Intrapulpal Temperature Change during Cavity Preparation on the Enamel and Dentin with an Er:YAG Laser

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The purpose of our study was to investigate whether the intrapulpal temperature during cavity preparation of enamel or dentin with Er:YAG laser still remained in range of safety for dental pulp protection when combined with appropriate water flow rate. The effect of different pulse repetition rates at the same pulse energy during ablation was evaluated as well.

Caries-free, restoration-free extracted human molar teeth were prepared for the specimen and divided two experimental groups of enamel and dentin. Each group comprised 5 specimens and each of tooth specimens were embedded into a resin block each and measuring probe was placed on the irradiated pulpal walls. For experiments of dentin ablation, enamel layers were prepared to produce dentin specimen with a same dentin thickness of 2 mm. A pulse energy of Er:YAG laser was set to 300 mJ and three different pulse repetition rates of 20 Hz, 15 Hz and 10 Hz were employed. Laser beam was delivered with 3 seconds and less per application over enamel and dentin surfaces constant sized by 3 mm×2 mm and water spray added during irradiation was a rate of 1.6 ml/min. Temperature change induced by Er:YAG laser irradiation was monitored and recorded

While enamel was ablated, there was no significant difference of temperature related to pulse repetition rates ($p=0.358$) and temperature change at any pulse repetition rate was negligible. Significant statistical difference in temperature changes during cavity preparation in dentin existed among three different pulse groups($p=0.001$). While temperature rise was noticeable when the dentinal wall was perforated, actual change of temperature due to Er:YAG laser irradiation was not enough to compromise safety of dental pulp when irradiation was conjugated with appropriate water spray.

Conclusively, it can be said that cavity preparation on enamel or dentin with an Er:YAG laser is performed safely without pulp damage if appropriate volume of water is sprayed properly over the irradiated site.

Key words : Er:YAG laser, Temperature, Water flow, Cavity preparation

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Ⅰ. INTRODUCTION

Following the introduction of the early ruby laser into dentistry[1], a variety 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 been discouraging. Insufficient ablation and thermal damage often account for the unfavorable results.

The report on the effect of Er:YAG laser on dental hard tissue by Hibst and Keller in 1989[2,3] gave rise to great concern about the Er:YAG as a potential alternative to dental drill and U.S. Food and Drug Administration (FDA) approved it as the first dental laser to be used for hard tissue ablation in 1997. A wavelength of 2.94 ㎛ emitted by Er:YAG laser has high absorbability in both the water and hydroxyapatite, leading to mechanical ablation process by microexplosion[4].

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, a reduced need for the administration of local anesthesics[5-9], and a good quality of cutting surface comparable to the surface produced by dental drill at high speed[10,11]. It has also been found that pulpal response to Er:YAG laser irradiation is minimal, reversible and similar to that of a high-speed handpiece[12-14].

In order to obtain safe and effective ablation for dental hard tissue with Er:YAG laser, there are a variety of parameters to be concerned about; pulse energy, pulse repetition rate, irradiation time, water flow rate and water contents of target tissue, etc. Based on the results of our previous study[15], water flow rate of 1.6 ml/min produced safe and effective ablation within a combination of 300 mJ/pulse and 10 to 20 Hz. However, a single application of Er:YAG laser for 3 seconds was given in our experiments so far, resulting in ablation only on the enamel surface. Tooth ablation confined to enamel surface with Er:YAG laser was effective and safe because that allows water spray to be applied properly to the irradiated site. However, it is in doubt about that the effect of water spray is still valid in case of the ablation at the deeper tooth structure. In particular, dentin was closer to pulp chamber compared with enamel, possibly leading to unfavorable laser-induced temperature rise in dental pulp.

The purpose of this study was to investigate whether the intrapulpal temperature during cavity preparation of enamel or dentin with Er:YAG laser still remained in range of safety for dental pulp protection when combined with an optimal water flow rate. The effect of different pulse repetition rate during ablation was evaluated as well.

Ⅱ. MATERIALS AND METHODS

Extracted human healthy molar teeth were prepared for the study. After cleaning the teeth, access cavity was made from occlusal surface of each tooth and pulp remnants were eliminated. Each of tooth specimens was embedded into resin block(auto-polymerized), pulp cavity was filled with physiologic saline and occlusal surface was covered with resin capping on which a hole in center was made to place a temperature-measuring probe (Pen recorder LR8100, Yokogawa Co., Japan) on the irradiated pulpal wall (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.

For dentin ablation, tooth specimens were prepared with a high speed drill, leaving dentin thickness of 2 mm of the specimens to allow same experimental condition.(Fig. 2) Manipulation to measure intrapulpal temperature was carried out in the same way with that of enamel specimens. The area of enamel and dentin to be prepared with Er:YAG laser was determined as 3mm×2mm and marked with a pen on the tooth surface of each specimen.

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

Based on the results of our previous study[15], a pulse energy of 300 mJ and a water flow rate of 1.6 ml/min was used during irradiation while a pulse repetition rate employed three conditions; 20 Hz, 15 Hz and 10 Hz. Laser beam for 3 seconds per single

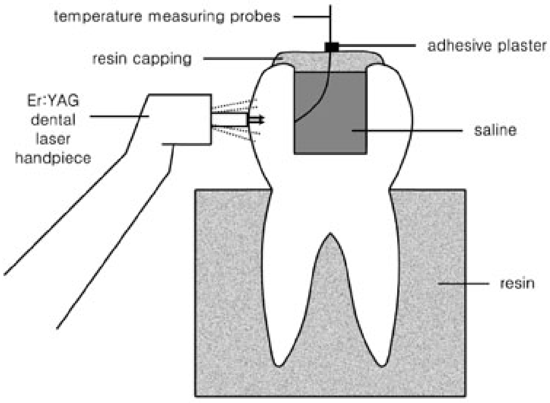

Fig. 1. A schematic of tooth specimen to monitor temperature change in dental pulp during ablation of enamel layer by using a temperature-measuring probe.

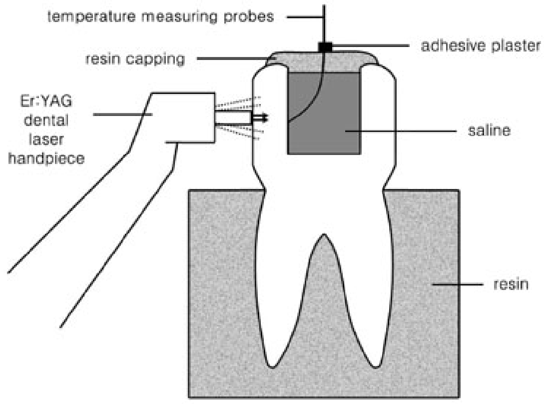

Fig. 2. A schematic of tooth specimen to monitor temperature change in dental pulp during ablation of dentin layer by using a temperature-measuring probe.

application[16] was delivered to the enamel or dentin surface in contact mode during cavity preparation.

Temperature change on irradiated pulpal wall was monitored while enamel surface sized by 3 mm×2 mm was prepared with Er:YAG laser until dentin surface was nearly exposed and while 3 mm×2 mm-sized rectangular area of dentin surface was ablated until dentinal wall was just perforated. Each experimental group included five specimens.

To analyze the influence of different pulse repetition rates on intrapulpal temperature during ablation, one-way ANOVA was used and multiple comparison t-tests were performed to identify the differences between the experimental groups.

Ⅲ. RESULTS

Table 1 shows the temperature change (ΔT=Maximum temperature-Start temperature) on the irradiated pulpal wall when cavity preparation sized by 3 mm×2 mm was carried out on the enamel and dentin by Er:YAG laser combined with a water flow rate of 1.6mm/min. The results represents that temperature on the irradiated pulpal wall decreased with simultaneous application of water and laser irradiation and increased again right after ceasing of irradiation and water spray. Maximum temperature during dentin ablation was obtained when dentinal wall was perforated.

While cavity preparation was done on the enamel, there was no significant difference of temperature among the three experimental conditions; 300 mJ× 20 Hz, 300 mJ×15 Hz and 300 mJ×10 Hz (ANOVA, p=0.358) and temperature change in all three groups was so negligible to minimize the risk of pulpal damage. Some cases exhibited even decrease of temperature with irradiation as compared to start temperature, likely due to application of water spray during Er:YAG laser irradiation(Fig. 3).

Significant statistical difference in temperature changes existed among three different Hz groups when 3 mm×2 mm-sized cavity was prepared in dentin until pulp chamber was perforated(ANOVA, p=0.001). The results of multiple comparison t-tests demonstrate that there was significant difference between 20 Hz and 10 Hz groups(p=0.000) and between 15 Hz and 10 Hz groups(p=0.006)(Fig. 4). The higher pulse was employed, the higher temperature rise induced by laser was induced. However, there was no significant difference between 20 Hz and 15 Hz groups(p=0.171). Temperature rise during all monitoring procedures was noticeable when the dentinal wall was perforated, but despite of the perforation, actual

Table 1. Temperature rise on the irradiated pulpal wall during ablation of dental hard tissue with the Er:YAG laser in conjunction with a water flow rate of 1.6 ml/min.

		300 mJ×20 Hz (N=5)	300 mJ×15 Hz (N=5)	300 mJ×10 Hz (N=5)	ANOVA
Enamel	Mean	ΔT= 0.10℃	ΔT= - 0.26℃	ΔT= 0.24℃	p=0.358
	SD	0.20℃	0.59℃	0.71℃	
Dentin	Mean	ΔT= 0.66℃	ΔT= -0.48℃	ΔT= -3.08℃	p=0.001
	SD	1.49℃	1.24℃	0.91℃	

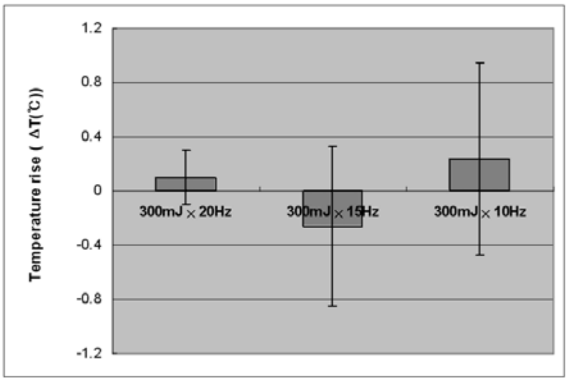

Fig. 3. Temperature rise(ΔT=Max temp-Start temp) on the irradiated pulpal wall during enamel ablation with the Er:YAG ablation in conjunction with a water flow rate of 1.6 ml/min. There was no significant difference between the three pulse repetition rate groups.

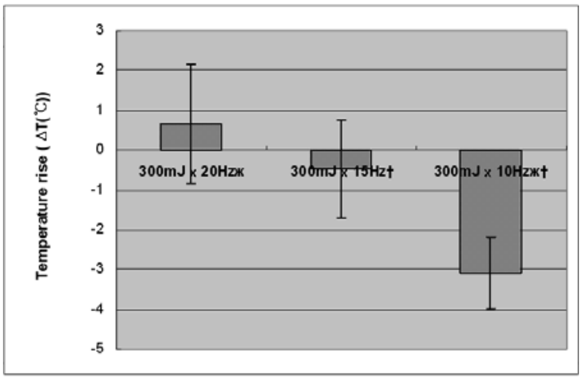

Fig. 4. Temperature rise (ΔT=Max temp-Start temp) on the irradiated pulpal wall during dentin ablation with the Er:YAG ablation in conjunction with a water flow rate of 1.6 ml/min. Significant differences existed between the same symbols.(※; p=0.000, † ; p=0.006)

change of temperature due to Er:YAG laser irradiation was very low and, furthermore, laser ablation induced decrease of temperature in the 15 Hz and 10 Hz groups(Table 1, Fig. 4).

Ⅳ. DISCUSSION

The Er:YAG laser emits at a wavelength of 2.94 ㎛ which is strongly absorbed by water which has the same absorption wavelength[2,3,17]. Because both enamel and dentin contain a small amount of water in their substances, the laser beam delivered by the Er:YAG laser works by utilizing the water in dental hard tissue which absorbs the radiant 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[18]. 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[3,8]. The following laser pulse removes the heated material. This accounts for the minimal thermal side effects associated with hard tissue ablation using the Er:YAG laser[8] and explains why the Er:YAG laser is suitable for ablation of enamel and dentin.

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, consequently further removal of enamel is inhibited[19]. Without the addition of a water spray, the tooth surface becomes dried out, resulting in reduced laser ablation efficiency, and that teeth irradiated without the 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[19,20]. Therefore, the simultaneous application of water spray during irradiation not only enables rapid ablation of enamel and dentin, but offers thermal protection to the pulp[13,18].

The water effects should be optimized by adjusting the water flow rate to the laser energy and pulse repetition rate. If the volume was too low, ablation was insufficient and heating of the tooth became significant[18]. If the rate of water flow is too high, it may result in a film of water that 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.21 Too high water also compromises good vision of operation for clinicians.

Hibst and Keller[8,21] recommended a water flow of 1 to 2 ml/min for a low pulse repetition rate (2-4 Hz) and energies ranging from 150 to 250 mJ and Armengol et al[20] reported that the water flow rate was 1.4 ml/min for a pulse repetition rate of 4 Hz and an energy of 140 mJ. In a previous study of ours comparing water flow rate of 1.69, 6.75 and 12.5 ml/min,[22] it was recommended a water flow rate of 1.69 ml/min for enamel and dentin ablation at a pulse energy of 250 mJ and for dentin ablation at 400 mJ/pulse, and 6.75 ml/min for enamel ablation at a pulse energy of 400 mJ, regardless of pulse repetition rate of 5, 10 and 20 Hz. Another study of ours[15] showed a similar results; the most effective ablation for 20 Hz and 200 or 300 mJ/pulse was obtained by a relatively low rate of water flow of 1.6 ml/min while having acceptable limits of temperature rise in the dental pulp. Safe and efficient ablation of dental hard tissue is governed by temperature effects on the dental pulp and surrounding tissues and by absorption of laser energy by tooth material[23]. It is said that pulpal damage can be expected with temperature rises above 5℃[24,25]. According to Zach and Cozean,[24] temperature rises of 5.6℃ in dental pulp can induce loss of pulpal vitality in 15% of teeth tested. Raising the temperature 11℃ will cause 60% necrosis and 100% when raised more than 17℃[26].

Our previous studies set irradiation time to 3 seconds, which resulted in ablation only on the enamel surface. Although irradiation exposure of 3 seconds or less per application of laser beam is recommended to ablate enamel effectively without any noticeable temperature rise[16], repeated exposure of even 3 seconds per single application during cavity preparation may provoke accumulation of laser energy, possibly leading to pulpal damage. Of course, higher volume of water can prevent dental pulp from being injured, but ablation efficiency can be compromised[15]. Therefore, this study tried to investigate temperature rise during a given sized cavity preparation, in particular in case of cavity preparation in dentin having less content of inorganic substances[27] and more approximation to dental pulp as compared to enamel.

While laser energy conjugated with water spray was delivered to tooth surface, there existed a tendency that temperature on irradiated pulpal wall was decreased or maintained without noticeable temperature rise and then increased again for a few seconds right after ceasing of irradiation and water spray. This finding had already been found in one of our studies[28], suggesting that addition of water spray for a second and more after irradiation reduces post-irradiation temperature rise which may lead to thermal damage on the dental pulp tissue. In case of dentin preparation in this study, the maximum temperature was obtained when dentinal wall was perforated.

While 3 mm×2 mm-sized cavity preparation was performing on the enamel, temperature change on the irradiated pulpal wall was trivial and there was no significant difference in temperature changes, regardless of pulse repetition rate. On the contrary, significant difference in intrapulpal temperature during cavity preparation in dentin existed among the three different pulse repetition rate groups but laser-induced temperature rise was also negligible, in spite of perforation of dentinal wall during cavity preparation. It is thought to be that cavity preparation was carried out on the dentin surface where all layer of enamel already removed, which allowed water sprayed to be distributed properly over the irradiated site. This result indicates that efficient and safe ablation of tooth material possibly depends on whether water spray added during laser ablation can reach accurately and appropriately the irradiated tooth surface. It is likely that proximity of water spray to deeper portion of dentin would be compromised in clinical situation, which suggests that special attention should be paid to proper distribution of water spray during cavity preparation with Er:YAG laser in order to avoid unfavorable thermal injury to dental pulp.

V. CONCULSIONS

When the Er:YAG laser irradiation was conjugated with appropriate water spray(1.6 ml/min in this study), a pulse energy of 300 mJ was be able to ablate effectively and safely enamel and dentin materials. Regardless of pulse repetition rates, temperature rise on the irradiated pulpal wall due to ablation of enamel layer was too low to induce pulpal damage. Although higher pulse repetition rate produced higher intrapulpal temperature during cavity preparation on dentin layer, actual rise of temperature was also in safety range for pulp.

Conclusively, it can be said that cavity preparation on enamel or dentin with an Er:YAG laser is performed safely if appropriate volume of water spray corresponding to irradiation parameters is given during irradiation. In case of cavity preparation in the deeper region of dentin, special attention should be paid to proper distribution of water spray over irradiated site.

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국문요약

Er:YAG 레이저를 이용한 법랑질 및 상아질 와동 형성시의 치수내 온도변화

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양희영 · 김미은 · 김기석

본 연구의 목적은 법랑질과 상아질에서 와동을 형성하는 동안 치수벽에서 발생하는 온도변화를 관찰하여 치수 손상 가능성을 평가하고자 하였고 조사반복율의 차이에 따른 영향도 함께 조사하고자 하였다.

발거된 건전 대구치에 access cavity를 형성하고 레진 block에 식립한 다음, 온도측정센서를 레이저가 조사될

치수벽에 위치시켰다. 레이저를 조사하는 동안 분사되는 물이 온도변화에 영향을 주지 않도록 하기 위해 레진을 이용하여 occlusal cap을 만들고 가운데 작은 구멍을 내어 온도측정센서가 들어갈 수 있도록 하였으며 치아의 내부는 생리식염수로 채웠다. 치아표본은 법랑질실험군과 상아질 실험군으로 나누고 각 군당 치아표본수는 5개로 하였다. 상아질군에서는 모든 표본의 상아질 두께를 일정하게 하기 위하여, 고속핸드피스를 이용하여 상아질 두께가 2 mm가 되도록 삭제하여 사용하였다.

3 mm×2 mm의 일정한 면적을 치면에 표시한 다음 와동을 형성하였는데, 법랑질군에서는 상아질 이 노출되는 순간까지, 상아질군에서는 상아질벽이 천공되는 순간까지 온도변화를 조사하였다. 조사방식은 접촉식(contact mode)으로 하였으며 레이저가 한번 조사되는 시간을 3초 이하로 유지하면서 와동을 형성하였다. 300 mJ의 펄스에너지, 10, 15, 20 Hz의 조사반복율, 1.6 ml/min의 물분사량이 가해지는 조건에서 레이저 조사측의 온도변화를 측정하였다.

본 연구의 결과에 따르면, Er:YAG 레이저 조사시 적절한 양의 물분사가 이루어질 때, 즉 1.6 ml/min의 물분사량과 300 mJ의 펄스에너지의 조건에서 법랑질에서 와동형성시 10, 15, 20 Hz 의 조사반복율 모두에서 온도상승이 미미하여 치수손상을 야기할 만한 온도상승이 이루어 지지 않았고 세 군 간의 유의한 차이도 존재하지 않았다($p=0.358$). 상아질에서의 와동형성시에는 조사반복율이 증가할수록 온도상승이 컸지만($p=0.001$), 실제 온도상승은 여전히 치수손상을 야기 하지 않는 안전한 범위에 있었다.

결론적으로 적절한 양의 물이 레이저 조사면에 적절하게 분사되기만 하면 법랑질이나 상아질에 서의 와동형성은 안전하게 시행할 수 있을 것으로 생각된다.

주제어 : Er:YAG 레이저, 온도, 물분사, 와동형성