖ Hu-Friedy Co., Chicago, IL.
¶ Opus 20, Opus Dent Ltd., Natanya, Israel.
# Opus 10, Opus Dent Ltd.
** SR 510 lock-in amplifier, Standford Research System, Sunnyvale, CA.
†† Jeol-JSM-T330A, JEOL, Tokyo, Japan.

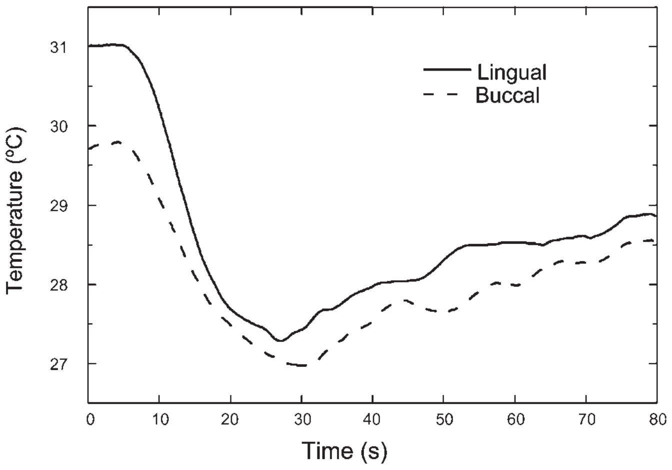

Figure 1.
Intrapulpal temperature change during Er:YAG laser irradiation for 30 seconds in a representative specimen (group A).

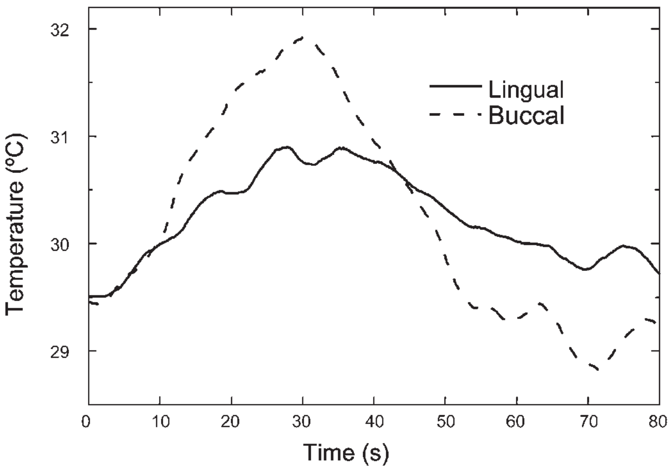

Figure 2.
Intrapulpal temperature change during diode laser irradiation at 1.0 W for 30 seconds in a representative specimen (group B).

degrees of rough surfaces in all of the specimens, but without residual deposits or any sign of smear layer; numerous sharp-pointed projections resulting from the ablation of cementum were evident (Fig. 4). Occasionally, in some specimens, tubular apertures were observed, which indicates the exposure of the underlying dentin.

On the other hand, the diode-lased specimens from groups B and C presented a superficial smear layer that varied in amount and shape, but practically no alteration on the root surface. There were no signs of thermal side effects such as charring, melting, necrosis, or fusion in either group. Minimal tissue ablation was observed in all specimens, with greater ablation in specimens from group C (Figs. 5 and 6).

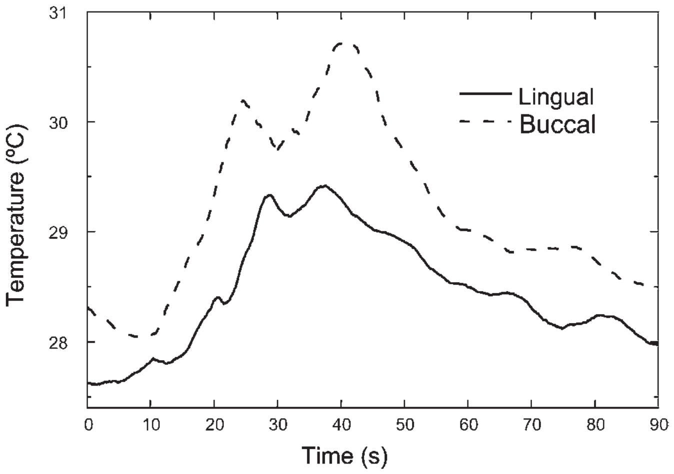

Figure 3.
Intrapulpal temperature change during diode laser irradiation at 1.4 W for 30 seconds in a representative specimen (group C).

Table 1.

Temperature Alterations within 30 Seconds of Irradiation (mean ± SD; n = 10)

Treatment	Temperature Alteration	*P* Value
Er:YAG laser (Group A)	–2.2 ± 1.5°C	<0.01
Diode laser 1.0 W (Group B)	1.6 ± 0.8°C	<0.01
Diode laser 1.4 W (Group C)	3.3 ± 1.0°C	<0.01

Significance of differences between the 3 groups calculated by means of the ANOVA test.

DISCUSSION

The depth of energy penetration and the variety of surface features resulting from laser irradiation depend on variables such as laser wavelength, optical and thermal properties of the target, power and energy densities, duration of exposure, and waveform.[19] The most critical features in determining the extent of tissue damage appear to be those over which the clinician has control: wavelength, waveform, rate of power, duration of exposure, energy densities, and utilization of a surface coolant. The results of this study indicated that Er:YAG laser irradiation combined with water cooling decreases the temperature (–2.2 ± 1.5°C). However, the diode laser induced some degree of temperature elevation in the pulp chambers (1.6 ± 0.8°C and 3.3 ± 1.0°C). Statistically significant differences were observed between the 3 groups: Er:YAG laser irradiation induced a temperature decrease, probably due to water cooling, and the 1.4 W diode laser caused the greatest temperature increase. A temperature increase within 5°C in the pulp has been reported as safe for

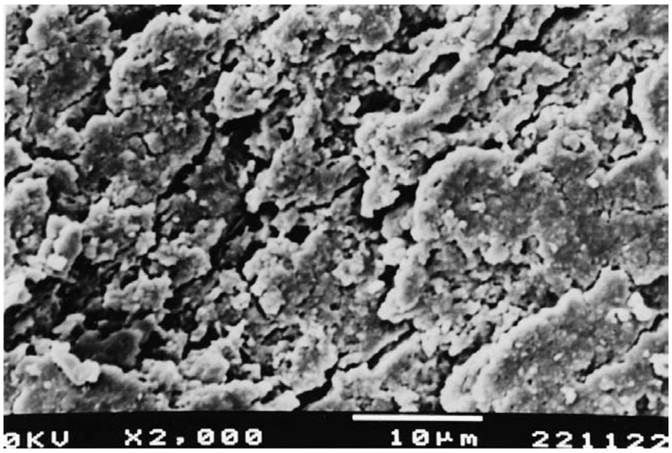

Figure 4.
SEM of cementum surface after SRP with hand instruments and Er:YAG laser irradiation for 30 seconds, with water coolant in vitro (100 mJ/10 Hz), showing an irregular and rough surface (bar = 10 μm; original magnification ×2,000).

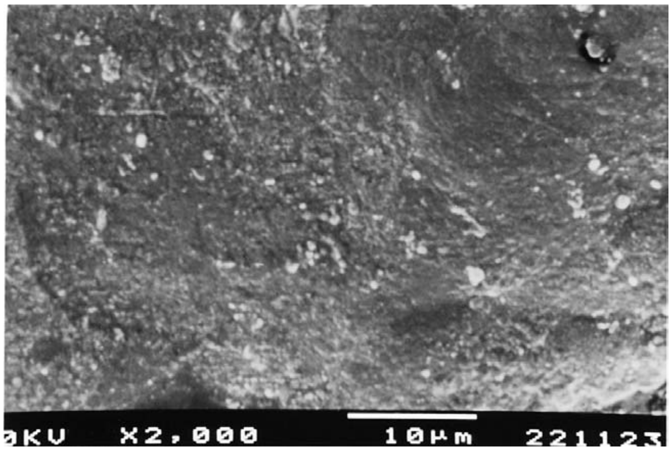

Figure 6.
SEM of cementum surface after SRP with hand instruments and diode laser (1.4 W) irradiation for 30 seconds in vitro, showing an irregular surface and the presence of smear layer (bar = 10 μm; original magnification ×2,000).

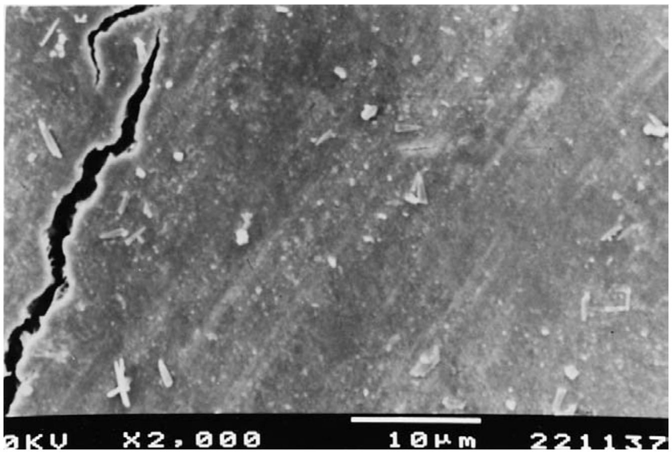

Figure 5.
SEM of cementum surface after SRP with hand instruments and diode laser (1.0 W) irradiation for 30 seconds in vitro, showing a regular surface and the presence of smear layer (bar = 10 μm; original magnification ×2,000).

pulpal survival.[20] Therefore, this level of thermal alteration during laser treatment is considered to be within the physiologically tolerable levels.

The root surface can also vary with the state of the cementum. The thickness of the cementum depends on the patient's age, but primarily on the periodontal techniques previously applied: hand or ultrasonic scaling and root polishing. Dentinal canaliculi are more or less calcified according to the patient's age, and they have different orientations depending on the location on the tooth. These factors affect thermal diffusion. The same measurements carried out on non-vital teeth might have different results because of the absence of odontoblastic endings within the dentinal canaliculi. Other factors such as morphological or calcic type can also affect the results.[21]

SEM observation of the Er:YAG laser-treated specimens revealed rough surfaces, but without residual deposits or any sign of smear layer formation. In contrast, SEM evaluation of diode-lased root surfaces showed a superficial smear layer composed of necrotic cells, organic matrix, and dentinal particles. However, there were no signs of thermal side effects (charring, melting, necrosis, or fusion) in any of the groups. An important consideration is the roughness of the residual root surface. The roughness of root surfaces treated with an Er:YAG laser has been reported as 20 to 25 μm.[8] The micromorphology of Er:YAG laser-treated root surfaces is comparable to that of surfaces submitted to conventional treatment and conditioning with citric acid or EDTA,[5,6] which, according to some authors, improves the attachment of fibroblasts.[22,23] Other studies have reported that a certain degree of roughness does not affect the healing results.[24]

The spatial extent and degree of tissue damage depend primarily on the magnitude of heat, exposure time, and on the distribution of heat inside the tissue. The deposition of laser energy, however, is not only a function of laser parameters such as wavelength, power density, exposure time, spot size, and repetition rate; it also strongly depends on optical properties of tissues, such as absorption and scattering coefficients. In order to determine the storage and transfer of heat, thermal properties of tissues, such as heat capacity and thermal conductivity, are of primary importance.[25]

In biological tissues, absorption is mainly due to the presence of free water molecules, proteins, pigments, and other macromolecules. The absorption coefficient strongly depends on the wavelength of the laser irradiation. In thermal interactions, absorption by water molecules plays a significant role. The Er:YAG laser has an energy wavelength peak of 2.94 µm, which corresponds to the absorption coefficient of water. Water evaporates, forming steam within the tissues. The internal pressure increases until explosion occurs, causing the destruction of inorganic substances before the melting point is reached.[9] SEM examination revealed that the Er:YAG laser ablated a portion of the underlying cementum ranging from superficial to deep, and that the treated surface had microstructural characteristics resulting from cementum ablation. Furthermore, it has been reported that there is little temperature increase on the root surface[26] or in the pulp chamber[7,8,26] during laser treatment with water cooling, which is in accordance with the findings of this study.

On the other hand, the application of a diode laser, with a wavelength of 810 nm at the parameters mentioned above, did not cause any microscopically detectable alterations on the root surface, because the absorption coefficient of water is small. Kreisler et al.[12] reported that there was no difference as to the patterns of cell growth and cell migration between diode-lased and unlased areas; cell attachment was slightly higher in the lased group than in the control group, although the difference was not significant and was unlikely to have any clinical relevance. However, in another in vitro study, Kreisler et al.[27] reported that the application of an 810-nanometer diode laser at a power output above 1.0 W in the decontamination of periodontal pockets may cause carbonization of the root surface. In the present study, at a power output of 1.4 W (group C), the specimens presented a superficial smear layer but nearly no alteration of the root surface. There were no signs of thermal side effects such as charring, melting, necrosis, or fusion; minimal tissue ablation was produced, and there was a small increase in the temperature inside the pulp chamber. These discrepant findings might be due to the mode of laser emission or to the time of exposure. The morphology of the root surface after Er:YAG laser treatment has been examined in numerous in vitro studies,[9,10,25,26,28,29] and the conclusion was that the Er:YAG laser seems to have sufficient potential for root surface modification, whereas a selective ablation of calculus was impossible. Studies on the effects of the diode laser on the root surface are scarce.[12,27] Furthermore, the results of a histological study in humans revealed that even periodontal regeneration can be accomplished on a previously diseased cementum surface if the bacterial deposits are mechanically or chemically removed.[30] In this context, it is important to refer to the results of previous studies which have shown that the Er:YAG and diode lasers also have high bactericidal potential.[13,31,32]

In conclusion, the characteristics of the root surface induced by Er:YAG laser irradiation and by diode laser irradiation are promising. The diode laser produces a less irregular surface due to its weak interaction with mineralized structures. The Er:YAG and diode lasers, at the parameters utilized in this study, did not cause undesirable increases in the temperature of the pulp. Finally, it must be emphasized that the results of this study were achieved under in vitro conditions. Other studies should be carried out in order to analyze the effects of this treatment on periodontal regeneration in vivo.

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