Effect of Pulse Energy and Pulse Repetition Rate at the Identical Total Power During Enamel Ablation Using an Er:YAG Laser

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The objectives of this study was to investigate the amount of tooth ablation and the change of intrapulpal temperature by Er:YAG laser as it relates to pulse energy and pulse repetition rate at the identical power and, thereby, to reveal which of the two parameters strongly relates with ablation efficiency and intrapulpal temperature.

Extracted healthy human molar teeth were sectioned into two pieces and each specimen was irradiated within the combination of pulse energy and pulse repetition time at the same power of 3W; 300 mJy×10 Hz group, 200 mJy×15 Hz group, and 150 mJy×20 Hz group. Each specimen comprised ten tooth specimens. A laser beam with conjunction of a water flow rate of 1.6 ml/min was applied over enamel surfaces of the specimens during 3 seconds and the ablation amount was determined by difference in weight before and after irradiation.

To investigate the temperature change in the pulp according to the above groups, another five extracted healthy human molar teeth were prepared. Each tooth was embedded into resin block and the temperature-measuring probes were kept on the irradiated and the opposite walls in the dental pulp during lasing.

When the power was kept constant at 3W, ablation amount increased with pulse energy rather than pulse repetition rate (p=0.000). Although intrapulpal temperature increased with pulse repetition rate, there were no significant differences among the groups and between the irradiated and the opposite pulpal walls, except at a condition of 150 y×20 Hz (p=0.033).

Conclusively, it is suggested that ablation efficacy is influenced by pulse energy rather than pulse repetition rate.

Key words : Er:YAG laser, Tooth ablation, Identical power, Ablation efficiency, Intrapulpal temperature

I. INTRODUCTION

Therapeutic effects of light have been verified in many ways since ancient times[1] and have finally led to the development of laser systems for medical use and clinical applications today. Following the introduction of the early ruby laser into dentistry,[2] a wide range of laser systems have been examined for dental use. While the use of most laser systems, including the carbon dioxide and Nd:YAG laser, have been proved to be safe and have valid applications for dental soft tissue, the results on dental hard tissue have not been encouraging. Insufficient ablation and thermal damage often account for the unfavorable results.

Since Hibst and Keller reported the effects of

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Er:YAG laser on dental hard tissue,[3,4] the Er:YAG laser has aroused great interest as a possible alternative to the dental drill, making cavity preparation both noise-free and vibration-free, while possibly reducing the need for local anesthesia.[5,6] Besides, the Er:YAG laser produces a good quality of cutting surface comparable to the surface produced by a rotary handpiece at high speed.[7,8]

Because of the same absorption wavelength with water, Er:YAG laser which emits the 2.94 ㎛ radiation are used to ablate dental hard tissue.[3,9,10] A small amount of water in enamel and dentin is a strong absorber of the laser radiation, leading to volumetric expansion and micro-explosion and subsequently to hard tissue ablation.[10]

It is widely accepted that ablation rate is influenced by variable conditions such as water spray, water content of the target tissue, and laser parameters including pulse energy, pulse repetition rate and so on, which also influence one another.[11] Among the aforementioned parameters, various studies on the effect of water spray demonstrated that simultaneous application of water spray enables efficient and safe tooth ablation with little thermal damage.[11-16] In this regard, determination of water flow rate seems to be very important in clinical applications using Er:YAG laser. Burkes et al[13] reported that if the volume of water was too high, vaporization of water occurred without ablation, and that if the volume was too low, ablation was insufficient and heating of the tooth became significant. Kim et al[17] suggested that tooth ablation with Er:YAG laser can be done effectively and safely at a energy between 200 and 300 mJ/pulse and a pulse repetition rate of 20 Hz when the lasing is conjugated with the water flow rate of 1.6 ml/min.

According to many researches, the ablation amount increased roughly as pulse energy or pulse repetition rate increased.[11,15,18] Hossain et al[15] reported linear relationship between ablation depth and energies at a given frequency and Li et al[18] exhibited close correlation for ablation depth per pulse of laser energy.

Nevertheless, it is, to our knowledge, still in lack the studies concerning ablation efficiency due to the change of pulse energy and pulse repetition rate in case that the power was set at a given amount. Thus, the objectives of the present study were to investigate the amount of tooth ablation and the change of intrapulpal temperature by Er:YAG laser as it relates to pulse energy and pulse repetition rate at the identical total power and, thereby, to reveal which of the two parameters strongly relates with ablation efficiency and intrapulpal temperature.

Ⅱ. MATERIALS AND METHODS

Five extracted healthy human molar teeth (caries-free and restoration-free) were prepared and sectioned into two pieces. Each specimen was irradiated at three irradiation conditions, respectively, according to the combination of pulse energy and pulse repetition rate at the same total power of 3 W; (1) 300 mJy×10 Hz, (2) 200 mJy×15 Hz, and (3) 150 mJy×20 Hz. Each experimental group consisted of ten specimens.

Quantitative measurements by a scale were performed to compare ablation efficiency. Before irradiation, specimens were weighed after the application of water spray for 9 seconds and drying with air syringe for 40 seconds to minimize potential measurement errors resulting from absorption of water that might have occurred during the lasing of the specimen. Irradiation was performed in contact mode with a tangential position of the quartz tip with 800 ㎛ in diameter and water spray of 1.6 ml/min[17] was directed at the ablation site. The irradiation was done three times for three seconds. After irradiation, the specimen was dried using an air syringe for 40 seconds and weighed again. The amount of ablation was determined to be the weight differences before and after lasing divided by three to account for the fact that each specimen was irradiated three times for three seconds. After measuring the weight twice, the mean value was selected.

To investigate the temperature change in the pulp related to the above groups, another five extracted healthy human molar teeth were prepared and cleaned for the specimen. Access cavity was made from occlusal surface of each tooth and pulp remnants were eliminated. Each tooth specimen was embedded into resin block (auto-polymerized), pulp cavity was filled with physiologic saline and occlusal surface was covered with resin capping on which two holes were made to place the temperature-measuring probes (Pen recorder LR8100, Yokogawa Co., Japan) on the irradiated and opposite walls in pulp cavity (Fig. 1). To prevent water sprayed during lasing from permeating pulp cavity and possibly affecting intrapulpal temperature, the gap between hole and probe was reinforced by using plaster adhesives. Each tooth was embedded into resin block and the temperature-measuring probes were kept on the irradiated and the opposite walls in the dental pulp during application of laser energy.

The Er:YAG laser system (SDL-3300E, B&B Systems Co. Korea) used for this study emits a light at a wavelength of 2.94 ㎛ and has a contact-type hadnpiece with the quartz tip (diameter = 800 ㎛) and its maximum average power was 6 W.

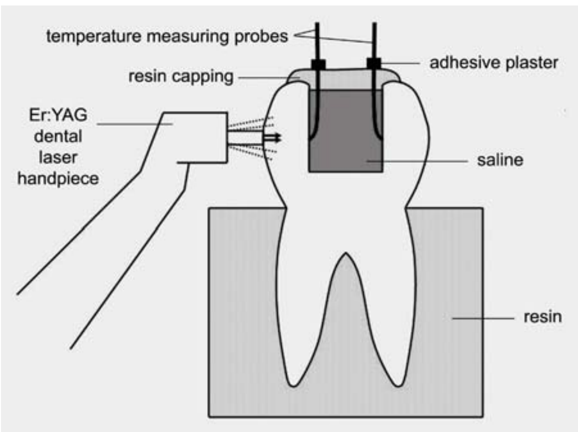

Fig. 1. A schematic of tooth specimen to monitor intrapulpal temperature change by using temperature-measuring probes.

For statistical analysis, Two-Way ANOVA and Multiple Comparison t-tests were used to compare the mean ablation amount and temperatures of the three experimental groups.

Ⅲ. RESULTS

Table 1 shows the ablation amount of three experimental groups related to the change of pulse energy and pulse repetition rate at 3 W and also demonstrated that there was significant difference among three conditions (p=0.000). In multiple comparisons of these groups, significant differences existed not only between 150 mJy×20 Hz and 200 mJy×15 Hz groups (p=0.003) but also between 150 mJy×20 Hz and 300 mJy×10 Hz groups (p=0.000) and there was no significant difference between 200 mJy×15 Hz and 300 mJy×10 Hz (p=0.057), suggesting that the ablation amount increased with pulse energy rather than pulse repetition rate when the power was kept constant at 3 W.(Fig. 2)

Concerning the change of intrapulpal temperature induced by irradiation, the change on the irradiated pulpal wall was negligible at any experimental condition, demonstrating 0.569 ± 0.358℃, 0.480 ± 0.432℃, 0.260 ± 0.279℃ in the 150 mJy×20 Hz, 200 mJy×15 Hz and 300 mJy×10 Hz groups, respectively.(Table 2) Although the intrapulpal temperature increased with pulse repetition rate, there were no significant differences among the groups and between the irradiated and the opposite pulpal walls.

Table 1. The amount (mg) of enamel ablated according to varied pulse energies and pulse repetition rates of Er:YAG laser when the total power was set at 3 W.

	N	Mean	S.D.	ANOVA
150 mJ×20 Hz	10	0.323	0.075	
200 mJ×15 Hz	10	0.453	0.014	p=0.000
300 mJ×10 Hz	10	0.532	0.068	

Irradiation time was 3 seconds and rate of water spray during irradiation was 1.6 ml/min.

Table 2. The change of intrapulpal temperature (℃) during irradiation of Er:YAG laser according to varied pulse energies and pulse repetition rates at the total power of 3 W.

Group	N	Irradiated wall	Opposite wall	
		Mean ± SD	Mean ± SD	
150 mJ× 20Hz	5	0.569 ± 0.358	0.200 ± 0.235	
200 mJ× 15Hz	5	0.480 ± 0.432	0.020 ± 0.045	NS[a]
300 mJ× 10Hz	5	0.260 ± 0.279	0.080 ± 0.084	
		NS[b]		

NS[a] stands for no significant difference among three groups and NS[b] stands for no significant difference between the irradiated and the opposite walls in the dental pulp. (Rate of water spray during irradiation was 1.6 ml/min and irradiation time was 3 seconds.)

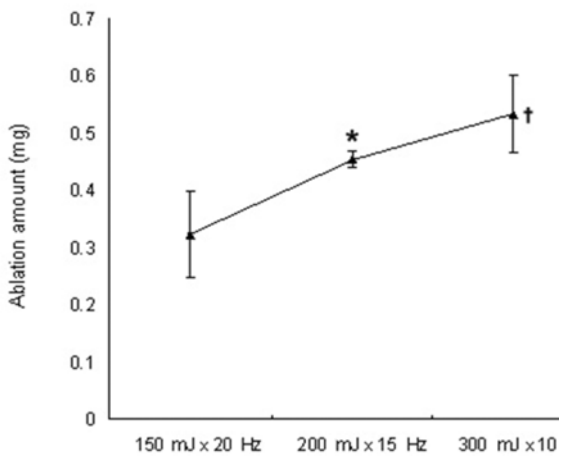

Fig. 2. Linear graph showing the ablation amount measured according to pulse energy and pulse repetition rate when total power was set at 3 W. * stands for significant difference between 150 mJy×20 Hz and 200 mJy×15 Hz groups and stands for significant difference between 150 mJy×20 Hz and 300 mJy× 10 Hz groups. (p=0.003 and 0.000, respectively)

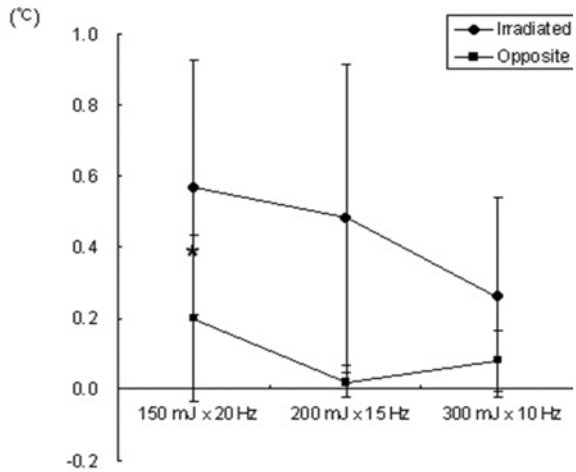

Fig. 3. Linear graph showing the change of intra-pulpal temperature(℃) during irradiation of Er:YAG laser according to varied pulse energies and pulse repetition rates at the total power of 3 W. * means significant difference between the irradiated and opposite walls at the condition of 150 mJy×20 Hz (p=0.033).

(Table 2 and Fig. 3) Exceptionally, significant difference between the irradiated and opposite pulpal walls was found only at 150 mJ×20 Hz group, having the highest pulse repetition rate of the three experimental conditions (p=0.003).

Ⅳ. DISCUSSION

Promising results have been reported in removing dental hard tissue by utilizing the Er:YAG laser.[19,20] Although some clinicians indicated that a lack of tactile sensation made it difficult to control the depth of the cavity being cut, laser ablation has obvious advantages, including minimal vibration and noise, and a reduced need for the administration of local anesthetics,[5,6,10,19,21] which are a main source of dental anxiety and phobia.

Dentin and enamel have high absorption peaks in the infrared region at 2.9 ㎛.[22] The laser beam delivered by the Er:YAG laser works by utilizing the water in dental hard tissue which absorbs the radient energy of the laser, and is heated to boiling, producing water vapor. The expansion of water as it becomes vaporized builds up pressure within the irradiated site until a micro-explosion occurs and a small portion of tissue is ablated.[13]

A lot of studies tooth ablation with Er:YAG laser exhibited that control of irradiation parameters are of critical importance to obtain effective ablation with little thermal damage of pulp. It is generally accepted that ablation rate increases with pulse energy and pulse repletion rate. Hossain et al[15] reported that the relationship between ablation depth and energies ranging from 100 to 400 mJ at a frequency of 2 Hz was almost linear in both enamel and dentin. Li et al[18] also exhibited the increase of ablation depth with pulse energy (ranging from 25 to 365 mJ) at 2 and 5 Hz, respectively and close correlation for ablation depth per pulse of laser energy as well. In a previous study of ours1), a pulse energy of 400 mJ produced more ablation amount in enamel as compared to 250 mJ/pulse conjugated with a water spray of 1.69 ml/min but ablation rate in dentin was compromised at a combination of pulse energy of 400 mJ and water spray of 1.69 ml/min. The most effective dentin ablation with 400 mJ /pulse was found at the higher water flow rate of 6.75 ml/min. Another study aforementioned[17] also showed that tooth ablation with Er:YAG laser can be done effectively and safely at a energy between 200 and 300 mJ/pulse and a pulse repetition rate of 20 Hz when the lasing is conjugated with the water flow rate of 1.6 ml/min. These findings support that irradiation parameters should correspond with one another. Table 1 indicates that the ablation rate increased with pulse energy notwithstanding lower pulse repetition rate at the same total power, possibly suggesting a strong relation of ablation rate with pulse energy.

The risk of thermal damage to the tooth by the Er:YAG laser is very low. Most of the energy is released in the ablation effect, whereas only a slight amount of the energy from the laser dissipates as heat in the superficial layers of the tooth.[4,19] The following laser pulse removes the heated material. This explains the safety of Er:YAG laser ablation with the minimal thermal side effect. However, once the available water in dental hard tissue has been vaporized and a small amount of ablation has occurred, no additional water is available for absorbing the energy.[23] If there were no water spray added during irradiation, the tooth surface becomes dried out, resulting in reduced laser ablation efficiency; and that teeth irradiated without addition of a water spray could become heated by the laser energy, resulting in heat-related changes, including the melting of enamel and the formation of bubble-like voids and cracks.[14,23] That is, simultaneous application of water spray with irradiation not only enhances ablation efficiency of dental hard tissue, but secures thermal protection to the pulp.[13,20] However, the water effects can be optimized by adjusting the water flow rate to the laser energy and pulse repetition rate. If the rate of water flow is too thick at the ablation site, requiring a greater amount of energy to be consumed for its removal, thereby decreasing the ablation rate and increasing the number of pulses needed for ablation.[24] Too much water also compromises vision of dentists during the laser ablation.[25]

According to our finding concerning change of intrapulpal temperature induced by Er:YAG laser irradiation, there was little thermal effect when a water spray of 1.6 ml/min was applied at the ablation site.(Table 2) However, it suggests the possibility of temperature rise due to a high pulse repetition rate the finding that temperature rise on the irradiated pulpal wall was observed at a condition of 150 mJ×20 Hz even though it was still in range of pulpal safety. It is generally accepted that the pulpal temperature rise of less than 5℃ during irradiation is safe for the pulp.[26] The higher the pulse repetition rate, the higher the thermal effect of irradiation could be expected.[18] It, therefore, is likely that to secure cooling time between pulses by lessening a pulse repetition rate enables tooth ablation with an Er:YAG laser to be safe, which needs an increase of a pulse energy. Until now, there have been lots of difficulties to develop a Q-switched Er:YAG laser with suprapulse, but it is assumed that further studies concerning it enhance safer and more efficient tooth ablation.

V. CONCLUSIONS

It is, based on the results from the present study, expected that ablation efficacy is influenced by a pulse energy rather than a pulse repetition rate.

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국문요약

Er:YAG 레이저를 이용한 치아 삭제시 동일출력에서 펄스에너지와 조사반복률의 영향

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Er:YAG 레이저를 이용한 치아경조직 삭제의 효율과 안전도는 물분사량, 조사시간, 조사방법, 에너지, 조사반복율 등의 다양한 변수에 의해 좌우된다. 이 연구의 목적은 출력을 고정한 상태에서 에너지와 조사반복율을 달리하였을 때 삭제율과 치수내 온도변화가 어떤 요소에 의해 더 많이 좌우되는지를 평가하고자 하였다.

발거된 건전 대구치를 두 조각으로 나누어 치아표본을 준비하여 300 mJ×10 Hz, 200 mJ×15 Hz, 및 150 mJ×20 Hz의 조건에서 1.6 ml/min의 물을 분사하면서 법랑질표면에 3초간 Er:YAG 레이저를 조사하였다. 레이저 조사 전후의 치아 무게를 측정하여 그 차이로 삭제율을 평가하였다. 각 군당 표본은 10개로 하였다.

위의 조건에서 발생하는 치수내 온도변화를 평가하기 위하여 발거된 건전한 대구치를 이용하여 access cavity를 형성하고 치수조직을 제거한 다음, hard acrylic resin으로 만든 block에 치아를 매식하고 레이저를 조사되는 측 치수벽과 반대측 치수벽에 온도측정탐침을 위치시켜 레이저조사과정과 그 후에 발생하는 온도변화를 측정하였다. 조사조건은 삭제율 평가시와 동일하게 하였으며 각 군당 표본은 5개로 하였다.

실험의 결과, 3W의 출력에서 치아삭제량은 펄스에너지의 증가에 따라 함께 증가되었다.(p=0.000) 반면에 치수내 온도는 조사반복율의 증가에 의해 상승되었으나 각 군별, 조사측간에 유의한 차이는 없었다. 다만, 150×20 Hz의 조사조건에서만 조사측 치수벽이 반대측에 비해 유의한 온도증가를 보였다(p=0.033).

본 연구의 결과는 Er:YAG 레이저의 치아삭제율은 조사반복율보다 펄스에너지의 영향을 많이 받는다는 점을 시사하고 있다.

주제어 : Er:YAG 레이저, 치아삭제, 동일출력, 삭제효율, 치수내온도