Effects of Erbium, Chromium:YSGG Laser Irradiation on Root Surface: Morphological and Atomic Analytical Studies


ABSTRACT

Objective: The purpose of this study was to investigate the morphological and atomic changes on the root surface by stereoscopy, field emission-scanning electron microscopy (FE-SEM), and energy dispersive X-ray spectroscopy (SEM-EDX) after erbium, chromium:yttrium, scandium, gallium, garnet (Er,Cr:YSGG) laser irradiation in vitro. Summary Background Data: There have been few reports on morphological and atomic analytical study on root surface by Er,Cr:YSGG laser irradiation. Methods: Eighteen extracted human premolar and molar teeth were irradiated on root surfaces at a vertical position with water-air spray by an Er,Cr:YSGG laser at the parameter of 5.0 W and 20 Hz for 5 sec while moving. The samples were then morphologically observed by stereoscopy and FE-SEM and examined atomic-analytically by SEM-EDX. Results: Craters having rough but clean surfaces and no melting or carbonization were observed in the samples. An atomic analytical examination showed that the calcium ratio to phosphorus showed no significant changes between the control and irradiated areas (p > 0.01). Conclusions: These results showed that the Er,Cr:YSGG laser has a good cutting effect on root surface and causes no burning or melting after laser irradiation.

INTRODUCTION

Since the effect of ruby laser irradiation on dental hard tissues was first reported in 1964, various lasers, such as ruby, CO₂, Nd:YAG, and Er:YAG lasers, have been studied regarding their effects on dental hard tissues. With regard to the application for root surface, the effects of various laser irradiation such as Nd:YAG, Er:YAG, CO₂, argon, and XeCl excimer lasers have been investigated. These lasers are useful for scaling and removal of smear layer and lipopolysaccharides (LPS). The treatment of root caries is of particular importance with an aging population. Review of current dental literature reveals that the prevalence of exposed root surfaces and root surface caries in the older adult population has been increasing with respect to aging and decayed/filled surfaces. It is clear that root caries prevention or treatment should begin once the root surface becomes exposed secondarily to periodontal disease with gingival recession.

An erbium, chromium:yttrium, scandium, gallium, garnet (Er,Cr:YSGG) laser device that emits a laser beam having a wavelength of 2.78 μm, has a mechanism of laser energy interaction with water at the tissue interface and has therefore been termed a hydrokinetic system (HKS). It has been shown to be capable of cutting dental hard tissues. This laser offers the advantages of straight and clean cuts and precise hard tissue cuts by virtue of laser energy interaction with water at the interface of tissues. However, there have been few reports investigating morphological changes at the root surface due to irradiation by Er,Cr:YSGG laser using field emission-scanning electron microscopy (FE-SEM) and atomic analytical study with the energy dispersive X-ray spectroscopy (SEM-EDX) on root surface irradiated by Er,Cr:YSGG laser.

The purpose of this study was to investigate the morphological and atomic changes on the root surface after Er,Cr:YSGG laser irradiation by stereoscopy, FE-SEM, and SEM-EDX in vitro.
MATERIALS AND METHODS

Sample preparation

Eighteen freshly extracted human premolar and molar teeth with no clinical sign of caries were used as samples in this study. The teeth were stored in 0.9% (wt/vol) NaCl without drying.

Laser device and laser irradiation

An Er,Cr:YSGG laser HKS device (Millennium, Biolase, San Clemente, CA) was used. The device emitted at 2.78 µm wavelength, pulsed duration from 140 to 200 µs, 20 Hz, and a power output ranging from 0 to 6 W. The delivery system consisted of a fiber optic tube terminated by a sapphire crystal tip (diameter 750 µm) bathed in an adjustable water-air spray. All samples were irradiated with water-air spray at 5.0 W and 20 Hz (pulse energy, 250 mJ; fluence, 56.6 J/cm²) for 5 sec while moving, according to the recommendations of the manufacturer. During laser irradiation, the tip was maintained in a vertical position so that it lightly touched the samples.

Stereoscopic and FE-SEM observation

After laser irradiation, all samples were observed by stereoscopy (SMZ-10, Nikon, Tokyo, Japan). Nine samples were randomly selected and dehydrated through a graded series of aqueous ethanol solutions (70, 80, 90, 95, and 100%) for 48 h at each concentration. The samples were dried by liquid CO₂ using a critical point dryer device (JCPD-3, JEOL, Tokyo, Japan), and then sputter-coated using a platinum ion sputter device (E-1030, HITACHI, Tokyo, Japan). The samples were then observed by FE-SEM (S-4700, HITACHI, Tokyo, Japan) at an accelerating voltage of 15.0 kV.

SEM-EDX examination

The other nine samples were fixed with a 10% formalin solution for 48 h, and then immediately perfused with a phosphate-buffered solution of pH 7.3 at room temperature and rinsed with distilled water. The samples were dehydrated through a graded ethanol series (70, 80, 90, 95, and 100%) for 24 h at each concentration and then embedded in a polyester resin block (Rigolac, Nissin, Tokyo, Japan). After the irradiated areas were flattened as much as possible by polishing (with the exception of a small portion of the bottom of crater on the surface that was selected for analyses), they were sputter-coated using a carbon-coating device (HUS-5GB, HITACHI, Tokyo, Japan) and were examined by SEM-EDX (S-2500CX, HITACHI, Tokyo, Japan and Model Delta V1, Kevex, Foster City, CA) at 10 kV accelerating voltage, tilt angle at 35°, and 3000X magnification. The nonirradiated areas of the same samples were used as a control. Fluorapatite [Ca₁₀(PO₄)₆F₂] (HITACHI) was used as a standard during the measurements, because of the greater structural stability of synthetic fluorapatite compared to hydroxyapatite (HAP).

Statistical analysis

The contents of calcium (Ca weight %) and phosphorus (P weight %) from the nine measurement points in the control and irradiated areas of each sample were recorded from the monitor.

FIG. 1. Representative FE-SEM photographs of the irradiated samples. (A) Irregular and rough surface of the crater produced by laser irradiation. (Original magnification, ×3000; bar represents 6 µm). (B) Irregular but clean surface, almost free from debris. Original magnification, ×10,000; bar represents 1.8 µm. (C) Very irregular and sharp-pointed surface. (Original magnification, ×30,000; bar represents 0.6 µm.)
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screen, and Ca/P weight ratio (WR %) and Ca/P molar ratio (MR %) were calculated. Statistical analyses were performed using the Mann-Whitney U test. Results were expressed as a mean ± standard deviation (SD), and a value of \( p < 0.01 \) was considered to be significant.

RESULTS

Effects of laser irradiation on root surface observed by stereoscopy and FE-SEM

Crater-like defects on the root surface were produced after laser irradiation. Craters having sharp edges and rough surface without presence of color change, which indicates burning and carbonization were observed by stereoscopy. No areas of melting were observed. Figure 1, A-C, shows representative photographs of the irradiated samples by FE-SEM. The surfaces of the craters appeared to be scale-like, irregular, and rough, but showed a homogeneous structure that was clean and almost free from debris (Fig. 1A, B). At a high magnification of 30,000× (Fig. 1C), intact sharp-pointed prisms of cementum were observed.

Atomic analysis by SEM-EDX

The results showed that the quantities of Ca (Ca weight %) in the samples were increased significantly in the irradiated areas compared with the control areas \( (p < 0.01) \). The content of P (P weight %) was not increased significantly after laser irradiation \( (p > 0.01) \). No significant changes in the Ca/P weight ratio or Ca/P molar ratio were shown at the irradiated areas \( (p > 0.01) \) (Table 1).

DISCUSSION

Recently, various studies on the effects of laser irradiation of dental hard tissues have been reported.4,11,15-18 Furthermore, different kinds of lasers have been used to demonstrate the capability of dental hard tissue cutting.2,15-18

An Er,Cr:YSGG laser hydrokinetic system has the capability of cutting dental hard tissues due to the wavelength of 2.78 \( \mu \)m, and the laser beam is delivered via a flexible fiber. It has been speculated that the mechanism of cutting was absorption of laser energy by fine water droplets, resulting in a violent yet controlled microexpansion that induced strong mechanical forces on targeted tissue surface. This resulted in hydrokinetic forces that produce mechanical separation of the calcified tissue surface cause quick and clean tissue removal.20 This was supported by the facts of strong absorption to water21 and low absorption to dental hard tissues by the wavelength of 2.78 \( \mu \)m.22

In this study, it was observed that a crater with a sharp edge, but rough and irregular surface, was produced by laser irradiation when the laser beam was directed at a 90° angle to the samples. No color changes indicative of burning or carbonization were detected by stereoscopy. Highly magnified observation by FE-SEM revealed minute changes in the form of gross concave and convex surfaces that were thought to be caused by micro-ablation and micro-recrystallization. These results support the former hypothesis of laser ablation mechanism of HKS.20

Because the 2.94-\( \mu \)m wavelength of the Er:YAG laser is very close to that of the Er,Cr:YSGG laser, the morphological findings by Er,Cr:YSGG laser irradiation were very similar to those reported previously for Er:YAG laser irradiation.23 However, the rough surfaces after Er:YAG laser irradiation were sharper than those by Er,Cr:YSGG laser irradiation. This might be due to the fact that after Er,Cr:YSGG laser irradiation surfaces were affected thermally more than those by Er:YAG laser, because the ablation is initiated at temperatures of approximately 300°C for Er:YAG laser and 800°C for Er,Cr:YSGG laser, well below the melting and vaporization temperatures of the carbonated hydroxyapatite mineral component \( (m.p. = 1200^\circ \text{C}) \).24 When using the Er,Cr:YSGG laser in the clinic, considerably more care must be taken to avoid pulp tissue injury during the Er,Cr:YSGG laser irradiation compared with Er:YAG laser irradiation.

SEM-EDX examination revealed that quantities of Ca (Ca weight %) in the irradiated areas increased significantly \( (p < 0.01) \) compared with control areas. The changes in Ca weight % are thus thought to result from some componential changes of atoms in dental hard tissues as a result of laser irradiation. We suggest that this may have been caused because organic components evaporated. Those changes were thought to accompany the temperature increase on the sample surfaces irradiated directly by the laser beam. Furthermore, substituent changes in tissues were thought to occur. However, no significant changes in the Ca/P weight ratio or in the Ca/P molar ratio were detected in the irradiated areas in any of the samples. Thus, it was thought that no chemical changes occurred in the irradiated tissues at the molecular level. However, we also concede that it is difficult to measure a Ca or P weight ratio accurately, even under the best of circumstances, because the interaction volume of the electron beam largely determines the energy levels recorded at the detector.25

Upon use of the laser in vivo, the thermal effect on pulp tissues is a major concern. Although temperature changes at the pulp chambers were not monitored in this study, the temperature increase at the pulp chamber caused by laser irradiation with water spray for root surface treatment should be low, because the 2.78-\( \mu \)m wavelength of the Er,Cr:YSGG laser is easily absorbed by water.21 Some research reports that temperature increases at the pulp chamber by Er,Cr:YSGG laser irradiation for cavity preparation were less compared with a conventional method using a burr, showing that this system had no apparent adverse thermal effect.16,20

Even though the mechanism of ablation of dental hard tissues by Er,Cr:YSGG laser irradiation is still unclear, we attribute it to the subsurface expansion of water, as reported by other investigators. The hydrokinetic system was thought to enhance

<table>
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<th>TABLE 1. ATOMIC ANALYSIS ON ROOT SURFACE</th>
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<tr>
<td><strong>Content</strong></td>
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<tr>
<td>Ca (weight %)</td>
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<td>P (weight %)</td>
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<td>Ca/P (WR %)</td>
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Values were statistically analyzed and expressed as a mean ± SD. *Shows a significant difference compared to the control \( (p < 0.01) \).
those reactions. In this study, various stereoscopic and SEM findings indicated that no carbonization was observed and the ablation of tissues presented as a regularly minute vaporization. Furthermore, a recent analytical study indicated that Ca content increased following laser irradiation, which suggests that atoms other than Ca decreased due to evaporation. This also suggests that laser irradiation might be used to decrease the solubility of dental hard tissues. Actually the effect of acid resistance by Er, Cr: YSGG laser irradiation was reported and expected to be imparted to the surface after laser irradiation. Previous studies have suggested that the temperature increase and the subsequent degree could decrease thermal subsequent effect to pulp than with other laser irradiation. These results suggest that an Er, Cr: YSGG laser system is suitable for application to dental hard tissue cutting on root surface.

CONCLUSION

These results showed that the Er,Cr:YSGG laser has a good cutting effect on root surface and offers advantages of no burning or melting after laser irradiation.

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REFERENCES


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