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Laser Education, Science and Safety

A review of dental laser education standards

Introduction

The "sound scientific basis and proven efficacy in order to ensure public safety" is one of the main eligibility requirements of the ADA CERP recognition standards and procedures.[1] The scientific foundation for understanding soft-tissue laser ablation and coagulation is based on the soft tissue's light scattering and absorption spectra.[2–7]

Unfortunately, some laser dentistry educational programs and publications include misinterpretations about soft- and hard-tissue laser science and safety. Such misrepresentations partially take their origin in the laser dentistry curriculum guidelines, which date back to the early 1990s.[8]

In this article, I'll discuss some important laser-tissue interaction concepts—ones that are missing from the vocabulary of the Laser Dentistry Curriculum Guidelines and Standards,[8] namely absorption spectra,[2–7] hot glass tip[9–11] and plasma plume.[12,13]

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Absorption spectra and soft-tissue laser ablation

A chromophore is defined as a molecule or substance capable of absorbing specific laser wavelengths. The main chromophores for ablation and coagulation of oral soft tissue are known to be hemoglobin, oxyhemoglobin, melanin and water.[2–7] These four chromophores are distributed unevenly within oral tissue. Water and melanin, for example, reside in the 100–300-µm-thick epithelium;[14] water, hemoglobin and oxyhemoglobin reside in the subepithelium (lamina propria and submucosa).[15,16]

Each of the oral soft tissue's four main chromophores has a known optical absorption coefficient spectrum. Fig. 1 presents absorption spectra for the different chromophore concentrations of water, melanin, hemoglobin (Hb) and oxyhemoglobin (HbO_2). Light scattering by the soft tissue is insignificant at erbium and CO_2 laser wavelengths. Light scattering by the soft tissue dominates over absorption at near-IR diode and Nd:YAG laser wavelengths, and facilitates a wider-spread coagulation and thermal damage. [2–7]

Fig. 1 illustrates how the oral epithelium (e.g., at 75 percent water and 2 percent melanin) absorbs the Nd:YAG and diode laser wavelengths in the 800–1,100nm range 100–1,000 times less efficiently than the CO_2 and erbium laser wavelengths. Fig. 1 also illustrates that the near-infrared Nd:YAG and diode laser wavelengths in the 800–1,100nm range are absorbed by the oral subepithelial soft tissue (e.g., at 75 percent water and 10 percent blood) approximately 1,000–10,000 times less efficiently than the CO_2 and erbium laser wavelengths.

The shallower the absorption depth (i.e., stronger absorption), the less energy is required to ablate the tissue within the exposed volume. Therefore, the mid-infrared erbium and infrared CO_2 laser wavelengths are highly efficient and spatially accurate laser ablation tools because of their very strong absorption by the soft tissue. The deeper the absorption depth (i.e., weaker absorption) and the stronger the scattering, the more energy is required to ablate the tissue. Therefore, the near-IR diode and Nd:YAG laser wavelengths are highly inefficient and spatially inaccurate photothermal laser ablation tools[17] because of their weak absorption by the soft tissue.

Hot glass tip

The near-infrared wavelengths of dental diode lasers cannot photothermally ablate soft tissue, except for high-melanin-content epithelium.[4–7] Instead, the near-infrared diode laser beam heats the charred distal end of its fiber optic glass tip to 500–900 degrees Celsius.[9–11] The glowing hot glass tip, then, conducts heat to the soft tissue.[9–11, 18]

Soft tissue is burned on contact with the hot glass tip. The efficacy of this device-tissue interface (charred hot glass surface) is highly dependent on multiple factors:

- The user's technique and skill in charring the glass tip.
- The user's hand speed and tip-tissue contact duration.[9-11]
- Degradation of the glass tip's char, which reduces tip temperature and increases the near-infrared-induced subsurface thermal-induced tissue necrosis, and leads to mechanical tearing of the tissue by the glass tip's edges.
- Biocompatibility and sterility of the char that's produced by burned ink or corkwood when applying the hot tip to the soft tissue.[19–20]

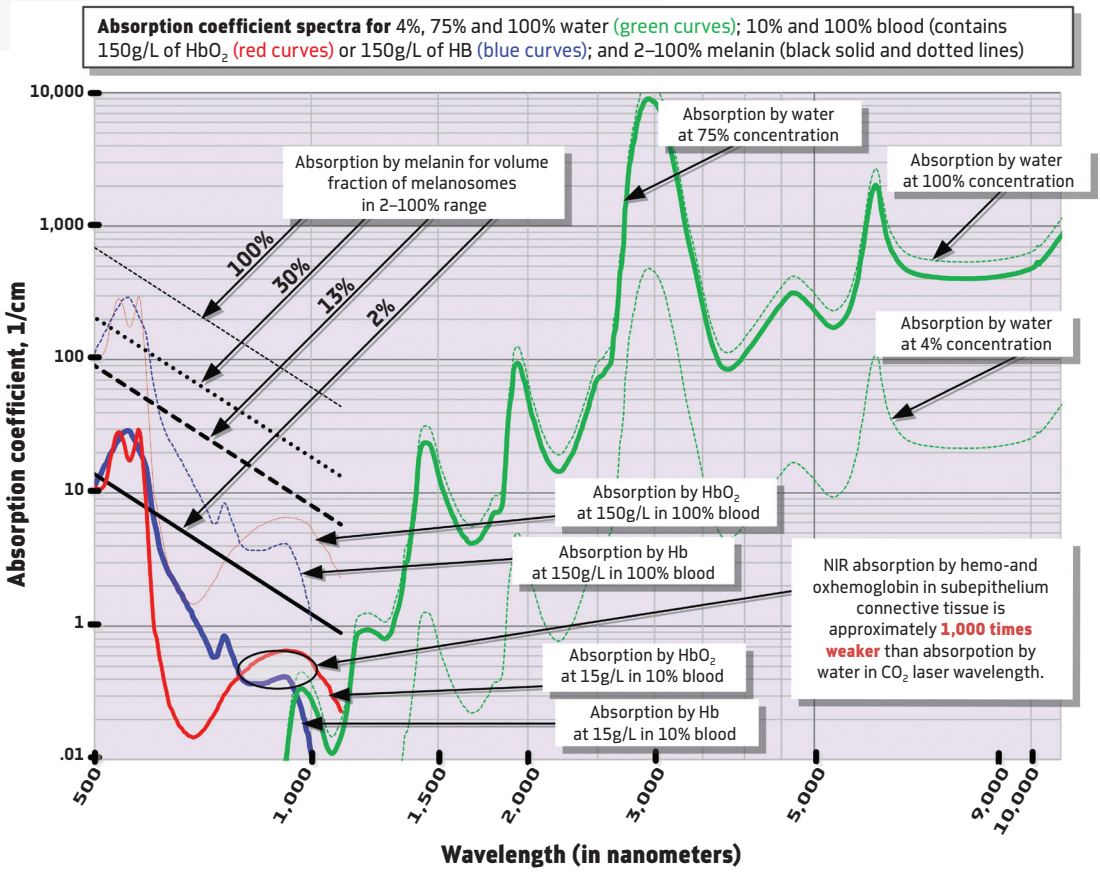

Fig. 1. *Optical absorption coefficient spectra at different histologically relevant concentrations of water, hemoglobin (Hb), oxyhemoglobin (HbO_2) and melanin based on data from References 2–7. Logarithmic scales are in use.*

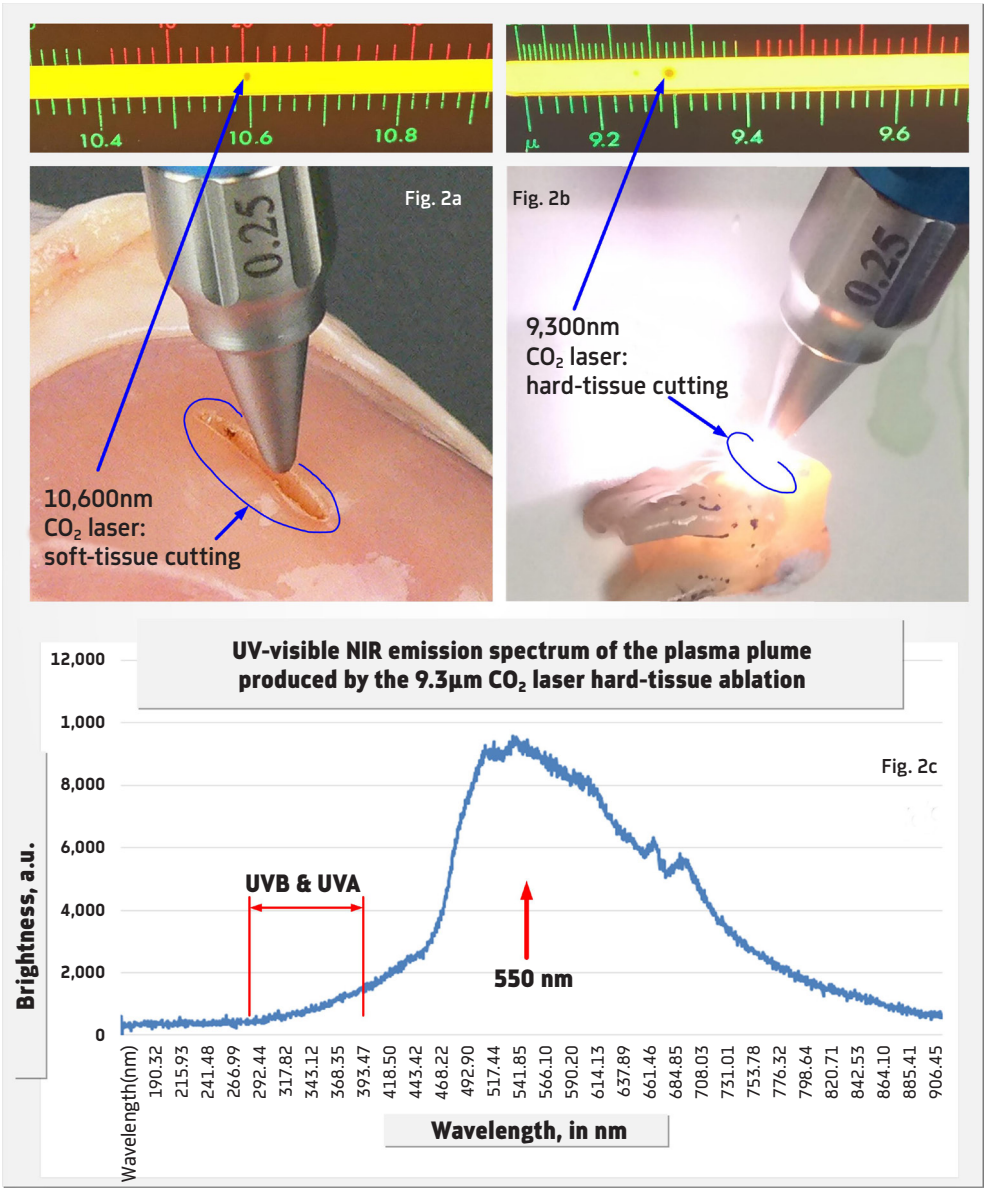

Fig 2a. *Soft-tissue 10,600nm laser cutting at low tissue-vaporization temperature of 100 degrees Celsius.*

Fig. 2b. *Hard-tissue 9,300nm laser (500 Hz with sub-100-µsec pulses with average power of 2.5 watts with 250µm spot size, with water irrigation) cutting at high tissue-vaporization temperatures above 5,000 degrees Celsius.*

Fig. 2c. *A hard-tissue (enamel of a freshly extracted human tooth) laser's plasma plume emission spectrum recorded with a 200–850nm range spectrometer with 1.5nm DWHM resolution (B&W Tek, Model BRC115U, SN120911304); emission peak around 530–560nm corresponds to plume's temperature in excess of 5,000 degrees Celsius in Plank's black body thermal radiation approximation. (Laser emission wavelengths measured with CO_2 laser spectrum analyzer (Optical Engineering, Model 16-A). Photos and data courtesy of LightScalpel.)*

- Biocompatibility of the hot glass and its cladding materials at 500–900 degrees Celsius operating temperatures when applying the hot tip to the soft tissue.[19]
- Biocompatibility of fractured glass produced by the thermal gradient-induced fractures of the hot glass tip at 500–900 degrees Celsius operating temperatures.[21]

Plasma plume

The ease of the soft-tissue CO_2 laser surgery (Fig. 2a) is largely based upon the low-temperature water vaporization at 100 degrees Celsius. The collateral damage in the heat-affected zone is much appreciated coagulation and hemostasis. In some hard-tissue cutting applications, however, a very high ablation temperature (approximately 5,000 degrees Celsius) could result in extremely bright thermal radiation (Figs. 2b and 2c).

The hard-tissue laser's "beam interactions with the hard tissue can generate intense plasma emissions … requiring suitable optical filtering for direct viewing," while "plasma emissions … may contain sufficient UV," requiring the UV exposure limits to be addressed. Also, the high brightness of the hydroxyapatite plasma in the visible spectrum (Figs. 2b and 2c) may interfere with the laser's pointing accuracy by affecting the target's visibility, because of the enamel's high translucence and light scattering.[12, 13, 22, 23, 24]

Summary

The science-based absorption properties of the soft tissue can adequately explain the different ablative and coagulative properties of practical lasers at different wavelengths. Such explanation depends critically on the concentration of the chromophores in the tissue. Similarly, the science-based absorption properties of the soft tissue explains that the only practical modality of soft-tissue cutting with practical diode and Nd:YAG lasers is the "hot tip."

Last, but not least, the nonbeam laser hazards and respective safety measures need to be addressed in view of the optical emission spectrum of the plasma plume created during the hard-tissue cutting with the 9,300nm lasers. All the above are absent from the laser dentistry education guidelines and standards,[8] but are critically important to be a part of the CERP-approved laser dentistry education in compliance with the ADA CERP standards.[1] ■

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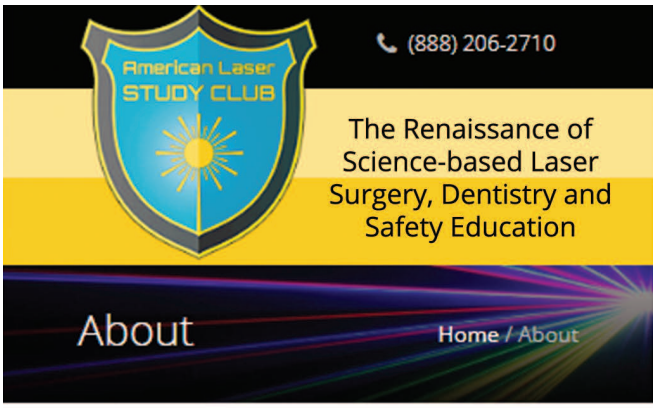

Mission

To fill the void in current Laser Surgery and Laser Dentistry education (i.e., the physics of laser tissue interaction, such as absorption, scattering, ablation, coagulation and hemostasis, soft and hard tissue ablation, laser safety, etc.) and help Physicians, Dentists, Veterinarians, and Practice Staff Members to excel at efficient and safe application of laser energy in everyday practice.

Vision

To promote Science-Based Laser Surgery, Dentistry and Safety Education*

* "Sound scientific basis and proven efficacy in order to ensure public safety" is one of the main eligibility requirements of the American Dental Association CERP Recognition Standards and Procedures (ADA.org/CERP).

To apply for membership, please visit our website at www.AmericanLaserStudyClub.org or scan the QR code

The shallower the absorption depth (i.e., stronger absorption), the less energy is required to ablate the tissue within the exposed volume.

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