Modeling Light Propagation in Skin for Visualization of Subcutaneous Veins

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Introduction

Vein Visualization systems are vein-contrast enhancement devices that use infrared light to highlight the underlying vasculature such as the Vein-Viewer that makes venipuncture, blood draw, and intravenous therapy easier. [1] Understanding how infrared light propagates in a real skin model is critical and a 3-D COMSOL model, shown in Figure 1, was developed for that reason. Factors affecting this model are location and topology of veins, light wavelength as well as its intensity, and variation in optical properties of skins. The aim of this work is to aid in optimization and improvement of the device design and practices.

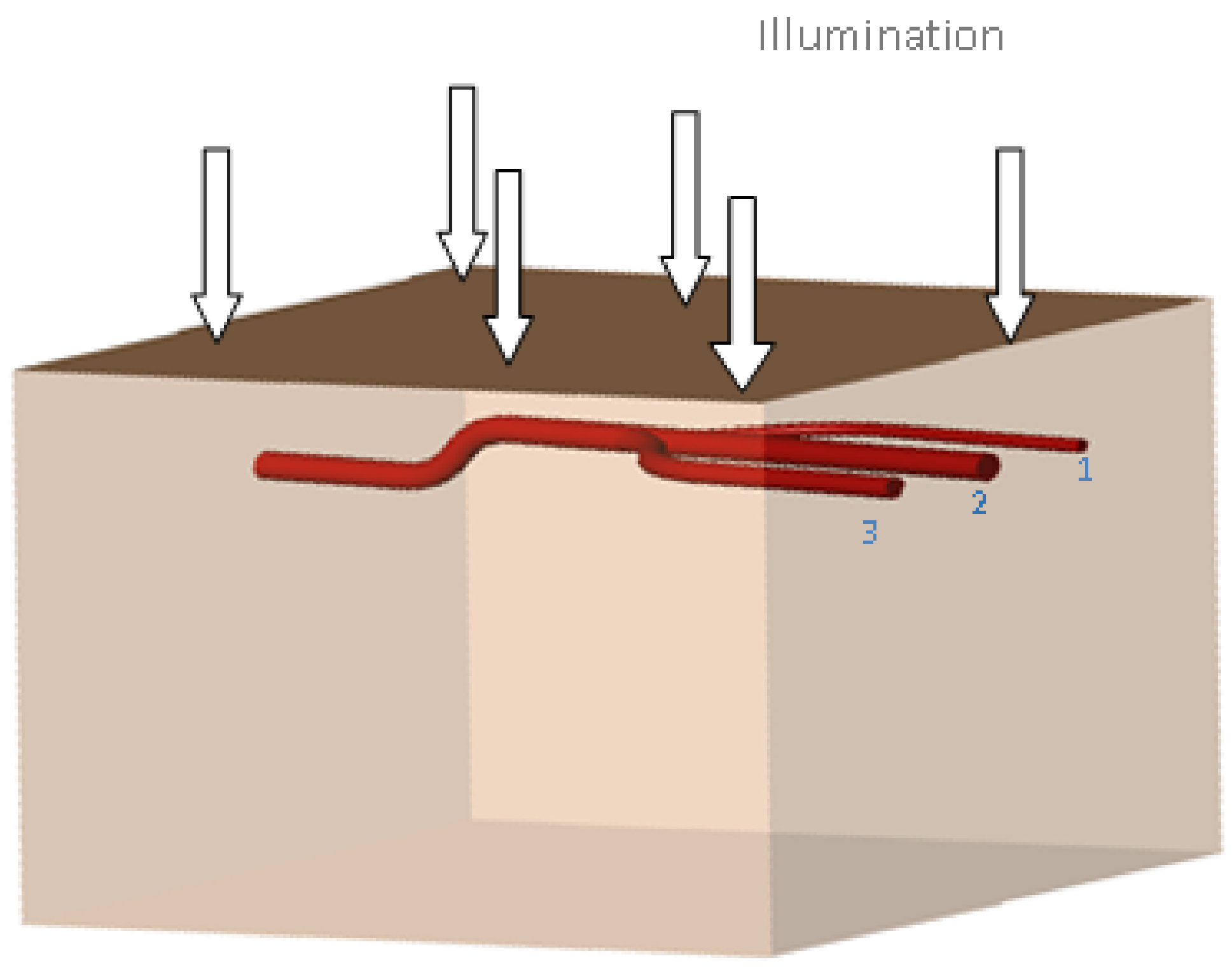

Figure 1. SolidWorks Schematics of the skin and subcutaneous Vein

Computational Methods

Photon transport in biological tissue can be modeled as the diffusion approximation of an RTE (radiation transfer equation) because the skin is a scattered dominated medium.[2] The RTE was expressed as Helmholtz equation, shown in Eq.1, in COMSOL and an LED light source was applied on the boundary which equation is shown in Eq.2. Continuity was used as boundary conditions where the skin and blood vessels are in contact.

$$\nabla \cdot (-c\nabla u) + au = f \qquad \textbf{(Eq. 1)}$$

$$-\mathbf{n} \cdot (-c\nabla u) = g - qu \qquad \textbf{(Eq. 2)}$$

Schematics of SolidWorks model of the skin including dermis, epidermis and subcutaneous dermis as well as the veins with different diameters and subcutaneous veins with different diameters.

Wavelength (nm)	Skin		Whole Blood	
	μ_a (cm^{-1})	μ'_s (cm^{-1})	μ_a (cm^{-1})	μ'_s (cm^{-1})
650	8.9	2.73	4.3	10
760	7.8	2.31	5.3	6.5
880	6.9	1.63	8.5	6.1

Table 1. Absorption and scattering coefficients of skin and whole blood [1]

Results

The COMSOL 3-D skin model showed clear distinction between the skin and sub-cutaneous veins where optical properties are significantly different as shown in Figure 2. Contrast between the tissue and blood vessels, shown in Figure 3, depends on wavelength of the light source and size and depth of the veins. The contrast was enhanced at the wavelength of 880 nm (Figure 4) and for larger veins (Figure 5), and reduced for deeper veins (Figure 6).

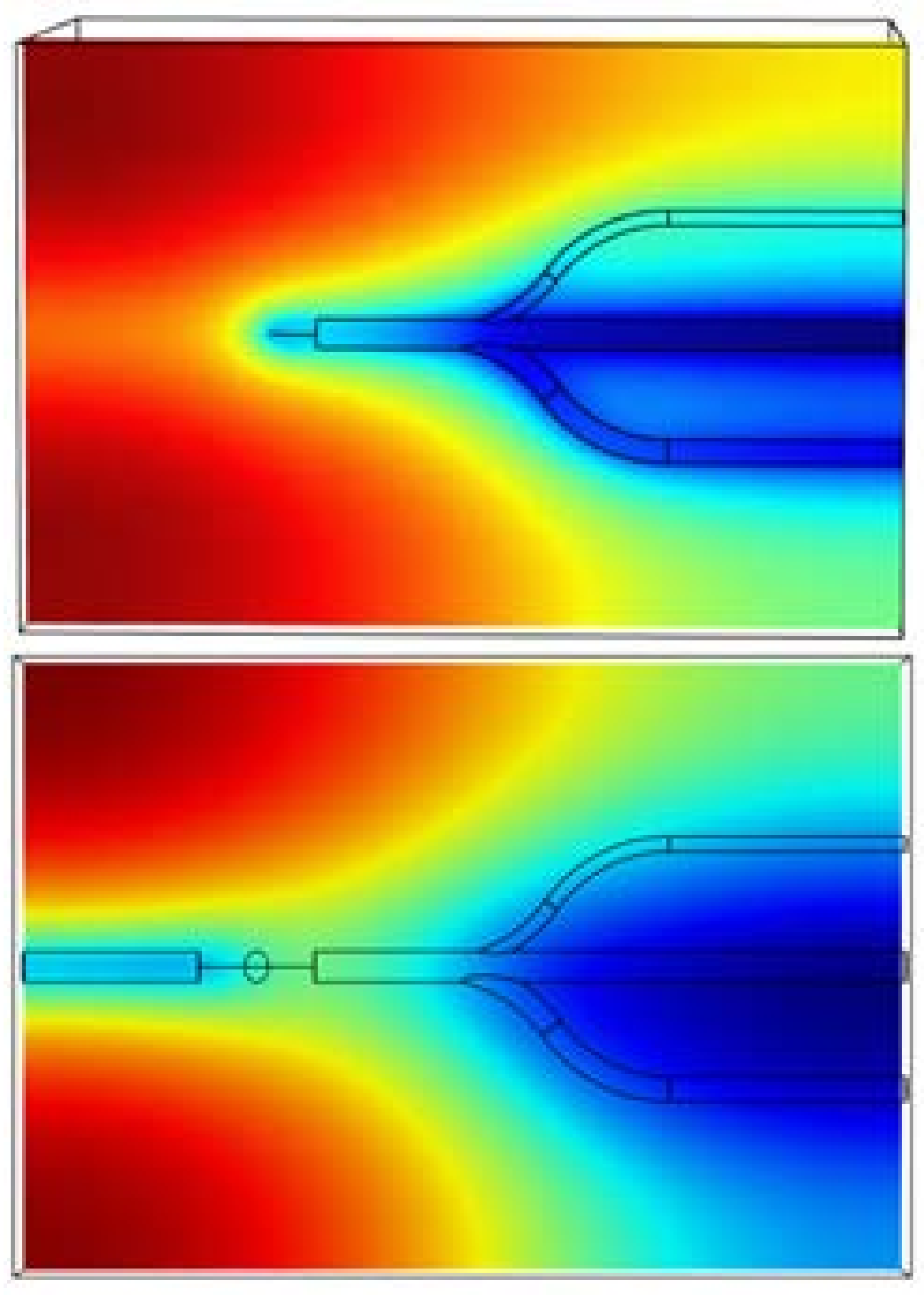

Figure 2. Light absorption by blood at different skin depths

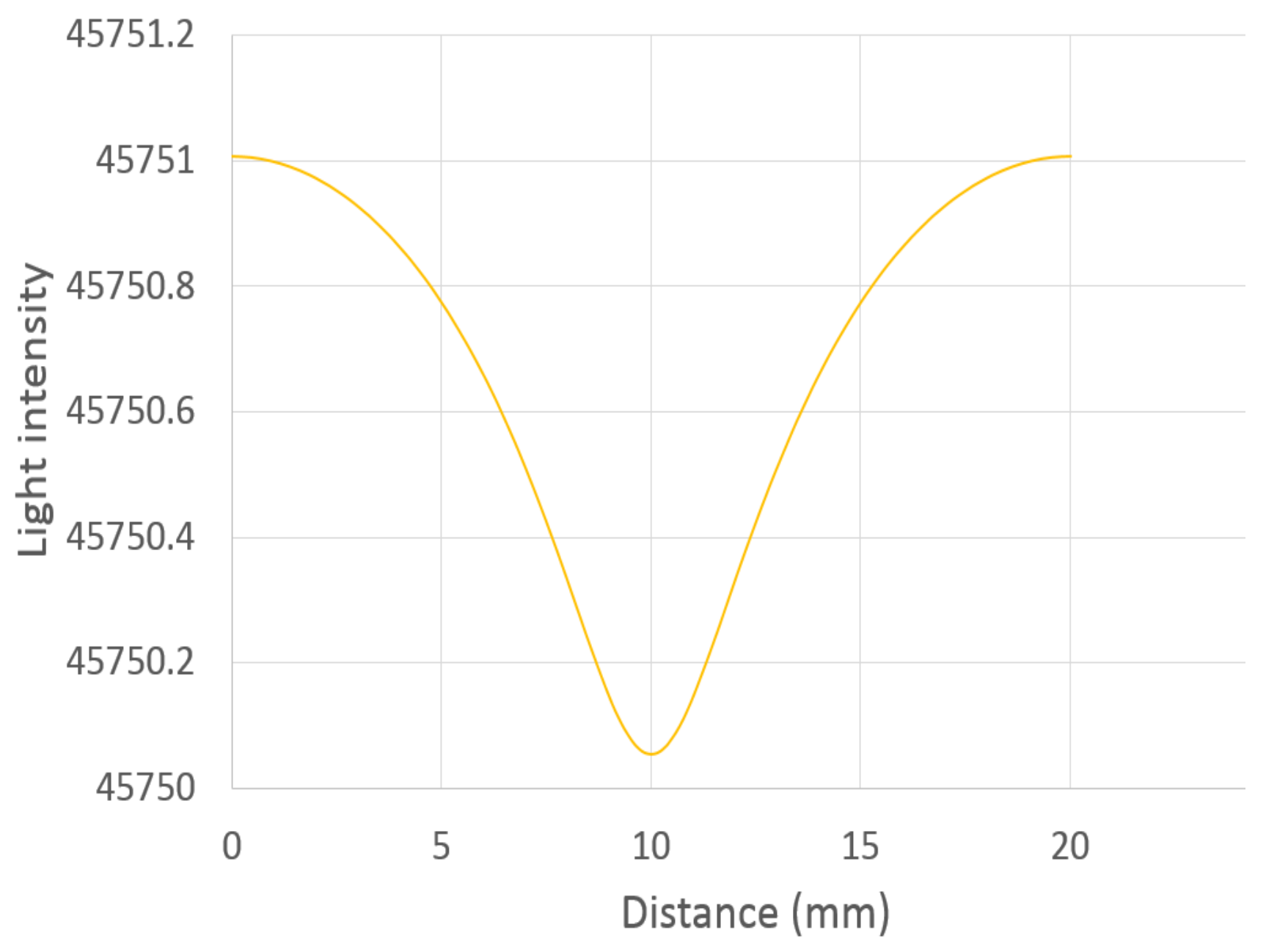

Figure 3. Light intensity determines the contrast

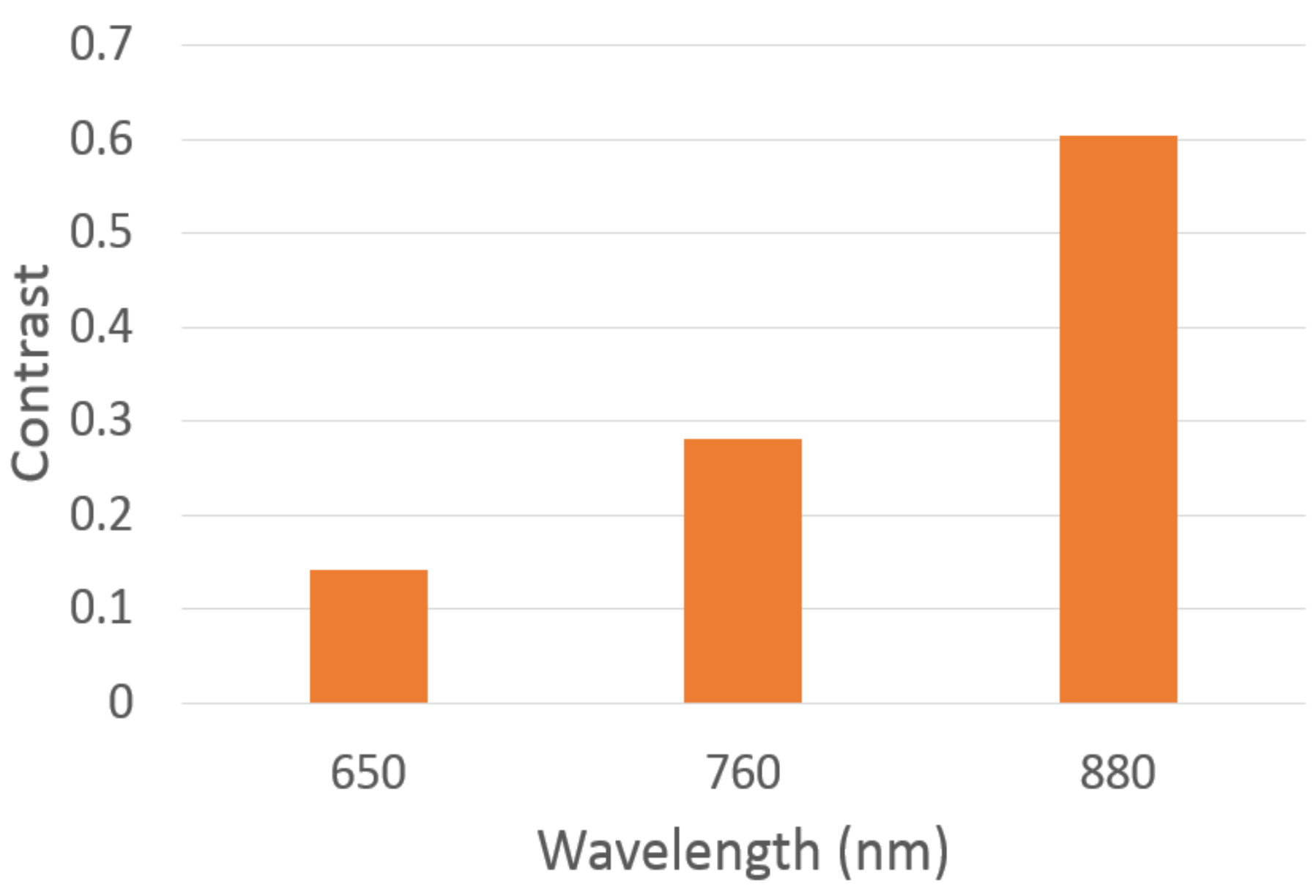

Figure 4. Light absorption at different Wavelengths of light sources

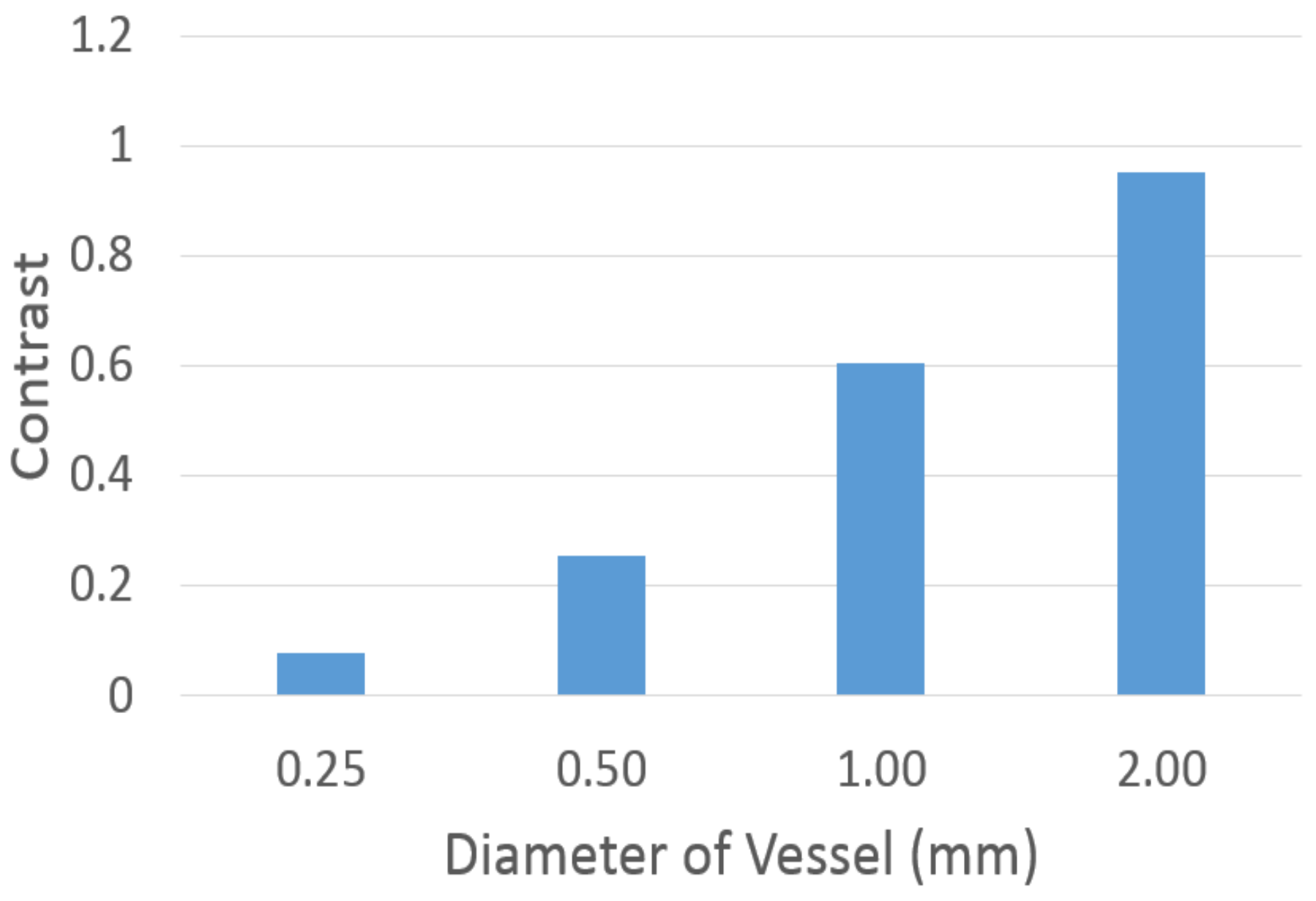

Figure 5. Light absorption at different vein diameters

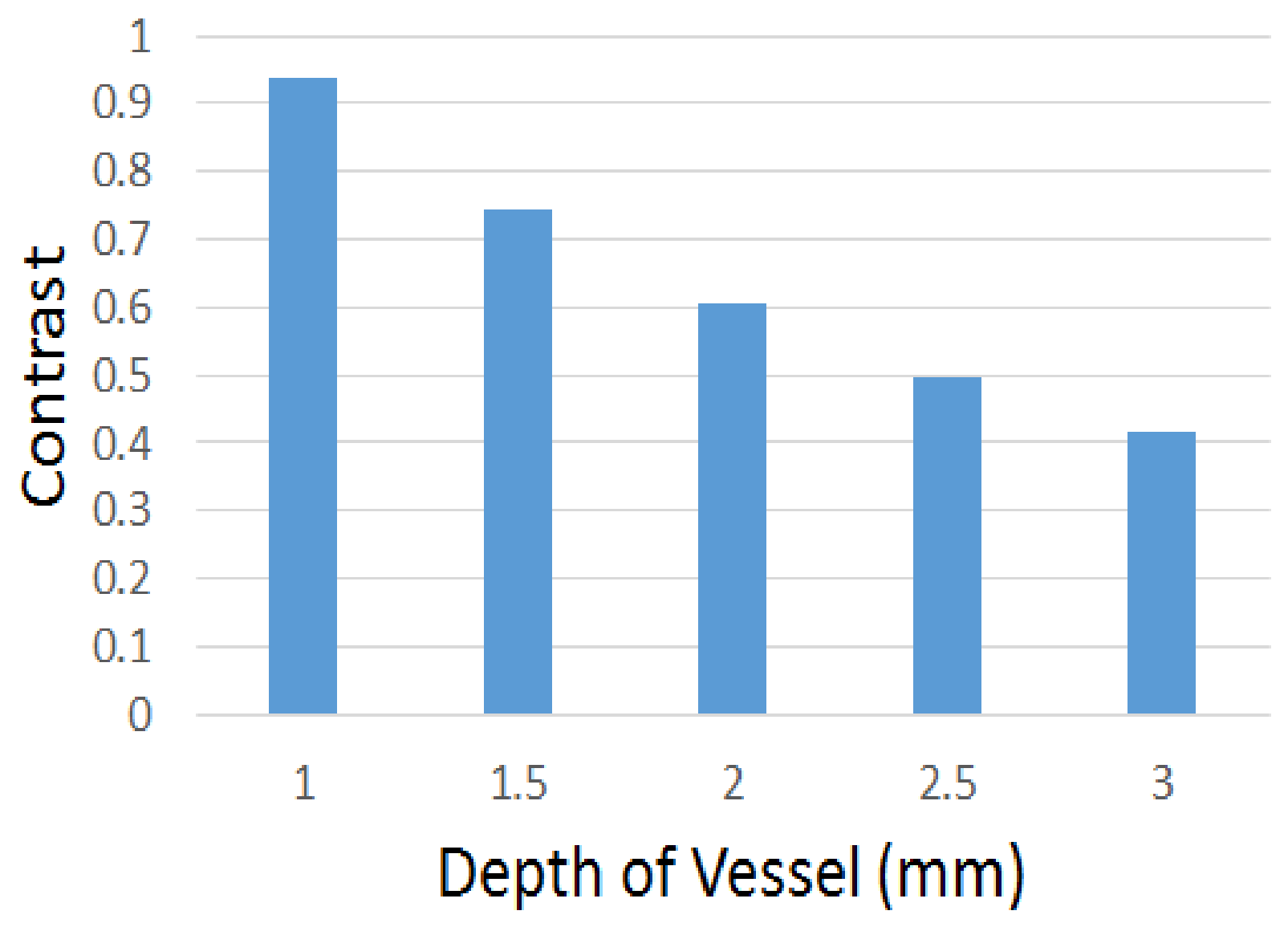

Figure 6. Light Absorption at different depth of the veins

Conclusions

The 3-D COMSOL model effectively shows the contrast of the veins from the surrounding tissue. The advantage of this model is that the topology of vasculatures can be modified easily using 3-D CAD modeling software or a scanner. This model can effectively be used to advance the design and practices of vein visualization devices for projection and clinical assessment of dermal blood vessels. Further research will compound a more complex 3-D geometry, location variation of the light source as well as the skin variation such as melamine.

References

1. H. D. Zeman, G. Lovhoiden, C. Vrancken, and R. K. Danish, "Prototype vein contrast enhancer," *Opt. Eng.*, vol. 44, p. 086401, 2005.
2. S. R. Arridge, "Optical tomography in medical imaging" *Inverse Problems,* vol. 15, p. R41, 1999.

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