Soft Tissue Laser Dentistry and Oral Surgery

Peter Vitruk, PhD, MInstP, CPhys, DABLS

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 The outdated Laser Dentistry Curriculum Guidelines [2] from early 1990s is in need of an upgrade with respect to several important laser-tissue interaction concepts such as Absorption Spectra and Hot Glass Tip.

This position statement of The American Board of Laser Surgery (ABLS) on soft tissue dentistry and oral surgery is written and approved by the ABLS’s Board of Directors. It focuses on soft tissue ablation and coagulation science as it relates to both (1) photo-thermal laser-tissue interaction, and (2) thermo-mechanical interaction of the hot glass tip with the tissue.

Laser Wavelengths and Soft Tissue Chromophores

Currently, the lasers that are practically available to clinical dentistry operate in three regions of the electromagnetic spectrum: near-infrared (near-IR) around 1,000 nm, i.e. diode lasers at 808, 810, 940, 970, 980, and 1,064 nm and Nd:YAG laser at 1,064 nm; mid-infrared (mid-IR) around 3,000 nm, i.e. erbium lasers at 2,780 nm and 2,940 nm; and infrared (IR) around 10,000 nm, i.e. CO_2 lasers at 9,300 and 10,600 nm.

The primary chromophores for ablation and coagulation of oral soft tissue are hemoglobin, oxyhemoglobin, melanin, and water [3]. These four chromophores are also distributed spatially within oral tissue. Water and melanin, for example, reside in the 100-300 µm-thick epithelium [4], while water, hemoglobin, and oxyhemoglobin reside in sub-epithelium (lamina propria and submucosa) [5], as illustrated in Figure 1.

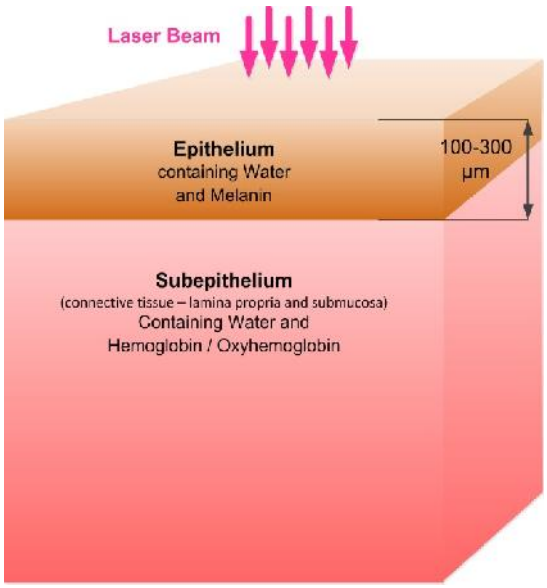

Figure 1. Simplified optical model of oral soft tissue consisting of (1) water-melanin-rich epithelium layer, and (2) water-hemoglobin-oxyhemoglobin-rich sub-epithelium (connective tissue inclusive of lamina propria and submucosa).

Laser Light Absorption and Scattering by the Soft Tissue

Each of the oral soft tissue's four main chromophores' absorption coefficient spectra are presented in Figure 2 for the different concentrations of water, melanin, hemoglobin (Hb), and oxyhemoglobin (HbO_2) [3, 6-11].

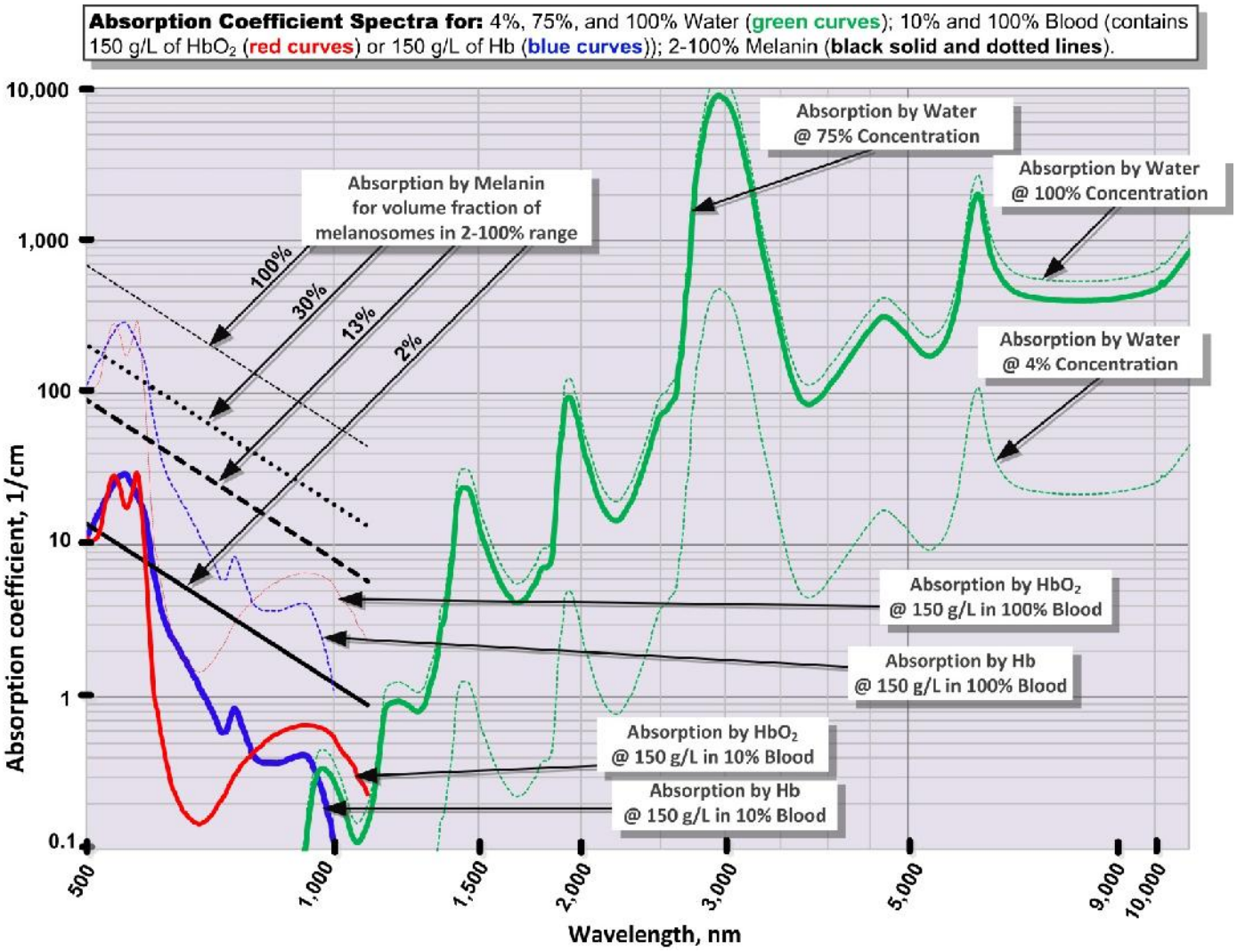

Figure 2. Optical absorption coefficient spectra at different histologically relevant concentrations of water, hemoglobin (Hb), oxyhemoglobin (HbO_2), and melanin [6-11]. Logarithmic scales are in use.

Figure 2 illustrates, for example, that the near-IR energy absorbed by the oral epithelium from the Nd:YAG laser and any diode laser having wavelengths between 800-1,100 nm, is, respectively, approximately 100-1,000 times less than the energy absorbed from the CO_2 and erbium laser wavelengths. This assumes that the common content of epithelium tissue is, by volume, 75% water and 2% melanin. The CO_2 laser's affinity for absorption in water molecules, then, helps explain some of its tissue interaction properties. Note, also, the effects of melanin; in this example, the figure represents a light epithelium pigmentation similar to a lightly pigmented epidermis. [8] Figure 2 also illustrates that the near-IR Nd:YAG laser and any diode laser having wavelengths between 800-1,100 nm are absorbed by the oral sub-epithelial soft tissue approximately 1,000-10,000 times less than CO_2 and erbium laser wavelengths. This assumes the content in sub-epithelium tissue (at 150 g of hemoglobin per 1 liter of blood) is 75% water and 10% blood.

Light scattering by the soft tissue dominates over absorption at near-IR diode and Nd:YAG laser wavelengths, [3,6-13] and is insignificant at erbium and CO_2 laser wavelengths.

Thermal Relaxation Time

Tissue cooling from blood flow during laser exposure, for the short pulse durations of practical interest, is insignificant, especially when tissue coagulation takes place. [3,6] The cooling efficiency of the tissue irradiated by laser light is, instead, determined by the tissue's thermal diffusivity (first described by Einstein [14]).

The time scale of how fast the irradiated tissue diffuses the heat away can be determined through the thermal relaxation time (its value is controlled by the wavelength-dependent absorption coefficient from Figure 2 and by tissue diffusivity [3,6,12,13]). Thermal relaxation time is a powerful concept for determining appropriate applications of laser energy for soft tissue laser ablation and coagulation:

- the most efficient heating of the irradiated tissue takes place when the laser pulse duration is much shorter than the thermal relaxation time,
- the most efficient tissue cooling takes place if the time duration between laser pulses is much greater than the thermal relaxation time,
- the most efficient tissue ablation (with the shallowest coagulation depth) takes place when the laser pulse duration is much shorter than the thermal relaxation time and the duration between laser pulses is much greater than the thermal relaxation time. Such pulsing specifications are referred to as SuperPulse [3,6],
- the least efficient tissue ablation (with the deepest coagulation depth) takes place when the laser pulse duration is much longer than the thermal relaxation time and the duration between laser pulses is much shorter than the thermal relaxation time).

Soft Tissue Laser Ablation

Soft tissue laser ablation (and incision and excision) is a process of vaporization of intra- and extracellular water heated by the laser light within the irradiated soft tissue. [3,6] Water vapors, rapidly steaming out of the intensely laser-heated soft tissue, carry with them cellular ashes and other by-products of this fast water boiling and vaporization process.

For a given laser beam diameter, the volume of irradiated tissue (if light scattering is negligible) is proportional to the absorption depth. The deeper the absorption depth (i.e., weaker absorption), the more energy is required to ablate the tissue. The shallower the absorption depth (i.e., stronger absorption), the less energy is required to ablate the tissue within exposed volume. Therefore, [3,6,10,11,13,15]:

- near-IR diode and Nd:YAG laser wavelengths are highly inefficient and spatially inaccurate laser ablation tools (especially at lower laser powers typical for dental applications) due to their weak absorption (see Figure 2);
- mid-IR erbium and IR CO_2 laser wavelengths are highly efficient and spatially accurate laser ablation tools due to their very strong absorption by the soft tissue (see Figure 2). The depth of ablation is proportional to fluence [3], i.e. it is directly proportional to laser power and inversely proportional to spot size and handspeed [16].

Soft Tissue Laser Coagulation

Coagulation occurs as a denaturation of soft tissue proteins that occurs in the 60-100°C temperature range. [17-19] This leads to a clinically significant reduction in bleeding (and oozing of lymphatic liquids) on the margins of ablated tissue during laser ablation (and excision, incision) procedures. Blood is contained within and transported through blood vessels; the diameter of blood vessels (estimated to range from 21 to 40 μm from measurements in human cadaver gingival connective tissue [20]). Laser coagulation is accompanied by shrinkage of the walls of blood vessels (and lymphatic vessels) due to collagen shrinkage at increased temperatures. For short laser pulses (shorter than thermal relaxation time), the photo-thermal coagulation depth during laser ablation of the soft tissue is proportional to absorption depth [6] (or inversely proportional to absorption coefficient from Figure 2):

- For erbium laser wavelengths, coagulation depths are significantly smaller than gingival blood vessel diameters [6]. Coagulation depth can be increased, [6] though, by (1) increasing the pulse width and pulse rate, and (2) by decreasing pulse fluence below the ablation threshold.
- The optical absorption and coagulation depths of the dental diode and Nd:YAG laser wavelength are significantly greater than those of the erbium and CO_2 laser wavelengths. Their coagulation effects extend beyond the diameters of blood vessels and can take place over extended volumes – far away from the ablation site where no coagulation is required. Dental diode and Nd:YAG laser wavelengths are often used, then, in non-ablative coagulative applications that require deeper tissue penetration of radiant energy.
- The optical absorption and coagulation depths for the CO_2 laser wavelengths are effective within the diameters of gingival blood vessels. Coagulation extends just deep enough into a severed blood vessel to stop the bleeding. A 10,600-nm CO_2 laser produces coagulation that is about 15 times deeper than an Er:YAG laser; its absorption coefficient is 15 times lower (see Figure 2). Coagulation depth can be increased, [4] though, by (1) increasing the pulse width and pulse rate, and (2) by decreasing pulse fluence below the ablation threshold. The CW operation mode at low fluence settings is used for non-ablative coagulative applications [3,6,13]. The SuerPulse [3,6] pulsed operation at high fluence is used for char-free ablative applications [19].

Soft Tissue Non-Laser Thermal Ablation and Coagulation by Diode Lasers

The near-IR laser wavelengths of dental diode lasers cannot be used to optically ablate soft tissue [3,6,10,11,16]. Instead, the laser optical energy of dental diode lasers is used to heat up the charred distal end of their fiber glass tips to 500-900°C; [22] their glowing hot [23] glass tips, then, conduct heat to the soft tissue. The diode lasers cut soft tissue as contact thermo-mechanical devices similar to electrocautery. The medical efficacy of this device-tissue interface (charred hot glass surface) is highly dependent on multiple factors:

- User's technique and skill in controlling the effectiveness of the tip's "initiation" (or "activation"), i.e., creating a light-absorbing char layer on the tip end;
- Monitoring the degradation of the glass tip's char surface which will increase the effective photo power output from the "partially transmitting" tip; the degraded char surface reduces tip temperature and leads to less ablation, an increased risk of near-IR-induced subsurface thermal-induced tissue necrosis, and mechanical tearing of the tissue by the cooler glass tip's edges;

- Assessing and clinically managing the biocompatibility [24] and sterility [25] of the char that is produced by burned ink or corkwood immediately before applying the hot tip to the soft tissue and, also, the biocompatibility of the glass and its cladding materials at 500-900°C operating temperatures;
- Staying within the thermomechanical thresholds for any thermal gradient-induced fractures of the hot glass tip at 500-900°C operating temperatures, while considering the biocompatibility [26] of possible fractured glass fragments;
- User's technique and skill in controlling hand movement and tip contact with the tissue; hot tip coagulation depth depends heavily on hand speed and tip-tissue contact duration. [22,27]

For more information about the Board and the Certification in Laser Dentistry, please visit www.americanboardoflasersurgery.org.

Training, Education, and Safe Use of Soft Tissue Dental Lasers

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