Study on Dental Hard Tissue Ablation by Er: YAG Laser

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Abstract

Objective: Recently, the Er: YAG laser has been applied clinically and shown excellent effectiveness in dental hard tissue ablation. However, its ablation efficiency is significantly inferior to that of high-speed rotary ablation, and prolongation of the treatment time has posed problems. To improve the ablation efficiency, attempts to increase the tip output and pulse repetition rate have been made, but various problems, including the effect on the dental pulp, remain unresolved. Paying particular attention to the irrigation device, our study group prepared a test tip that sprays the irrigation fluid as a mist by modifying the conventional irrigation mechanism with the cooperation of J. Morita MFG. Corp., and evaluated the ablation efficiency.

Materials and Methods: Healthy human molar teeth, used as samples, were filed to the enamel and dentin using a model trimmer, polished using waterproof abrasive paper to #2000, and irradiated with a laser by operating the moving stage at 1 mm/s. Laser irradiation was performed by setting the distance to the sample at 0.5, 1.0, and 2.0 mm. The group in which laser irradiation was performed using C600F was regarded as a control group, and the group in which laser irradiation was performed using the test tip as the mist spray group. Each sample was examined under a laser microscope, and the cross-sectional area was calculated (n=5).

Results: The cross-sectional area was significantly greater in the mist spray group than in the control group at an irradiation distance of 0.5 mm in enamel and at 0.5 and 1.0 mm in dentin ($p<0.05$).

Conclusion: In laser ablation of dental hard tissue, spraying the irrigation fluid as a mist was suggested to be effective for improving the ablation efficiency.

Keywords: Er: YAG laser, hard tissue ablation, ablation efficiency

Introduction

Since 1964, when Goldman et al.[1] reported the possibility of removing foci of dental caries using a ruby laser, research on the clinical application of lasers in the dental field has advanced, and lasers have been used for various treatments, including endodontic, periodontic, surgical, and restorative treatments[2-7]. In 1989, Hibst and Keller reported that enamel, dentin, and dental caries could be efficiently ablated using the Er: YAG laser[8,9].

While the Er: YAG laser has been evaluated from various viewpoints, it has also been applied clinically. In restorative treatments, also, the Er: YAG laser, which produces less noise and vibration and causes milder stress to patients, makes more comfortable treatment of caries possible[10-12], and is expected to replace the conventional rotary ablator.

Dental ablation (transpiration) using the Er: YAG laser is significantly inferior to high-speed rotary ablation in terms of the ablation efficiency, and has problems such as the long treatment time. To improve the ablation efficiency, attempts to increase the tip power output and repetition rate (pulse rate) have been made, but many problems, such as the effect on the dental pulp, remain unresolved. One cause of the decrease in ablation efficiency is the retention of water infused from the tip during ablation in the cavity, preventing the steady ablation of teeth.

Our group noted the importance of the irrigation device and considered that the water layer retained on the cavity surface can be thinned, and the ablation efficiency can be improved, by changing the irrigation mechanism from conventional infusion to spraying as a mist. Then a test tip that sprays the irrigation fluid as a mist was prepared, and its effect on the ablation efficiency and thermal effect on dental pulp were evaluated.

Materials and Method

Erwin® Adverl (Morita, Fig. 1), a laser generator, was used for the experiment. As irradiation tips, conventional C600F with a head diameter of 600 µm (Fig. 2) and a test tip that had the same head diameter but sprayed the irrigation fluid as a mist (Fig. 3) were used. Irradiation was performed under 2 sets of conditions: a head output power and pulse repetition rate, respectively, of 100 mJ and 10 pps or 30 mJ and 25 pps. The power output at the head was measured and determined using LaserMate-P (COHERENT), a laser power measurement device.

The experimental procedure is described below. This experiment was approved on the basis of the regulations of the Osaka Dental University Committee of Medical Ethics (Approval No. 110739).

1. Sample preparation

1) Ablation efficiency

Caries-free healthy human molar teeth extracted, immersed in physiologic saline, and preserved by freezing at the Department of Oral Surgery, Osaka Dental University Hospital were used as sample teeth by thawing them before the experiment. The sample teeth were split into halves buccolingually along a plane parallel to the dental axis, and flat surfaces of enamel and dentin were exposed using a model trimmer and polished with waterproof abrasive paper to #2000. They were irradiated at a distance of 0.5, 1.0, or 2.0 mm by operating the moving stage at 1 mm/s.

2) Thermal effect

Dentin blocks were cut out from areas near the pulp of thawed human teeth, polished with waterproof abrasive paper to #2000, and 1.0 mm thick plates were prepared. Their circumferences were reinforced with wax, and their reverse sides were colored with black oil ink. They were irradiated by moving the tip at 1 mm/s.

2. Measurement of samples

1) Ablation efficiency

The laser-ablated surface of each sample was examined under a laser microscope (KEYENCE VK series) (×100). Five samples irradiated under each condition were examined (n=5), and the cross-sectional area was measured at 5 randomly selected points per sample. The mean of the 5 values was regarded as the measured value of the sample.

2) Thermal effect

Five samples irradiated under each condition were examined (n=5). Each sample was irradiated using C600F and the test tip. The temperature was measured using infrared thermography (Neo Thermo TVS-700, Nippon Avionics Co., Ltd.) from the non-irradiated surface of the sample, and temperature increases were compared.

3. Statistical procedures

The group irradiated using C600F was regarded as a control group, and the group irradiated using the test tip as a mist spray group, and the results of measurements were statistically analyzed by one-way ANOVA and Tukey's test ($P<0.05$).

4. SEM

After the measurement, each sample was impregnated with Au and examined under the scanning electron microscope (JSM-5610LV, JOEL).

Results

1. Ablation efficiency

Figures 4, 5, 6 and 7 show the cross-sectional areas of enamel and dentin, respectively. Figures 8, 9, 10 and 11 show SEM images of various samples. Under irradiation conditions of 100 mJ and 10 pps, the cross-sectional area was significantly greater in the mist spray group at an irradiation distance of 0.5 mm in enamel samples and at 0.5 and 1.0 mm in dentin samples (Fig 4, 6). Under irradiation conditions of 30 mJ and 25 pps, the cross-sectional area was significantly greater in the mist spray group at an irradiation distance of 0.5 mm in enamel samples and at 0.5 and 1.0 mm in dentin samples (Fig 5, 7). The data at an irradiation distance of 2.0 mm were excluded because the ablated surfaces were unclear, and the measurements were unreliable. Regardless of the irradiation conditions, the cross-sectional area in the mist spray group at an irradiation distance of 1.0 mm was comparable to that in the control group at 0.5 mm. In both enamel and dentin samples, the cross sectional area decreased with increases in the irradiation distance. On SEM images, appearances suggesting melting of the dental substance were observed in enamel, and many fine cracks were observed in dentin, with both C600F and the new tip. No difference in the irradiation surface was noted between the tips.

2. Thermal effect

Figures 12 and 13 show increases in the temperature under different irradiation conditions. At 100 mJ and 100 pps, the temperature increase was 2.6 and 2.9°C in the control and mist spray groups, respectively, with no significant difference. At 30 mJ and 25 pps, the temperature increase was 1.6 and 2.1°C, respectively, also showing no significant difference. Figures 14 and 15 show SEM images of various samples. On SEM images, appearances suggesting melting of the dental substance were observed in enamel, and many fine cracks were observed in dentin, with both C600F and the new tip. No difference in the irradiation surface was noted between the tips.

Discussion

The emission wavelength of the Er: YAG laser is 2.94 μm, being close to the peak absorption band of water. Therefore, irradiation energy is absorbed by hydroxyl radicals and water in hydroxyapatite, which is the primary component of dental hard tissue, and it causes vapor explosion and destruction from inside the molecule, making the ablation of enamel and dentin by transpiration possible[13)].

In laser irradiation, the ablation efficiency has been reported to improve with decreases in the distance between the tip head and irradiated object as the energy density increases, the thickness of the interposing water layer decreases, and the amount of laser energy that the irradiated object receives increases[14)]. Also, as for the irradiation method, there are contact and non-contact irradiation forms with the tip head in contact and not in contact, respectively, with the irradiated object. Contact irradiation is advantageous in that irradiation errors can be prevented, and friction caused by ablation can be more directly sensed with the fingers, but time-associated wear of the tip and decreases in the head output and ablation efficiency have been reported as its disadvantages[15-17)]. Wear of the tip and the decrease in the head output have been reported to be caused by mechanical damage of the tip due to contact with the irradiated object, impact of the rebound of ablation fragments, blocking of the laser beam and thermal damage of the head due to ablation fragments adhering to, and melting on, the head[15-17)]. In this study, in consideration of the decrease in the ablation efficiency due to wear of the tip, non-contact irradiation was performed by separating the tip from the dental surface. At a distance of 0.5 mm, the ablation efficiency was significantly higher in the mist spray group in both enamel and dentin. This suggests that the ablation efficiency was improved because the irradiation energy was less attenuated by spraying the tooth with a mist of irrigation fluid, and as retention of the irrigation fluid in the cavity could be prevented. However, no significant difference was observed when irradiation was performed with a head output of 100 mJ, a pulse repetition rate of 10 pps, and a distance of 2.0 mm. This is considered to have been due to increases in the thickness of the interposing water layer and associated attenuation of the irradiation energy due to absorption by water.

Evaluation of the safety as well as ablation efficiency is necessary in laser ablation of hard tissue. Particularly, in laser ablation of dentin, the thermal effect on the pulp is important. Generally, if the laser beam is absorbed by the superficial layer of the irradiated body, deep tissue damage is considered to be slight. However, on the irradiation of teeth, particularly dentin, radiated heat is considered to be a major factor in pulp injury[18]. The thermal effect of the Er: YAG laser on the surrounding tissue has been reported to be controllable by irrigation of the irradiation field[19]. According to reports, Er: YAG laser energy is markedly absorbed by water, its absorption efficiency is about 10 fold higher compared with a CO_2 laser. Er: YAG laser is used as a laser scalpel, the time in which the heat affects the tissue in the irradiation field is extremely short, and the increase in the temperature of the surrounding tissue is slight, so the thermal effects on the surrounding tissue are negligible[20-24].

There have been a few studies on the effect of Er: YAG laser irradiation on the dental pulp. Since the studies' conditions of laser irradiation were variable, precise comparison of the effects on the pulp is impossible. However, Sekine[3] and Takano[25] both reported no difference in the effect on the pulp on short- or middle/long-term observation of cavity formation in dogs. There is a report comparing temperature changes during laser irradiation according to the presence or absence of a medium in the pulp cavity[26], and reports on the *in vivo* cooling effect of, and heat dissipation by, pulp blood flow[27,28], suggesting that the increase in temperature caused by Er: YAG laser irradiation is slight and does not cause serious damage to the pulp. Burkes et al.[19] reported that enamel and dentin can be ablated efficiently by Er: YAG laser irradiation, and that the increase in the temperature in the pulp cavity during ablation is about 4°C. Takizawa[29] also reported that, by irrigation with water for cooling, the thermal effect on the pulp could be controlled effectively, and ablation of dentin restricted to the irradiation field could be performed.

In this study, the relative rather than absolute temperature was measured, and increases in the relative temperature shown by thermography were evaluated for comparison with the conventional C600F tip. According to a report by Zach et al.,[30] temperature increases within 5.0°C had no effect on the pulp, but 5.6°C or greater increases were suggested to cause extensive pulp damage, and 11°C or greater increases to cause pulp necrosis. In this study, the measured increases in the dentin temperature were 2.9 and 2.1°C, and, since they were less than 5.0°C with no effect on the pulp, the new tip is considered to exert no thermal effect on the pulp.

The responses of the pulp to laser irradiation are considered to be affected by the wavelength[31] and irradiation conditions. Studies evaluating the responses of the pulp under various irradiation conditions reported contradictory results: the duration of irradiation exerted greater effects than the output in one study[32], but the output showed greater effects than the irradiation time in another[33]. However, severer pulp damage is considered to be sustained with increases in the power density or energy density if the irradiation method is the same[34]. Kawata et al.[26] reported that the laser beam was converted to thermal energy on the irradiated surface, that this thermal stimulus increased with irradiation energy, and that the temperature rose with increases in the irradiation time and output. Under the 2 sets of irradiation conditions employed in this study, the ablation efficiency was high on high-output irradiation, but the temperature increase was smaller on low-output irradiation. However, the difference in the temperature increase was slight, and the difference in the output of Er: YAG laser irradiation with irrigation is considered to cause no marked change in the pulp response. On SEM images, structures characteristic of laser ablation, such as fine cracks and the opening of dental tubules, were noted in dentin samples, but no change associated with the difference in the tip was observed on the irradiated surface. This also suggests that the new tip is similar to C600F in its clinical effectiveness.

Regarding the effects of Er: YAG laser irradiation on the pulp, it is generally considered to cause severer damage to areas of the pulp along the dental tubules at the site of ablation, but the effects of laser irradiation have been reported to be observed in the pulp located in the direction of irradiation as well as in the areas along the dental tubules[25]. Since the laser beam travels in a straight line, its effects differ greatly compared with those of the high-speed air turbine. Therefore, it is also considered necessary to perform laser ablation by taking the direction and angle of irradiation sufficiently into consideration[24].

Further evaluation of the effects of various clinical situations, including changes in irradiation conditions and the direction and angle of irradiation, is considered necessary.

Conclusions

The following conclusions were reached as a result of the study on dental ablation with the Er: YAG laser using the test tip.

1. Spraying the irrigation fluid as a mist was suggested to be effective for improving the efficiency of laser ablation of dental hard tissues.
2. Compared with the present C600F, the new tip caused no change in the thermal effect on the pulp, and is considered to be clinically effective.

Acknowledgments

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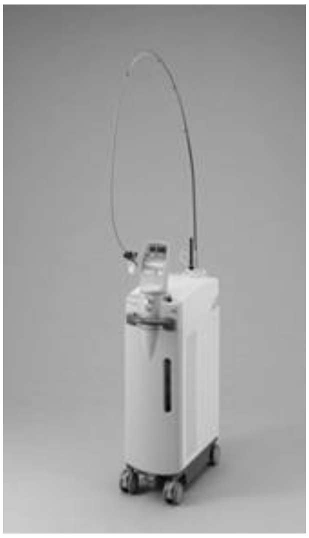

Fig. 1 Erwin® Adverl

Fig. 2 C600F

Fig. 3 New tip

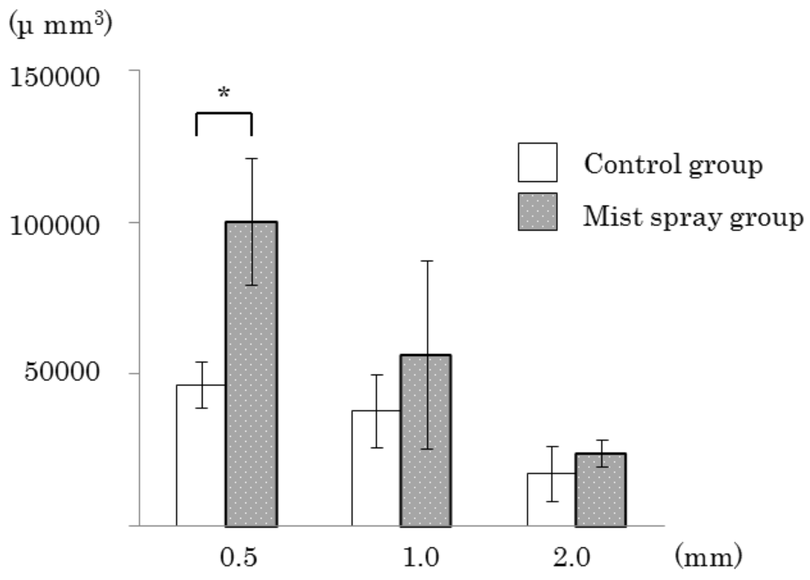

Fig. 4 Experiment 1: Cross-sectional area of ablated enamel (100 mJ: 10 pps)

*: Significant difference in Tukey's test ($p<0.05$)

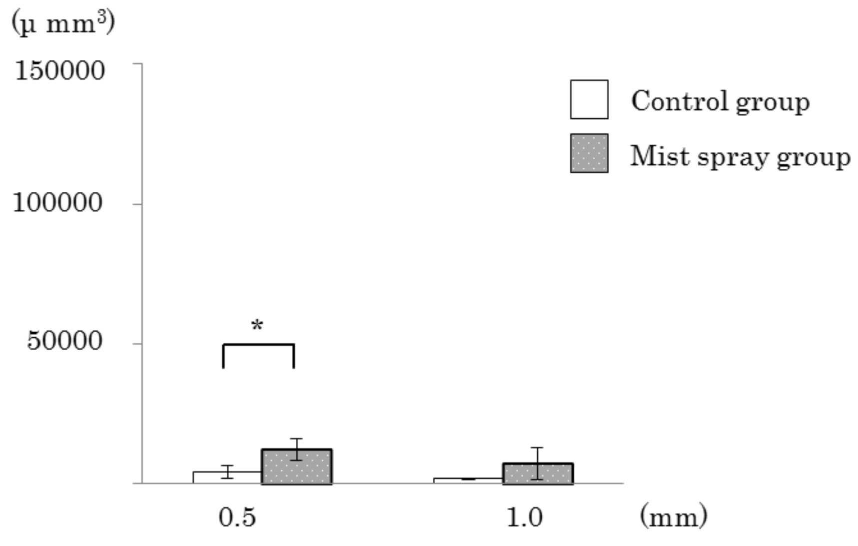

Fig. 5 Experiment 1: Cross-sectional area of ablated enamel (30 mJ: 25 pps)

*: Significant difference in Tukey's test ($p<0.05$)

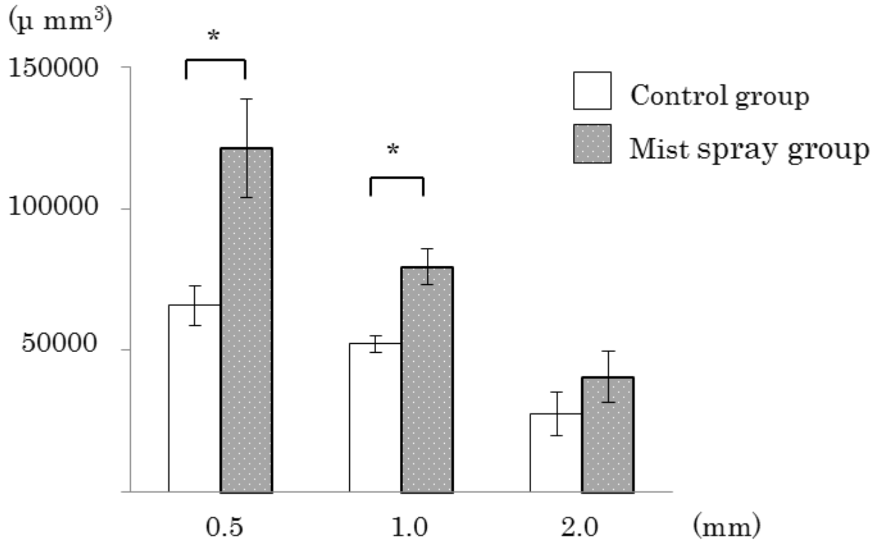

Fig. 6 Experiment 1: Cross-sectional area of ablated dentin (100 mJ: 10 pps)

*: Significant difference in Tukey's test ($p<0.05$)

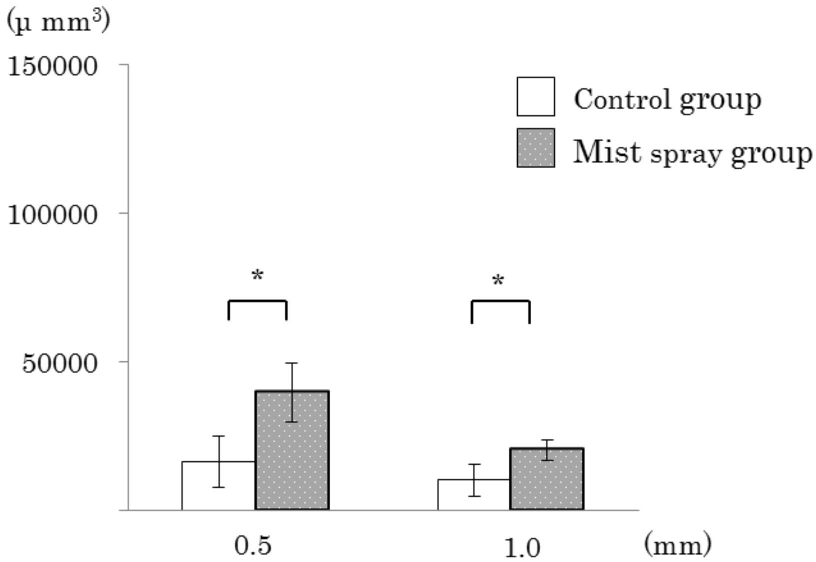

Fig. 7 Experiment 1: Cross-sectional area of ablated dentin (30 mJ: 25 pps)

*: Significant difference in Tukey's test ($p<0.05$)

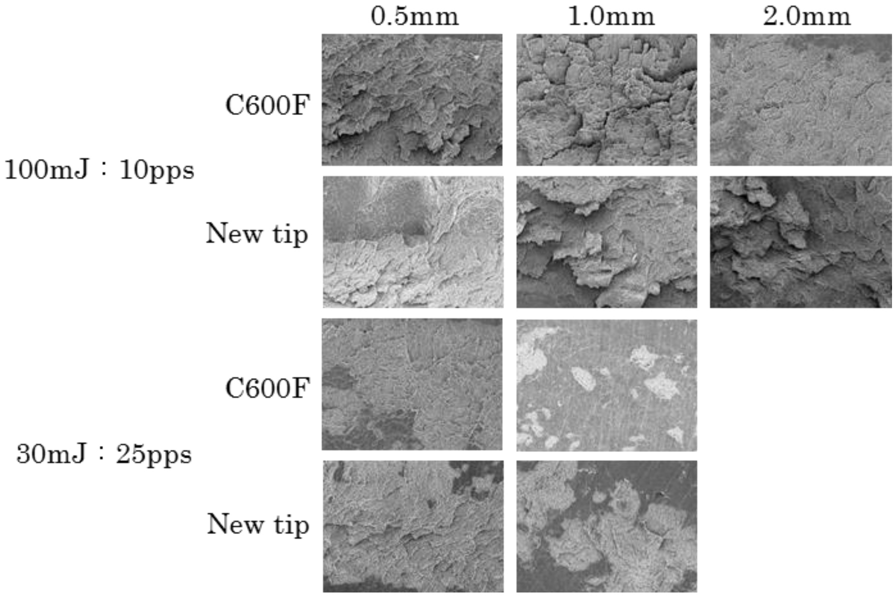

Fig. 8 Experiment 1: SEM images of enamel samples (×200)

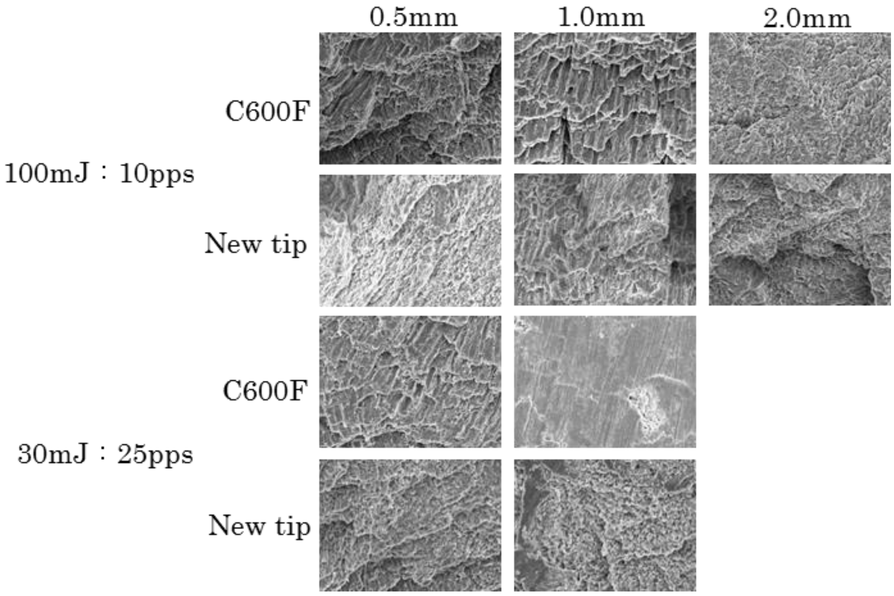

Fig. 9 Experiment 1: SEM images of enamel samples (×1,000)

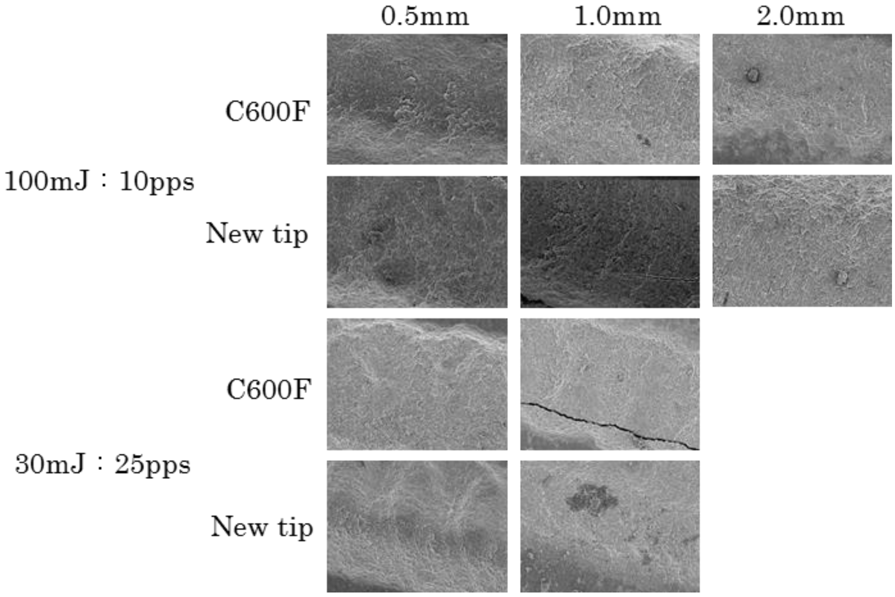

Fig. 10 Experiment 1: SEM images of dentin samples (×200)

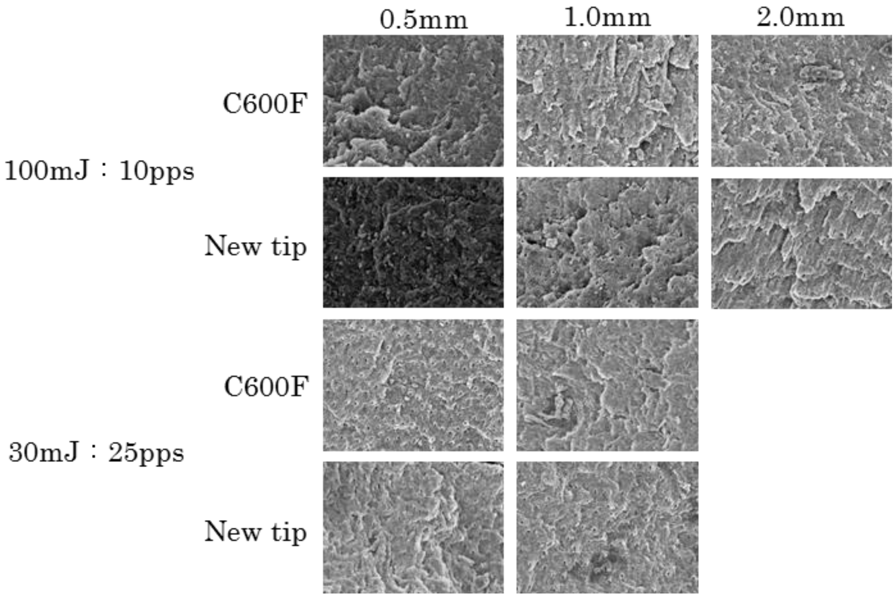

Fig. 11 Experiment 1: SEM images of dentin samples (×1,000)

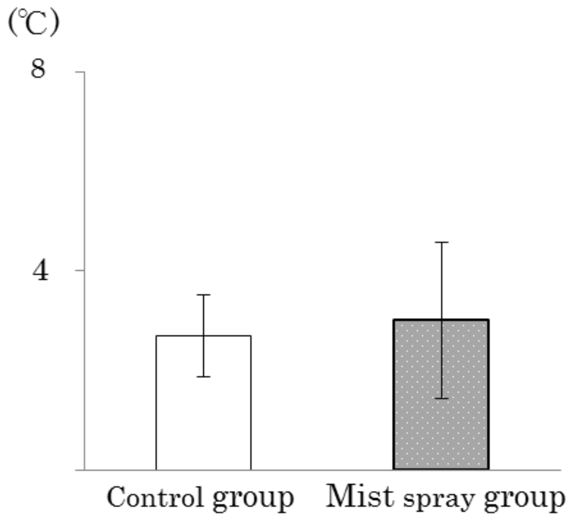

Fig. 12 Experiment 2: Temperature increases (100 mJ: 10 pps)

No significant difference in Tukey's test

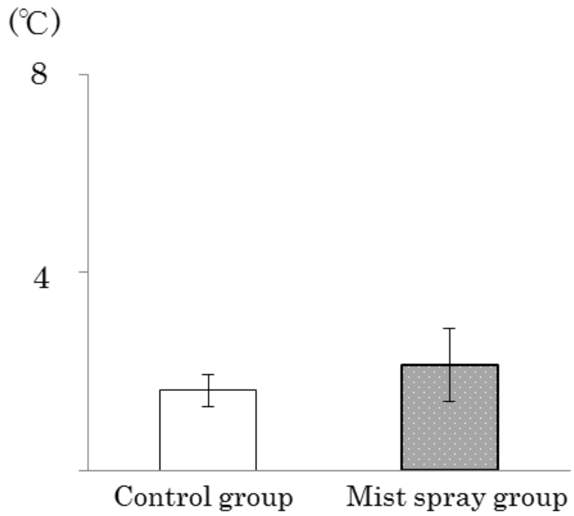

Fig. 13 Experiment 2: Temperature increases (30 mJ: 25 pps)

No significant difference in Tukey's test

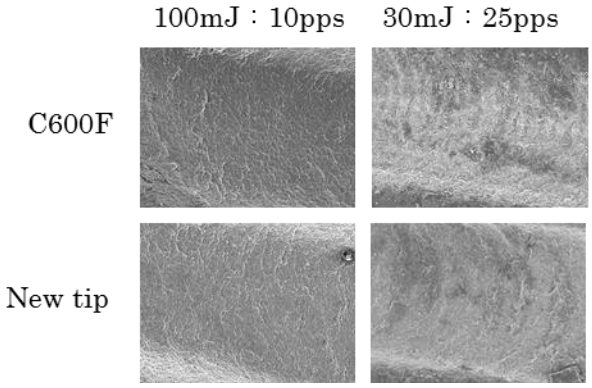

Fig. 14 Experiment 2: SEM images of dentin samples (×200)

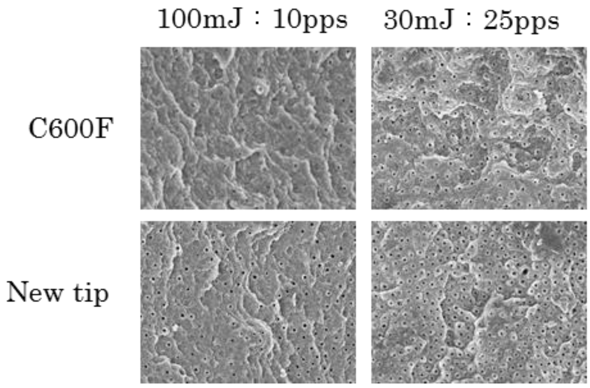

Fig. 15 Experiment 2: SEM images of dentin samples (×1,000)

抄録

目的：近年，歯の硬組織切削において Er：YAG レーザーは特に優れた効果を示し，臨床応用されている．しかしながら，高速回転切削器具には切削効率では到底及ばず，治療時間の延長などが問題となっている．切削効率を向上させるために先端出力や繰り返し速度を上げる試みがされてきているが，歯髄への影響など様々な問題を抱えている．我々の研究グループは注水装置に着眼し，従来の注水機構ではなく霧状に噴霧注水できる装置を利用し，モリタ製作所の協力の下，注水方式を霧状に改良した試作チップを作製し，切削効率について検討した．

材料と方法：被験歯として健全ヒト大臼歯を用い，エナメル質および象牙質までモデルトリマーにて面出しを行い，耐水研磨紙にて#2000 まで研磨を行った後，1mm/s でムービングステージを移動させ，レーザー照射を行った．レーザー照射は試料までの距離を 0.5，1.0 および 2.0 mm に規定した．C600F にてレーザー照射を行った群をコントロール群，試作チップにてレーザー照射を行った群を霧状噴霧群とした．各試料はレーザーマイクロスコープにて観察を行い，断面積量を計測した（n＝5）．

成績：エナメル質では距離 0.5mm で，象牙質では距離 0.5 および 1.0mm で霧状噴霧群はコントロール群よりも有意に高い値を示した（$p < 0.05$）．

結論：歯の硬組織切削において，霧状噴霧がレーザーによる切削効率の向上に有効であることが示唆された．

キーワード：Er：YAG レーザー，硬組織切削，切削効率