Broadband extraction of tissue optical properties using a portable hybrid time-resolved continuous wave instrumentation: characterization of ex vivo organs

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Abstract: Successful demonstration of a unique portable CW-TDDOS system for accurate and multiwavelength retrieval of tissue optical properties. Determining these properties has potential to improve the diagnosis and treatment outcomes in clinical and sports settings.

1. Introduction

Current broadband continuous wave (CW) systems are able to perform reflectance and transmittance measurements, which can be used to extract tissue optical properties. The extended wavelength range to the near-infrared allows the investigation of the optical properties in the wavelength range where light penetrates deeper into tissues (optical windows). Characterizing tissue optical properties in the optical windows is attractive to the medical device industry, as they have been exploited for novel optical diagnostics tools and treatment modalities requiring information from centimeters under the tissue surface. Optical properties can be extracted by using analytical models or numerical methods based on the radiative transfer equation. The accuracy for broadband CW systems relies on the constraints applied by the wavelength-dependency of the chromophore spectra and scattering properties. On the other hand, the amplitude of the absorption and scattering coefficients may differ depending on the model used to describe the CW signals. The possible inaccuracy in the amplitude of the optical properties can be overcome by calibrating the optical properties with a gold standard technique such as time-domain diffuse optical spectroscopy (TDDOS) systems. With this in mind, we present a novel portable combination between CW and TDDOS for accurate estimation of broadband optical properties in tissue-mimicking phantoms and *ex vivo* organs. The system will be used in a colorectal cancer detection study currently approved by the research ethics committee.

2. Material and Methods

The portable system consists of a broadband CW diffuse transmittance system and a near-infrared TDDOS system used independently in order to prevent crosstalk between the two instruments. The CW system [1] contains a broadband light source (HL-2000, Ocean Optics, Edinburgh, United Kingdom) which sends the excitation light to the sample through a 1000-µm-core 0.39 NA Low-OH-Silica fiber optic probe (M35L01 Fiber Patch Cable, Thorlabs, Munich, Germany). The transmitted light is detected by a visible wavelength spectrometer (QE-Pro, Ocean Optics, Edinburgh, United Kingdom). After collecting intensity measurements, the data was post-processed in order to obtain the sample optical properties. The TDDOS system, developed at Politecnico di Milano, employs two pulsed laser diodes (670nm and 830nm) and a SIPM detector to estimate the absolute optical properties (absorption and reduced scattering coefficients, μ_a and μ_s' respectively) of the tissue under study [2,3]. The portability of the two systems is shown in figure 1A.

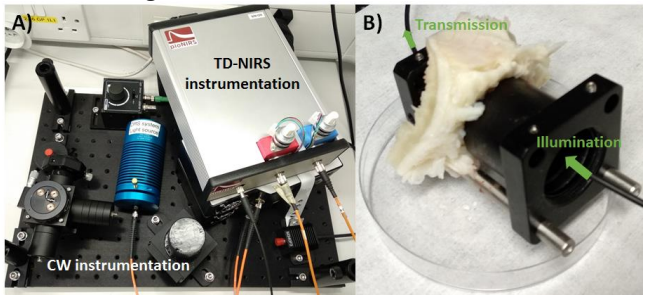

Fig.1 A) Portable broadband CW and TDDOS instrumentation and B) Transmittance measurement setup.

The system was characterized by using a phantom matrix kit [4] in order to check the performance of the combined (CW+TD) portable system. The phantom matrix contains 24 phantoms with μ_a ranging from 0.1 to 1 cm^{-1} and μ_s' from 5 to 25 cm^{-1} and well characterized using broadband time domain system [5]. Then, the optical properties of *ex vivo* tissues the liver, bone marrow, heart, kidney, fat, and muscle were extracted by using our hybrid system. The transmission measurements were performed by using a customized probe or the setup shown in figure 1B.

3. Results

The linearity of the portable system at 825 nm to extract optical properties (μ_a and μ_s') of the phantom matrix kit is shown in Fig. 2.

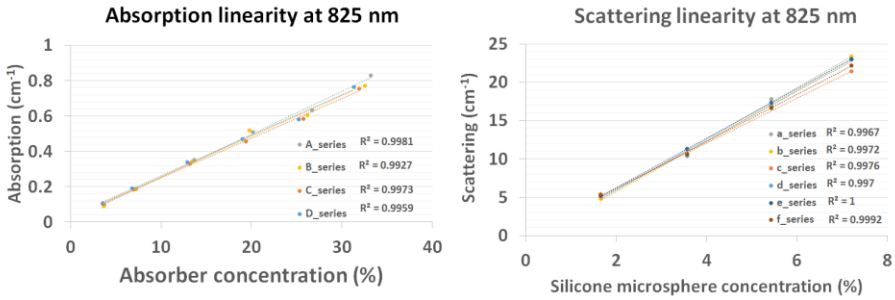

Fig.2 TDDOS characterization of the absorption (left) and scattering (right) linearity of the phantom matrix kit.

The estimation of the tissue optical properties is consistent to what is biologically expected, as the μ_a of high vascularized tissues (e.g. muscle, heart and kidney) is from 2 to 8 times higher compared to relatively low vascularized ones (e.g. bone marrow), due to the differences in blood, lipid and water content. Our results suggest our hybrid CW-TDDOS system was capable of accurate extraction of broadband tissue optical properties.

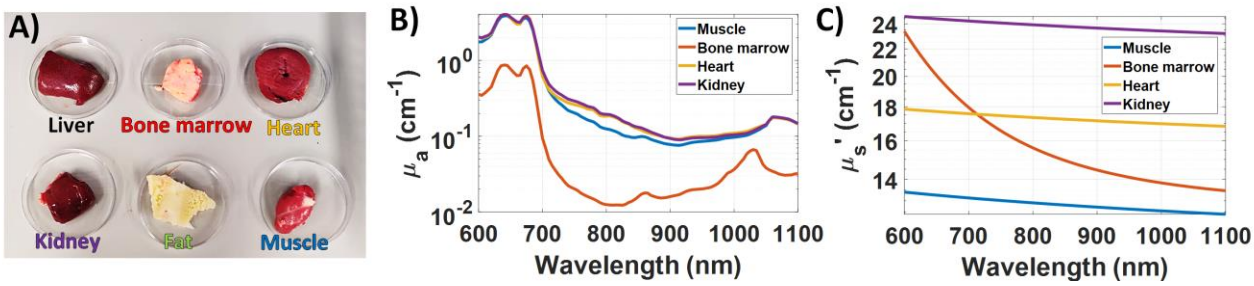

*Fig.3 A) Measured e*x vivo *tissues, B)* μ_a *and C)* μ_s' *of the* ex vivo *tissues.*

4. Conclusions

We successfully demonstrate the accuracy of a unique portable CW-TDDOS system for multiwavelength retrieval of tissue optical properties, which can be used for clinical or sports medicine applications. Moreover, our hybrid CW-TDDOS has potential to extract the biochemical depth profile of biological tissues in order to improve the diagnosis and treatment outcomes. Future work includes *in vivo* colorectal cancer detection studies.

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