Optical properties of biological tissues measured at infrared wavelengths

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Abstract: We measured the reduced scattering coefficient and absorption coefficient of biological tissues of rats for 980nm and 1863nm. Results suggest potential presence of a chromophore other than water that absorbs infrared radiation in tissues.

1. Introduction

In recent years major advances have been made in optical stimulation techniques, including infrared neural stimulation (INS) and has been found as an important method to for biomedical research. However, the primary mechanism underlying infrared photoactivation of neurons and cardiomyocytes previously reported has yet to be characterized [1,2,3]. The mechanism of photoactivation may be thermal, mechanical, photochemical or electric. An important similarity between these mechanisms is that the propagation of light in tissue plays a critical role in the light-tissue interactions. The ability of light to penetrate any tissue and deposit energy via the optical absorption properties of the tissue is key to potential basic science and therapeutic applications. In this paper, we use single integral sphere and Inverse-Monte-Carlo [4] method to show the interaction between infrared light and biological tissue. Identifying the optical properties of tissues at the long-wavelengths is a key step in developing future applications.

2. Result of optical property measurement

To characterize the light propagation in biological tissues, the absorption coefficient and scattering coefficient were measured to enable further modeling. A custom-designed setup including a single integral sphere was used to obtain the data and use inverse Monte-Carlo system to determine the coefficients. We have compared fresh tissues from rats. The use of laboratory animals was approved by the University of Miami Animal Care and Use Committee and was in compliance with USDA and NIH Guidelines for the Care and Use of Laboratory Animals. We utilized brain, optical nerve, sciatica nerve, muscles and heart as the targeted samples and used liver and distilled water for controls.

Table 1 Comparison of coefficients measured from liver and DI water

Sample		Wavelength	Absorption coefficient (mm^{-1})	Reduced scattering coefficient (mm^{-1})	g
Rat	Present study	980nm	0.27	6.9	0.94
Rat	[5]	980nm	0.62	6.6	0.93
DI Water	Present study	980nm	0.045	-	-
DI Water	Present study	1863nm	2.1	-	-
DI Water	[6]	980nm	0.046	-	-
DI Water	[6]	1863nm	2.0	-	-

Table 1 highlights the comparison of the optical properties at the two wavelengths for distilled (DI) water and fresh rat liver to previously published study [6]. The results of the present study compared well with the published values providing confidence in our methodology.

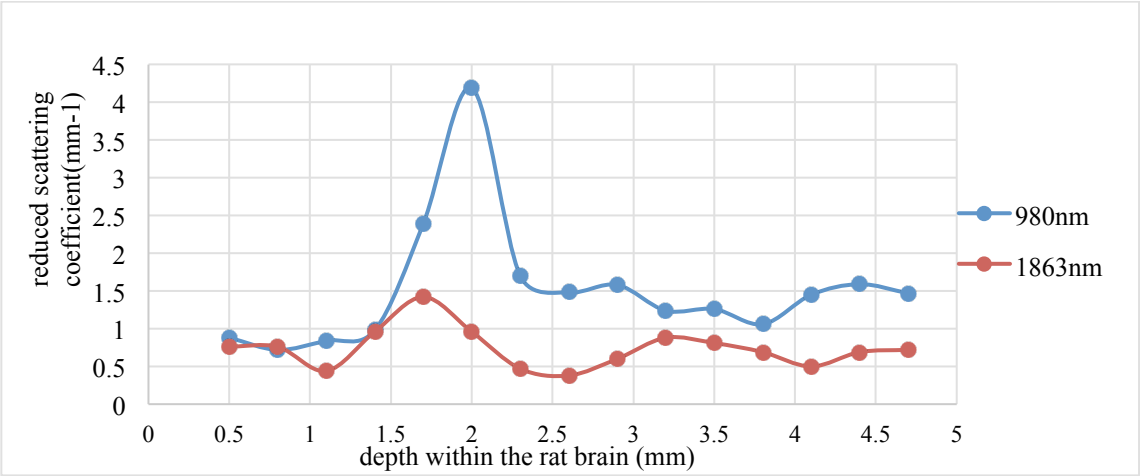

Figure 1. Comparison of reduced scattering coefficient of brain tissues for 980nm and 1863nm

Figure 1 shows the reduced scattering coefficient of rat brain for 980nm and 1863nm. Reduced scattering coefficient for 980nm increased to ~4.2/mm at a depth of 2 mm with an average of ~1.5/mm. In comparison for 1863nm, the reduced scattering coefficient increases to 1.5/mm near a depth of 1.7 mm with an average ~0.4/mm. These results imply the difference between white matter and gray matter and are confirmed from a previous study at 750nm (see Figure 2, [7]). The reduced scattering coefficient in 750nm was carried out by using a needle-like probe and showed a similar trend corresponding to our result. Though the depth at which the peak occurred was different. This is potentially due to a difference in methodology used in our study compared to the measurements carried out *in vivo* [7]. For our measurements, the brain was frozen prior to sectioning with a microtome to obtain consistent thickness levels. It is possible that the freezing process may shrink the size of the tissue.

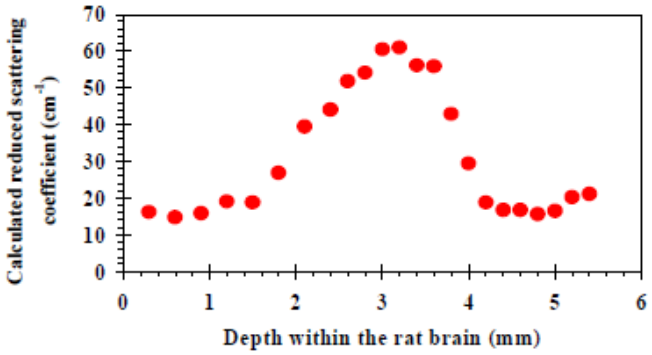

Figure 2. Absorption coefficient of brain for 750nm [5]

Figure 3 shows the absorption coefficient of fresh brain tissues for 980nm and 1863nm. The absorption coefficient also showed a difference between gray matter and white matter, albeit it was weaker when compared with the scattering coefficient. For 980nm, the absorption coefficient of brain was significantly higher than that of water. The result suggests that there is a secondary effect to photothermal interactions and can be explained by the absorption spectrum of cytochrome c oxidase, the candidate mitochondrial chromophore. Similar results are obtained from rat muscle and heart tissues (Table 2), including for1863nm. The absorption coefficient of muscle for 1863nm was ~1.973/mm and for heart it was ~1.637/mm. These are lower that the absorption coefficient of water for 1863nm. Given the water content in the tissue, a secondary effect to photothermal interactions is possible. Recent studies have suggested that mitochondria may be the primary source of the intracellular calcium transient observed in response to pulse-by-pulse infrared neural stimulation at this wavelength [3,8].

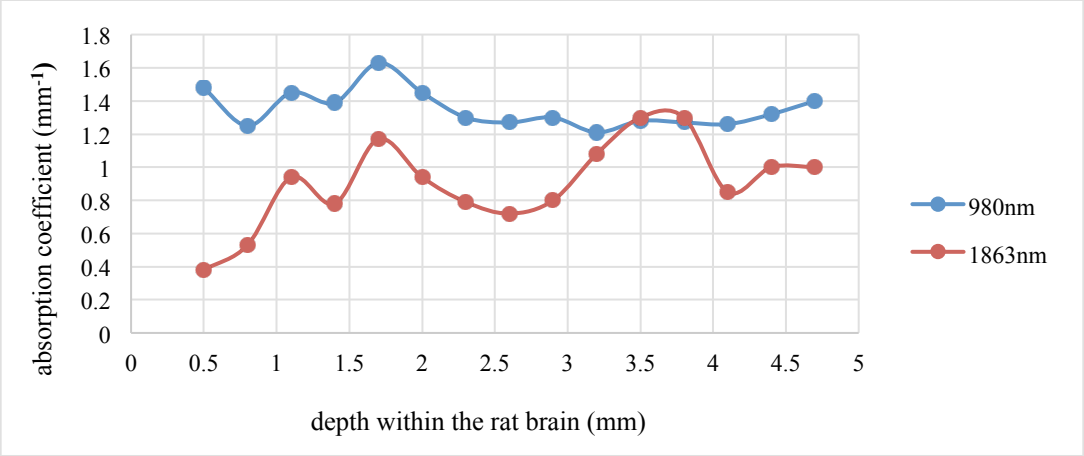

Figure 3. Brain absorption coefficient in 980nm and 1863nm

Table 2. Optical properties of rat muscle and heart

Species	Wavelength	Absorption coefficient (mm^{-1})	Reduced scattering coefficient (mm^{-1})
Muscle	980nm	0.18	0.28
Muscle	1863nm	1.97	0.11
Heart	980nm	0.62	0.41
Heart	1863nm	1.63	0.67

We carried out the measurements in rat nerves. Table 3 shows the the optical properties of the optic and sciatica nerves at the two wavelengths. It is evident that for both 980nm and 1863nm, the absorption coefficients of these nerves are higher when compared to water. The results suggest that similar to 980nm, absorption of the long wavelength infrared by the tissue may result in secondary effects and may be driven by the mitochondria.

Table 3. Optical properties of rat sciatica nerve and optical nerve

Species	Wavelength	Absorption coefficient (mm^{-1})	Reduced scattering coefficient (mm^{-1})
Optical nerve	980nm	0.32	3.59
Optical nerve	1863nm	2.17	0.55
Sciatica nerve	980nm	0.31	1.98
Sciatica nerve	1863nm	2.27	0.36

3. References

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