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How CO_2 lasers cut, coagulate soft tissue

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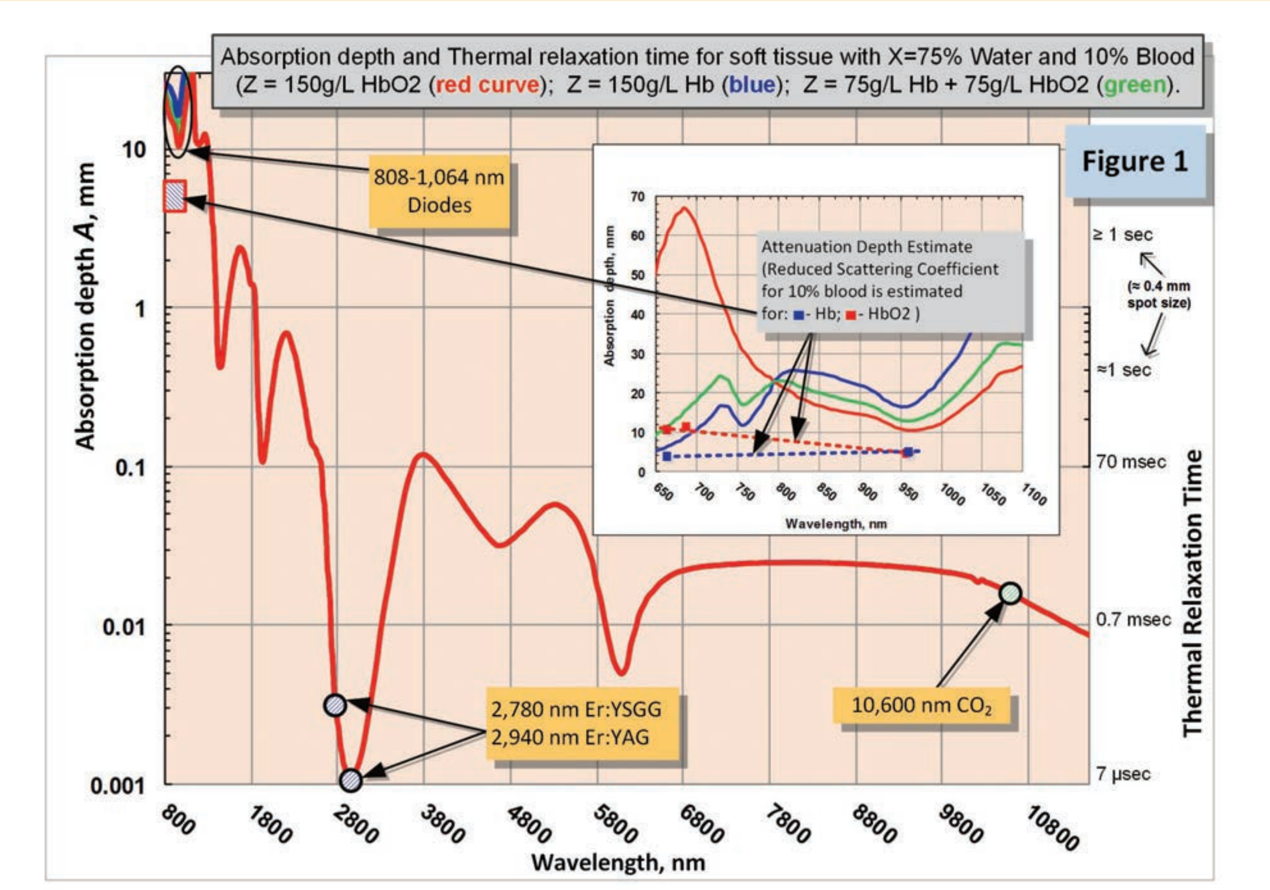
For The Education Center

The key to the success of soft tissue lasers is their ability to cut and coagulate the soft tissue at the same time.

The soft tissue photo-thermal ablation and photo-thermal coagulation efficiencies for the soft tissue ablative veterinary and dental lasers on the market today (Near-IR diodes at 808-1,064 nm; Mid-IR Erbium lasers at 2,780 nm and 2,940 nm; and IR CO_2 laser at 10,600 nm) are best understood through the known optical absorption coefficient spectra of the soft tissue's four main chromophores: water, melanin, hemoglobin (Hb) and oxyhemoglobin (HbO_2).[1]

Soft Tissue Absorption Depth Spectrum

Optical absorption depth (and estimated Near-IR attenuation depth) spectrum for sub-epithelial and sub-dermal connective soft tissue with 75 percent water and estimated 10 percent blood presence (containing hemoglobin and/or oxyhemoglobin) at normal concentration of 150g/L can be derived from soft tissue absorption and scattering coefficients and is presented in **Figure 1**. Both Erbium laser (approximately 3,000 nm) and CO_2 laser (approximately 10,000 nm) wavelengths are highly efficiently absorbed by the soft tissue and, as will be shown below, are efficient at cutting and ablating the soft tissue purely radiantly (non-contact). At the same time, the Near-IR diode lasers (approximately 1,000nm) are highly inefficiently absorbed by the soft tissue (**Figure 1**) and, therefore, cannot be used radiantly for cutting and ablating the soft tissue.



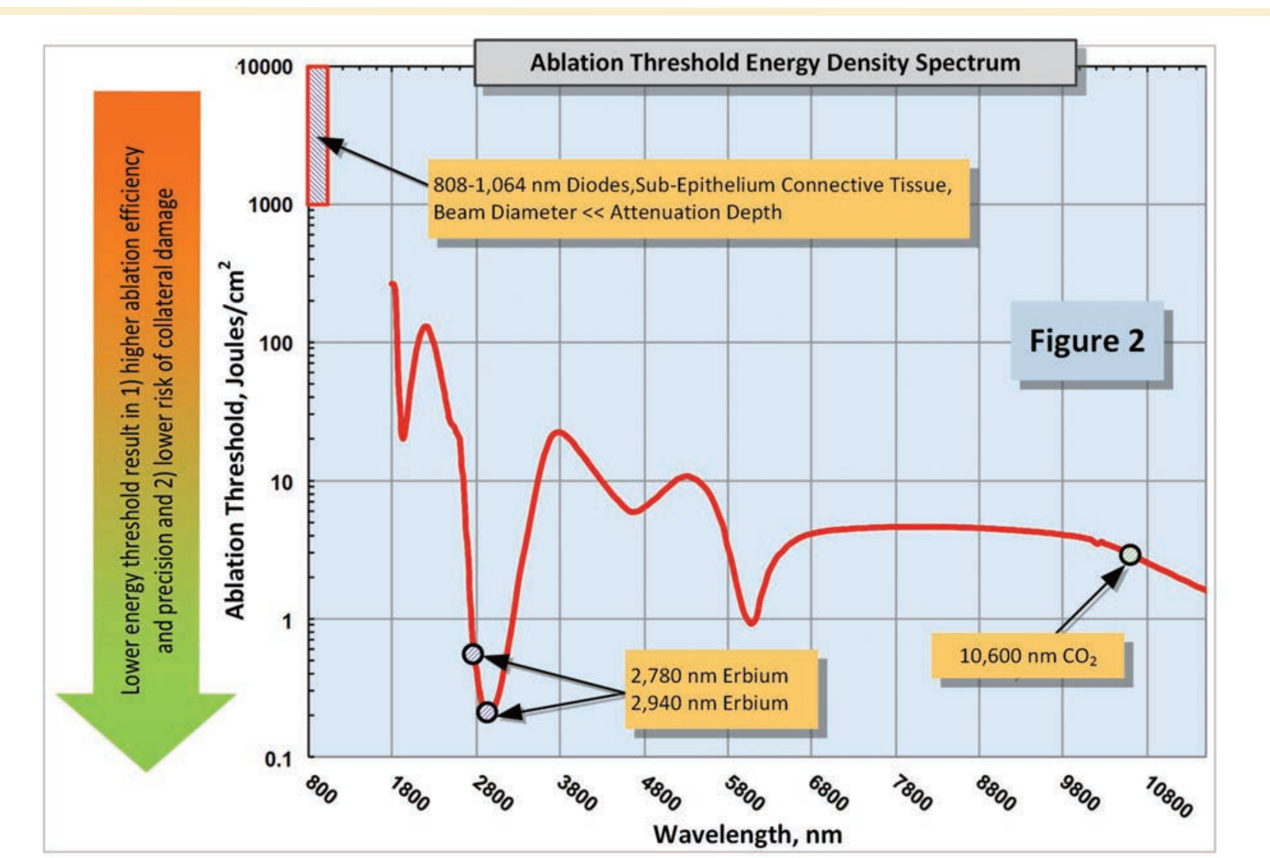


Photo-Thermal Ablation Efficiency

Soft tissue photo-thermal ablation is a process of vaporization of intra- and extra-cellular water by heat generated by laser energy absorbed by the tissue.

For a fixed laser beam diameter (or spot size), the volume of the tissue exposed to laser beam is proportional to the optical penetration depth in Figure 1. The shorter the penetration depth, the less energy is required to ablate the tissue. The longer the optical penetration depth, the greater the volume of irradiated tissue, and therefore more energy is required to ablate the tissue within the irradiated volume of tissue.

The minimum amount of laser energy required to vaporize an irradiated volume of soft tissue, for different depths of light absorption from **Figure 1**, can be easily calculated for known thermodynamic properties of water. Such calculated ablation threshold energy density spectrum is presented in **Figure 2** for conditions most suited for high efficiency photo-thermal ablation (pulse duration $t \leq T_R$ Thermal Relaxation Time) with minimum collateral damage to the surrounding tissue (pulse repetition rate f >> $1/T_R$), commonly referred to as SuperPulse.

The Near-IR wavelengths 800-1,100 nm are characterized by 100s-1,000s times greater thresholds than Mid-IR and IR wavelengths because of weak Near-IR absorption by the soft tissue's chromophores.

In sharp contrast to Near-IR wavelengths, the Mid-IR and IR wavelengths are highly energy efficient at ablating the soft tissue photo-thermally with very low ablation threshold intensities **(Figure 2)** due to extremely small volumes of irradiated tissue because of extremely short absorption depths **(Figure 1)**.

Photo-Thermal Coagulation Efficiency

Coagulation occurs as a denaturation of soft tissue proteins that occurs in the 60-100°C range, leading to a significant reduction in bleeding (and oozing of lymphatic liquids) on the margins of ablated tissue during laser ablation (and excision, incision) procedures. Since blood is contained within and transported through the blood vessels, the diameter of blood vessels B (estimated to range from 21 to 40 μm with average value of 31 μm—from measurements in human cadaver gingival connective tissue[1]) is a highly important spatial parameter that influences the efficiency of photocoagulation process. Photo-thermal coagulation is also accompanied by hemostasis due to shrinkage of the walls of blood vessels (and lymphatic vessels) due to collagen shrinkage at increased temperatures.

The coagulation depth value H relative to the blood vessel diameter B is an important measure of coagulation and hemostasis efficiency; it is easily calculated from the laser energy profile deposited inside the tissue, and is presented in **Figure 3**. Laser light intensity is assumed at the ablation threshold.

For H<<B (see Erbium laser wavelengths in **Figure 3**), optical absorption and coagulation depths are significantly smaller than blood vessel diameters; coagulation takes place on relatively small spatial scale and cannot prevent bleeding from the blood vessels severed during tissue ablation.

For H>>B (diode laser wavelengths in **Figure 3**), optical absorption (Near-IR attenuation) and coagulation depths are significantly greater than blood vessel diameters; coagulation takes place over extended volumes—far

REFERENCES...

1. Vitruk, P. Oral soft tissue laser ablative and coagulative efficiencies spectra. Implant Practice US. Nov-Dec 2014;7(6):19-27.

away from ablation site where no coagulation is required.

For H≥B (CO_2 laser wavelengths in **Figure 3**), coagulation extends just deep enough into a severed blood vessel to stop the bleeding; the coagulation is more efficient then for the above two cases H<<B, and H>>B. Coagulation depth can be further increased by pulse width/rate increase (which allows heat diffusion from irradiated volume into surrounding tissue)—a switch from SuperPulse to CW settings on popular Aesculight and LightScalpel models.

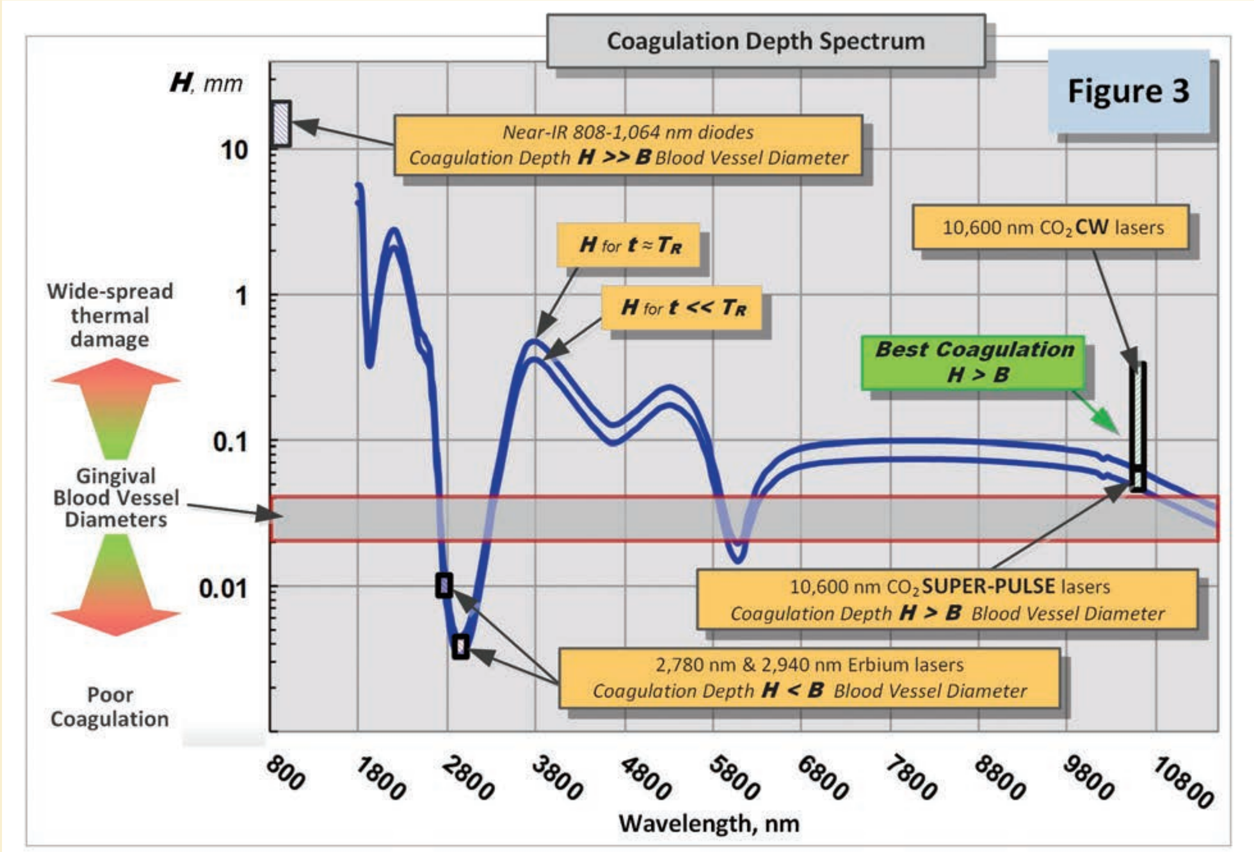
Summary

IR CO_2 laser wavelength is a highly efficient and spatially accurate photo-thermal ablation tool with excellent coagulation efficiency (close match between coagulation depth and oral soft tissue blood capillary diameters).

Mid-IR Erbium laser wavelengths are highly energy efficient and spatially accurate photo-thermal ablation tool with poor coagulation efficiency. Coagulation depth can be increased by pulse width/rate increase.

Near-IR 800-1,100 nm diode wavelengths are highly energy inefficient and spatially inaccurate photo-thermal ablation tools with wide spread thermal damage.

Near-IR diode laser light circa 1,000 nm is not used to optically ablate the oral soft tissue; instead, the diode laser optical energy is used to heat up the charred distal end of the fiber glass tip to 500-900˚C,[1] which then heats up the soft tissue through heat conduction from hot glass tip: soft tissue is burned off (ablated) on contact with the hot charred glass tip, while the margins of the burn are coagulated. Unlike non-contact surgical lasers (such as CO_2 or Erbium), the soft tissue ablative diodes are contact thermal non-laser wavelength-independent devices ●



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This Education Center article was underwritten by Aesculight of Woodinville, Wash., the manufacturer of the only American-made CO_2 laser.