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Spectroscopic study of ejected dental tissue after Er:YAG laser ablation

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Abstract

By means of IR spectroscopy, we determined the teeth ablation mechanism by an Er:YAG laser oscillating at 2.94 μm. Ejected dental material, ablated by the laser from human teeth, was deposited on an IR window and the absorption spectra were measured in the range 2500–20,000 nm. Sound teeth were used, and the corresponding film spectra were compared to spectra obtained by traditional methods. The films spectra obtained do not differ appreciably from those obtained by the traditional method for sound teeth, indicating that the material ejected by an Er:YAG represents the tooth condition.

The obtained results confirm that a spectroscopic analysis of a tooth treated with an Er:YAG laser can be done measuring the absorbance of a film composed of ejected material without the need to slice it. In addition, we could determine that the laser absorption occurs mainly by the interstitial water, and the temperature elevation of the ejected material does not exceed 60°C.

Keywords: Er:YAG laser; Ablation; Spectroscopy; Temperature; Protein; Demineralization

1. Introduction

Laser applications define one of the most important areas of dentistry today. Using the laser it is possible to treat the tooth in a wide variety of new conditions that reduce pain, mechanical stress, noise, and post-operative problems, without anesthesia in most of the cases. Lasers [1] can act as high precision tools in numerous applications in soft and hard dental tissues, as for example in gum treatment, decay removal, sealant application, teeth whitening, drilling, etc [2]. In the last years, lasers became attractive and affordable for clinical use in dental tissue removal by ablative processes, due to recent developments in the diode laser and solid-state laser technology [3,4].

The wavelength of the Er:YAG laser radiation is 2.94 μm, which coincides with the absorption peak of the stretching mode of the water molecule [5], thus being strongly absorbed. This intense absorption within tooth micropores heats up the water instantaneously, changing its phase to vapor, increasing the pressure inside the micropore. This effect breaks the hydroxyapatite structure [6,7], leading to microexplosions that eject dental tissue away from the laser interacting volume. As a

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result, an Erbium laser pulse focalized on the tooth is drastically absorbed, and the thermal effect is therefore highly localized and is restricted to a region near the tooth surface.

Comparing the strong absorption of the Er:YAG by teeth with the absorption of other infrared resonant lasers as Neodymium or Holmium ones, much less energy is required for dental tissue ablation with Er:YAG. This makes the use of Erbium lasers more appropriate than those others, since the lower energy deposited for ablation diminishes the thermal effect, which is desirable to prevent irreversible damages in the dental pulp that occur if the tooth temperature rises by more than 5.5°C [8] during the laser irradiation.

Of great interest and concern is the plume created during the Er:YAG laser ablation of dental tissue. The plume, which consists of ejected material, its formation mechanism, and the eventual presence of potentially toxic materials being created in the ablation process is beginning to be understood [9]. Hard dental tissue consists mainly of enamel, dentine and water in a proportion that depends on the type and local structure of the sample. Due to the microexplosions, the ablation is not a vaporization process, but is rather produced by the pressure build-up inside the micropores of the tissue. When this pressure exceeds the tensile strength of the tissue, ablation occurs by means of localized microexplosions. A higher plume velocity due to higher pressures inside the tissue can be produced by increasing the energy density of laser irradiation.

In this paper, we report the spectroscopic characterization of the plume material ejected from dental tissue by pulsed Er:YAG laser irradiation at 2.94 μm. We are reporting this spectroscopic characterization in the literature for the first time, as far as we know.

2. Experimental setup

The teeth used are extracted human molars obtained from the Faculdade de Odontologia da USP, and were conserved in a physiologic serum to avoid cracking due to dryness.

Erbium laser pulses were focalized upon the tooth, and the ejected ablated material was deposited on an IRTRAN substrate, which is transparent in the optical range from 725 to 10,000 cm^{-1}. This substrate was positioned at approximately 2 cm from the laser focus point, as is shown in Fig. 1. The ejected dental plume formed a uniform film of the ablated material on the substrate with a good adherence to its surface, being removed only by mechanical abrasion. The ablation point was constantly changed by moving the tooth sample to avoid carbonization. The absorption spectra of the films of the ablated materials were measured in the infrared using double beam spectrophotometer.

The laser system used is a commercial KaVo KEY-Er:YAG Laser operating at 2.94 μm without water spray as coolant, with a flexible optical fiber to a handpiece for the beam delivering. This system allows the selection of the pulse energy from 60 to 500 mJ and a repetition rate from 1 to 15 Hz. In all the experiments, we used a pulse energy of 300 mJ at 10 Hz repetition rate for one-minute irradiations.

The absorption spectra of the films were measured by a Nicolet 740 FT-IR in the range of 2500–20,000 nm (or 4000–500 cm^{-1}).

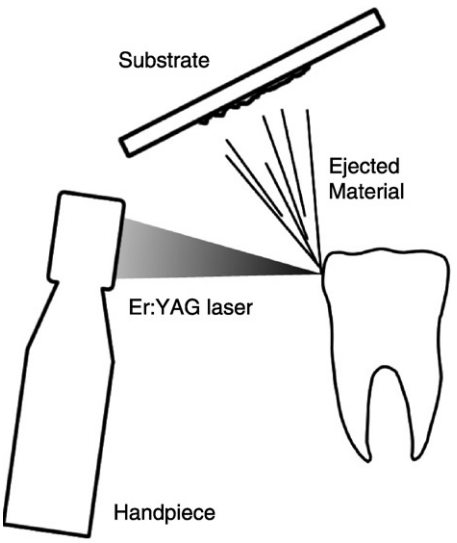

Fig. 1. Experimental setup.

3. Results

We studied the optical spectra of the deposited film of ejected hard dental tissue material after ablation by an Er:YAG laser, for sound teeth, in the near-infrared and far-infrared regions. In Fig. 2 we can see the IR absorption spectra for both the deposited material ablated from hard dental tissue and for a dehydrated human tooth found in the literature [10], and their similarities. The literature spectrum was obtained by using thin slices of tooth having between 100 and 200 μm of thickness. In this conventional technique, the tooth should be cut into slices from which the

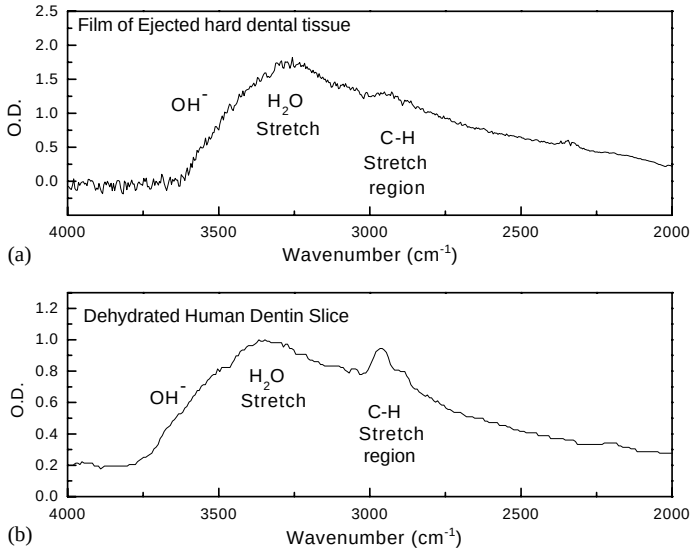

Fig. 2. FT-IR spectra for sound teeth; (a) absorption spectrum for a film of sound tooth ejected ablated dental material; (b) absorption spectrum for a dehydrated tooth slice obtained from the literature [10].

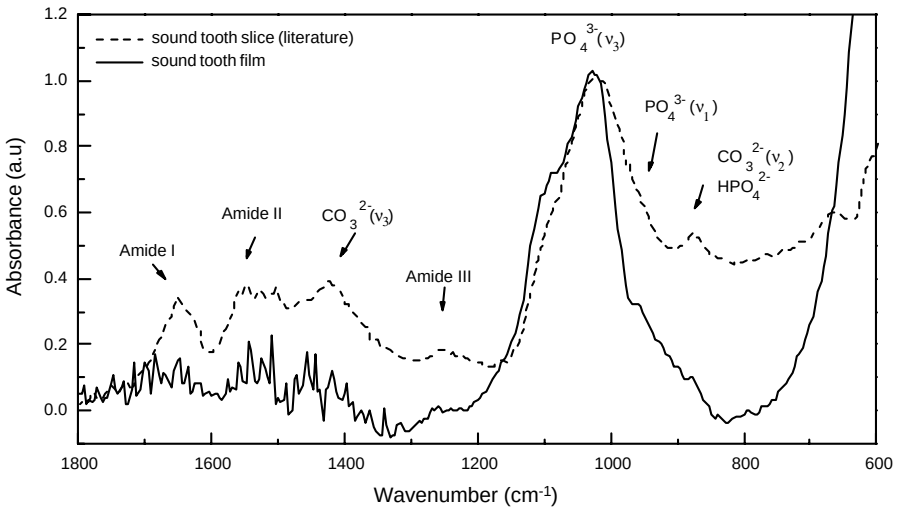

Fig. 3. Absorption spectra of hard dental structure in the range 1800–600 cm^{-1}. The dotted lines represents the literature spectra from teeth slices, and the continuous lines the spectra obtained by us from the deposited films of ablated material under Er:YAG pumping.

absorption spectrum is measured, and therefore is destroyed.

Details of the absorption spectra of the deposited films of sound teeth in the range of 1800–600 cm^{-1} can be observed in Fig. 3, along with literature spectra. This spectral region is particularly important in this work because it contains the absorption bands of minerals and proteins that compose the tooth, and also because the absorption spectra of slices of sound and demineralized teeth are available in the literature for comparison [11]. In Fig. 3 the absorption spectrum measured from the film of ablated sound tooth and the absorption spectrum of a sound tooth slice (literature) is compared, and a great similarity between these spectra structures is observed. This result corroborates the previous one that Er:YAG laser ablation does not alter the spectroscopic and chemical characteristics of the ablated material in a significant way. However, in films spectra shown in Fig. 3, we notice that the absorption bands of PO_4^{3-} (around 1030 cm^{-1}) are much more resolved and narrow in comparison with the teeth slices spectra, which is more compatible with demineralized samples. This effect is probably caused by the reduction of Ca^{2+}–(PO_4^{3-}) bonds, which is responsible for the band enlargement and its asymmetry. In addition, the major protein absorption bands [11,12] at 1650–1700 cm^{-1} (amide I, due to C=O bond stretching), 1550 cm^{-1} (amide II, due to N–H and C–N), and at 1240 cm^{-1} (amide III, C–N and N–H) are observed to be present in the films of the laser ablated material. In Table 1 all the absorption peaks of organic and inorganic species found in the films of ablated material are listed.

Table 1
Infrared absorption peaks [11] for the species present in teeth

Specie	Absorption peaks (cm^{-1})
Amide I	1650
Amide II	1540
Amide III	1240
CO_3^{-2} (ν_2)	870–960
CO_3^{-2} (ν_3)	1450–1550
PO_4^{-3} (ν_1)	960
PO_4^{-3} (ν_3)	1030
HPO_4^{-2}	880

4. Conclusion

Finally, in this paper we present results showing that a large similarity exists between the absorption spectrum of a film of deposited dental material ablated by an Er:YAG laser at 2.94 μm, and the absorption spectrum of a tooth obtained by the slicing method. The spectra similarities hold for sound teeth, demonstrating that irradiation with this laser does not alter the chemical composition of the ablated material. In addition, we showed that it is possible to spectrally characterize a tooth with a simple method, without slicing and destroying it.

From the data shown, we assume two main processes occurring during the Er:YAG laser interaction with the tooth. One of the processes involves the interaction of the laser with the structural OH^- group present in the Hydroxyapatite, and the other one with the interstitial water.

From the spectra shown in Fig. 3 we propose a chemical reaction mechanism resulting from the interaction of the laser with the hydroxyapatite structural OH^- resonant absorption band. This interaction breaks the OH bond liberating H^+ free ions, which start the demineralization process, liberating Ca^{2+} ions that can stabilize as carbonate. This carbonate creation explains the increasing of the absorption below 600 cm^{-1} in the film spectra.

The other process, in which the Er:YAG laser interacts with the interstitial water, is the main one causing the ablation. If the interaction occurred with the hydroxyapatite structural OH, the dental characteristics would be absent from the spectra of the films. Also these microexplosions does not elevate the temperature of the ejected material by more than 60°C, as evidenced by the presence of protein lines on the absorption spectra of the films.

As conclusions, we can affirm that the main ablation is due to absorption by interstitial water, preserving the particular characteristics of each tooth. In addition, the presented method introduces a simple, nondestructive and reliable way to obtain a tooth spectrum.

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