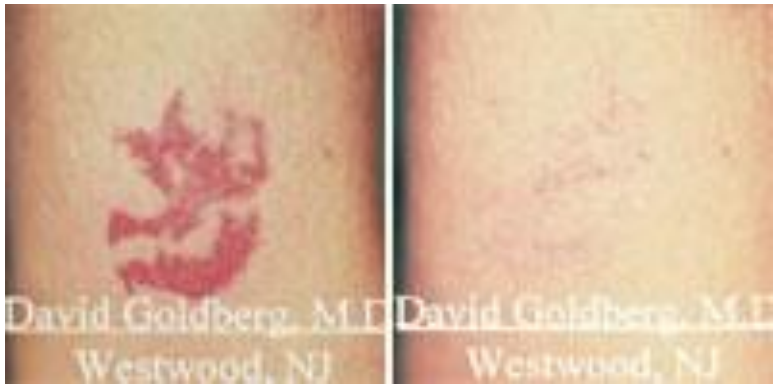
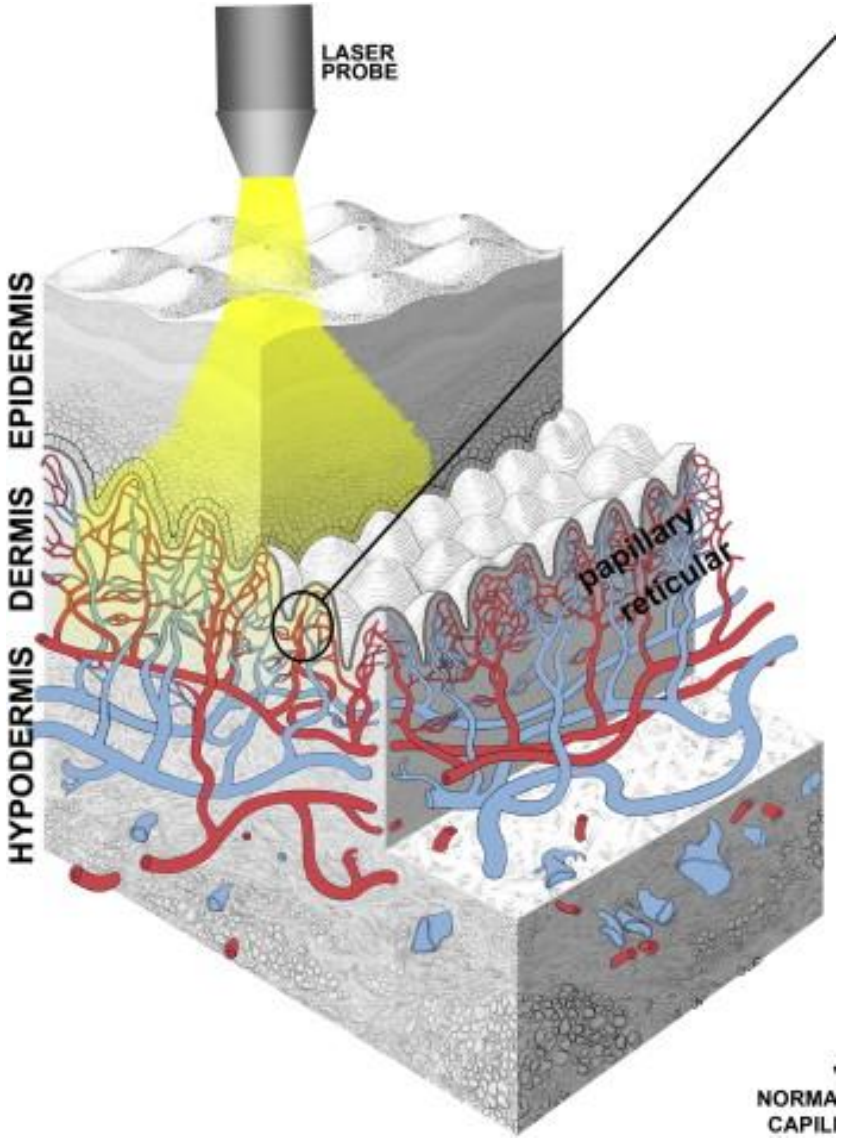
Exercise for week 11
“laser treatment of Port Wine Stains”

Port wine stain (PWS) is a cutaneous vascular malformation involving post-capillary venules which produce a light pink to red to dark-red-violet discoloration of human skin. Histopathological studies of PWS show a normal epidermis overlying an abnormal plexus of dilated blood vessels located in the dermis. [1, 2]

Mikhail Gorbachev has a prominent port-wine stain on his forehead (Wikipedia, PWS article)



Successful treatment of PWS with laser light
Journal of the American Academy of Dermatology
Volume 34, Issue 1 , Pages 1-25 , January 1996



PWS vessels are found in the reticular plexus [2].

Epidermal thickness (50–150 µm) and melanin concentration in human skin, as well as PWS blood vessel diameter (30–300 µm) and depth distribution (100–1000 µm) vary on an individual patient basis and even from site to site on the same patient [2].

The clinical objective of PWS laser treatment is to induce irreversible thermal injury to the ectatic blood vessels, which will stimulate a suitable wound healing response, while avoiding nonselective damage to the healthy epidermis and dermis [1].

Typical criterion for thermal injury:
The average temperature must rise across the vessel lumen by $\Delta t=80°C$ at least.

Journal of the American Academy of Dermatology
Volume 67, Issue 2, August 2012, Pages 289–304.e29

Question:

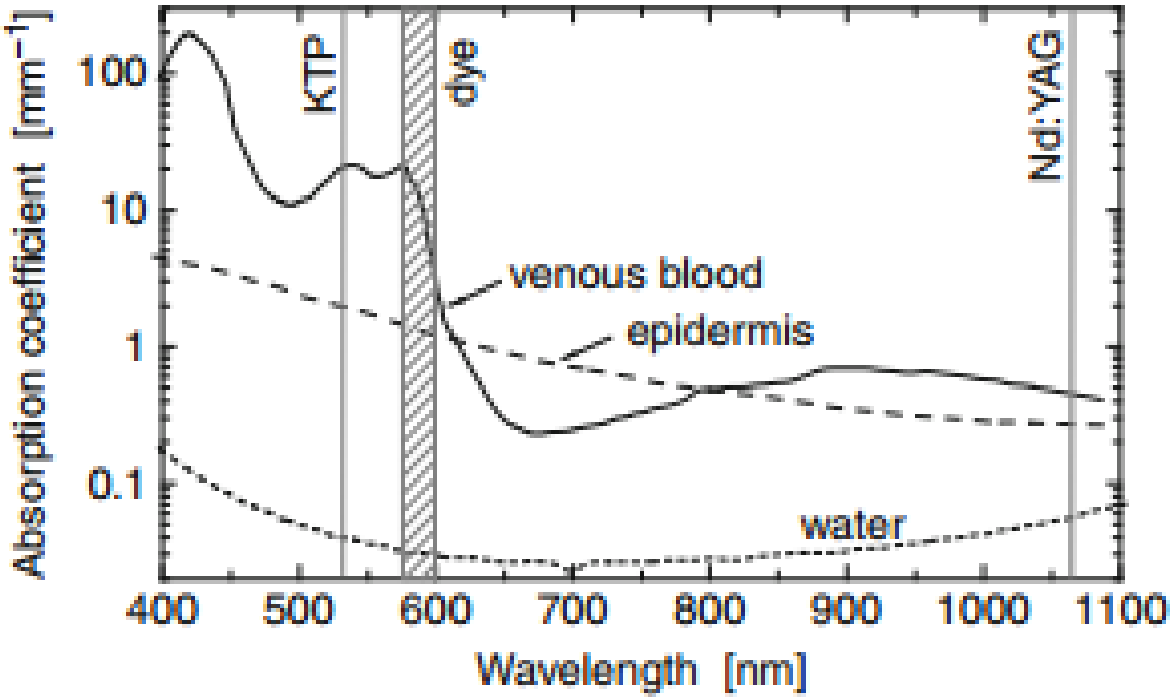
On a specific patient, Optical Coherence Tomography (OCT) investigations indicated that the ectatic vessels to be destroyed are located at a depth of 0.5 mm and have an average diameter of 300 µm. Assuming that the epidermal thickness is 50 µm and using the following hint slides, identify and discuss the optimal parameters of a laser beam (power, wavelength, pulse duration, spot size…) to treat selectively PWS by photothermolysis.

References (On Moodle):

[1] Optical-Thermal Response of Laser-irraddiated Tissue
Editors: Ashley J. Welch, Martin J.C. van Gemert. (2nd Edition; 2011)
Look, in particular, pp 879 – 880.

[2] An overview of clinical and experimental treatment modalities for port wine stains, JAAD Volume 67, Issue 2, August 2012.

Hint: Selective absorption



Absorption spectra of venous blood (oxygenation level SatO2 = 70%, typical of PWS vessels), epidermis (light skin) and water. Vertical lines indicate wavelengths of interesting laser sources.

Hint: Temperature increase following light absorption for a « short* » pulse of light

$$\Delta T = \mu_a H / \rho c$$

where μ_a is the absorption coefficient (typical units, cm^{-1}), H is the radiant exposure (typical units, J cm^{-2}), ρ is the density (gm cm^{-3}), and c is the heat capacity (J $°C^{-1}$ gm^{-1}). For tissue, a reasonable estimate is that $pc \approx 4.2$ J cm^{-3} $°C^{-1}$;

* Such is the case if the duration of the pulse is shorter than the thermal relaxation time ($\tau_R \approx r^2/4\alpha$, where r is the characteristic dimension of the absorbing target, and α is the thermal diffusivity of the material (for tissue a reasonable estimate is $\alpha \approx 1.3 \times 10^{-3}$ cm^2 s^{-1}).

e.g., If r = 100 µm → τ_p= 19.2 ms

Optical-Thermal Response of Laser-Irradiated Tissue: Ashley J. Welch, Martin van Gemert, Springer, 2010.

Hint: penetration of light in tissues

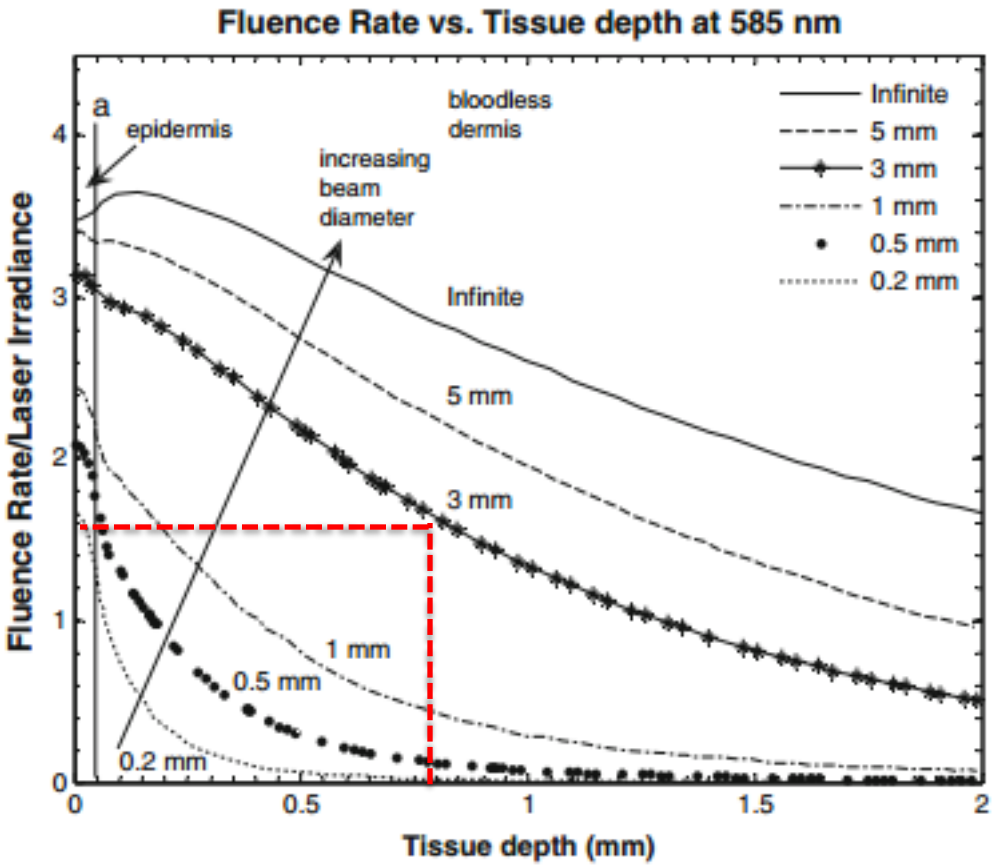


Fig. 3.15 The fluence rate within the skin below the beam center is fluenced (due to scattering) by the beam diameter. For the same incident irradiance (1 W/cm^2), the larger the beam (spot) diameter, the greater is the fluence rate. These Monte Carlo calculations were made for a flat top beam profile at 585 nm using optical properties summarized in Table 23.2

Hint: Optical properties of blood, the epidermis and the dermis

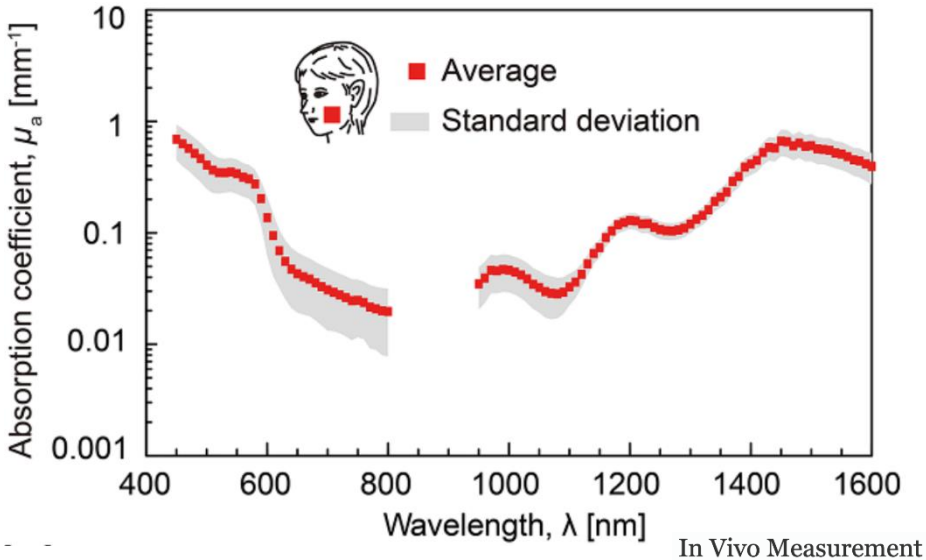
Table 23.1 Absorption coefficient (μ_a) and scattering coefficient (μ_s) of whole blood as a function of wavelength for oxygen saturation levels of 100 and 70% (hematocrit 0.40) [35–39]

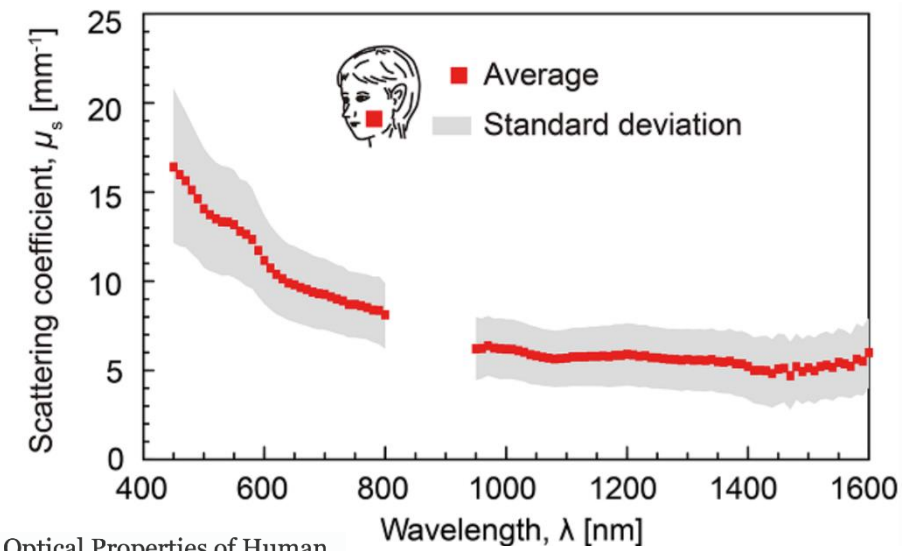
	Absorption coefficient (mm^{-1})		Scattering coefficient (mm^{-1})	
Wavelength (nm)	$SatO_2 = 100\%$	$SatO_2 = 70\%$	$SatO_2 = 100\%$	$SatO_2 = 70\%$
532	26.6	23.1	30.6	30.1
577	35.4	31.4	28.8	28.5
585	19.1	18.6	30.4	29.7
590	6.9	9.1	31.3	30.3
595	4.3	6.0	31.4	30.4
600	2.5	4.0	31.3	30.4
1064	0.5	0.22	13.5	12.9

Property @ 532 nm	Epidermis	Dermis
Refractive index n	1.4	
Anisotropy factor g	0.8	
Absorption coefficient μ_a	$0.55\,mm^{-1}$	$0.27\,mm^{-1}$
Scattering coefficient μ_s	$31.36\,mm^{-1}$	$20.18\,mm^{-1}$

From: https://doi.org/10.1038/srep11016

Hint: Optical properties of blood, the epidermis and the dermis





In Vivo Measurement of Optical Properties of Human Skin for 450–800 nm and 950–1600 nm Wavelengths

Takahiro Kono & Jun Yamada

International Journal of Thermophysics **40**, Article number: 51 (2019) | Cite this article

Property @ 532 nm	Epidermis	Dermis
Refractive index n	1.4	
Anisotropy factor g	0.8	
Absorption coefficient μ_a	0.55 mm^{-1}	0.27 mm^{-1}
Scattering coefficient μ_s	31.36 mm^{-1}	20.18 mm^{-1}

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