Experimental Study of FEL Irradiation onto Human Enamel and Dentin

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Abstract: Wavelength tunable Free Electron Laser, FEL, was irradiated onto the polished surfaces of human tooth enamel and dentin using the FEL system at Laboratory for Electron Beam Research and Application (LEBRA) in Nihon University. LEBRA-FEL system was so powerful that only 2 mJ/pulse shot resulted in an apparent pit on the surfaces. The pit showed neither marked scorch nor formation of secondary crystalline phase revealed by micro-XRD and micro-FTIR. Optimum wavelength for pit formation on the dental hard tissues was about 3.0 mm. However, the optimum wavelengths for enamel and dentin should be at 3.2 mm, 3.0 mm, respectively. The results strongly suggested that the ablation mechanism by laser irradiation for dental hard tissues might be not the simple interaction of laser beams with water, but complex phenomena, which could not be neglected of the hard tissue components and structure.

Key words: Free Electron Laser, Irradiation, Optimum Wavelength, Enamel, Dentin

Introduction

Diagnostics, therapeutic, and surgical techniques of lasers are good examples in treating the disorders of heart valves, skin, eye, pathological stones, and dentistry. The laser use in dental field has gained a lot of importance in the past few years[1]. The interaction of infrared (IR) lasers with hard tissues essentially seemed to be through its absorption in water, and therefore Er:YAG 2.94 mm laser is widely used in the dental clinical fields. Although the mechanism is not well understood yet, it is assumed that low boiling point components of hard tissues such as water, collagen or proteins, get quickly vaporized by heating. The rapidly expanding vapor then entrains and removes the mineral component, hydroxyapatite. The work on ablation threshold of teeth using a (Hydrogen Fluoride?) HF pulsed laser reported a threshold of 10–15 mJ/mm^2 (1–1.5 J/cm^2), the explosive evaporation level of water causing mass ejection from teeth[2]. The higher value of the ablation threshold of 150–200 mJ/mm^2 (15–20 J/cm^2) for direct evaporation of the hard components of the teeth itself accompanied by plasma formation has been reported. The pulse duration for HF laser is 400 ns. A threshold of less than 2 J/cm^2 for *Q*-switched CO_2 laser has been reported[3]. To clarify the wavelength effect of laser irradiation on the ablation of biological hard tissues, some attempts have been carried out using free electron lasers (4-14, Table 1). This study aimed to examine the optimum wavelength for hard tissue ablation using the wide range wavelength tunable LEBRA-FEL system in Nihon University.

Table 1. FEL and other laser irradiation studies on dental hard tissues.

Materials and Methods

Thin sections of the pooled human teeth were used in this study. The irradiation planes were polished with stone polishers. The free electron lasers (FEL) with a range from 1.0 mm to 6.0 mm in wavelength were generated at LEBRA in Nihon University. The detailed LEBRA-FEL system and the irradiation instrument were described in elsewhere[15]. Briefly, the LEBRA-FEL, tuned in a range from 1.0 mm to 6.0 mm with 0.2 mm intervals, was irradiated and focused on the dental hard tissues with about 2 mJ/pulse power adjusted by a mechanical camera-ready iris. The pit formation on the polished surfaces was observed by binocular microscope and measured by a laser digital topographic-meter.

Results

Fig. 1 showed the FEL irradiation instrument and the results of the FEL irradiation on the dental hard tissues. The pit formation was maximized at 3.0 mm wavelength of FEL irradiation and attenuated with the deviation from this level.

Fig. 2 showed our previous study of the ablation effect on the dental enamel and dentin surfaces by irradiating FEL at 3.0 mm wavelength with the comparison of Er:YAG 2.94 mm laser. The FEL irradiation makes neither remarkable changes nor scorches at and around the formed pits, whereas the experimentally high powered Er:YAG laser demonstrated the scorches at the pits on dentin. No apparent crystalline phase change was observed on these FEL-ablated pits by micro-XRD and micro-FTIR.

Fig. 3 showed the correlation between the depth of the pits and the wavelength of FEL irradiation. The topographic measurement clearly revealed that the optimum wavelengths for the pit formation of enamel and dentin were 3.2 mm and 3.0 mm, respectively. Other than 3.0 mm, with the changes in the wavelength either by increasing or decreasing, the pit formation was rapidly decreased. By binocular scopic observation, FEL irradiation with the wavelengths of longer than 4.0 mm and shorter than 2.2 mm showed no apparent effect on the dental hard tissues.

Fig. 1. The FEL irradiation instrument (left-top) and the results. Irradiations of FEL at the wavelengths 2.3mm (left-bottom),

3.1mm (right-top), and 2.7mm (right-bottom) are shown. Each of the three spots were corresponding to one-shot, small pits, and two-shots, large pits.

Fig. 2. Comparison of the ablation effect of FEL at a wavelength of 3mm with Er:YAG laser at 2.94mm on the dental enamel and dentin.

Fig. 3. Topographic measurement of the pits formed by the FEL irradiation. Left-top: 3.8 mm FEL, Left-bottom: 3.2 mm FEL, Right-top: 3.0 mm FEL, Right-bottom: 2.6 mm FEL. The depth scales were arbitrarily enlarged. Note: the EDJ regions were always deeply excavated by the FEL irradiations.

Discussion

It is generally accepted that the ablation affectivity is closely related with the laser pulse structure and wavelength. Factors regarding the optical source are i) Wavelength, ii) Fluencies, iii) Peak Fluencies, iv) Total Fluencies, v) Duration period, and vi) Pulse Structure. Factors regarding the targeted tissue are i) Inorganic and organic components as well as water content; for example, enamel is constituted of 96 % well crystalline biological apatite as inorganic and 2 % proteins as organic components, and 2 % water, whereas dentin is composed of 70 % low crystalline biological apatite, 20 % collagen and non collagenous proteins (NCP), for the same components, respectively, and 10 % of water. There are also many histological and optical structural differences between enamel and dentin.

Using the wavelength tunable free electron laser at LEBRA in Nihon University, we were able to differentiate the optimum wavelengths for the ablation of enamel and dentin. The optimum wavelengths for the ablation of enamel and dentin were 3.00 mm and 2.98 mm, respectively. This result gave rise to a question for the conventional hypothesis about the laser-hard tissue interaction in which the rapidly expanding vapor from water inside disrupts the surrounding apatite crystallites, resulting in breaking down of the hard tissues[16)]. Based on this mechanism, there is no difference for the tissue ablation between dental enamel, dentin and bone. The LEBRA-FEL irradiation makes neither scorch on the surfaces nor any changes on the crystalline biological apatite in human enamel and dentin[17)]. These observations of FEL irradiation for the dental enamel and dentin should need a revised or novel concept for ablation effects on these hard tissues.

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	Nd:YAG laser	Er:YAG laser	CO2 laser	Other laser	FEL
Wavelength	1.06 μm {1.06 μm (1986) bone}	2.94 μm 2.79 μm (2001) {2.9 μm (1986) hard tissue}	10.6 μm 9.3, 9.6, 10.3, 10.6 μm (2002) 9.6 μm (2001) {10.6 μm (1986) hard tissue}	2.6-3.1 μm HF (2005) 9.6 μm Er:YSGG (2005) 2.79 μm Er:YSGG (2002) 9.6 μm Ho:YAG (2002) {2.7-3.0 μm HF (1990) bone}	1.0-6.0 μm LEBRA (2005) 8.8-10.6 μm MID-FEL (2002) 3.0-9.2 μm MARK III-FEL (2001) 6.65, 9.64, 10.6 μm BFEL (2001) 9.64 μm BFEL (2001) 6.0-7.5 μm Vanderbilt (1997) {3.0 μm FEL (1988) hard tissue}

Wavelength of FEL and Other Laser Irradiation Studies on Dental Hard Tissues