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Broadband optical spectroscopy of the human adipose and muscle tissues – an *in-vivo* pilot study

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ABSTRACT

The ability to non-invasively monitor *in-vivo* the human muscle and adipose tissue is of great practical use and hence of growing interest in the fields of clinical diagnostics and preventive medicine. Optical methods, such as diffuse optical spectroscopy (DOS) applied in the near-infrared spectral region could be of great interest in clinical scenario. In this work, we present a pilot study based on multi-distance broadband time-domain diffuse optical spectroscopy (TD DOS) to characterize *in vivo* the subcutaneous adipose tissue (abdominal region) and the vastus lateralis muscle (thigh region). The study was performed using a fully automated portable TD DOS instrument on a set of 24 healthy adult volunteers. The optical properties of these two tissue types were obtained over the broad wavelength range of 600-1100 nm. The results suggest a clear influence of the stratified nature of the two regions considered, namely the abdomen and thigh, on the recovered optical properties. This work demonstrates how multi-distance broadband diffuse optical spectroscopy could be complimentary in fields like the non-invasive spectroscopy of adipose tissue and the standard DOS-based muscle oximetry.

Keywords: diffuse optics, non-invasive, heterogeneous, time domain, adipose tissue, muscle, absorption

1. INTRODUCTION

Optical methods like Diffuse Optical Spectroscopy (DOS) have been used to non-invasively investigate various organs of the human body, like the breast, forehead, and bone[1,2]. More recent works have also successfully demonstrated the use of this technique in monitoring the effects of diet control on abdominal fat tissue[3,4] and of exercise-related mechanisms on the skeletal muscles[5,6]. Efforts have also been directed towards improving the reliability of optical techniques for these applications[7]. However, both the abdominal and the muscular regions of the human body provide a rather layered structure, composed primarily of three layers: the superficial epidermal and dermal layers, a subcutaneous adipose tissue (SAT)/lipid layer, and an underlying muscle layer. All these layers, in principle, could contribute to the absorption and reduced scattering coefficients obtained using DOS measurements, thereby contaminating the information on a specific layer.

In this paper, we use a portable multi-distance broadband time-domain (TD) DOS instrument for the broadband characterization of subcutaneous fat tissue in the abdominal region and of skeletal muscle in the thigh region (vastus lateralis). This preliminary study performed on 24 healthy volunteers is aimed at understanding the influence of the aforementioned tri-layered nature of these tissue types on the time distribution of the diffusively reflected light. This knowledge will then be used to optimize the experimental and analysis conditions for an upcoming clinical study.

2. EXPERIMENTAL DETAILS

A fully-automated, portable, bedside clinical instrument based on a supercontinuum pulsed laser source tunable over 600–1100 nm range and a Silicon PhotoMultiplier (SiPM) detector were employed for this study. The acquired data was analyzed using a Monte Carlo simulation-based analysis model. Further details regarding the instrument and analysis can be found in Ref. 8.

The absorption and reduced scattering spectra from the abdomen and muscle tissues for a total of 24 healthy volunteers (12 M and 12 F), with a diverse range of age (25-75 years) and BMI (18–30 kg/m^2) are presented below. The measurements on the abdomen were performed at a distance of 4 cm to the left of the navel and those on the muscle at one-third the length

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of the thigh (hip to knee) measured from the knee. TD data were collected over a broad range of wavelengths (600-1100 nm) and at three source-detector separation distances (1, 2, and 3 cm).

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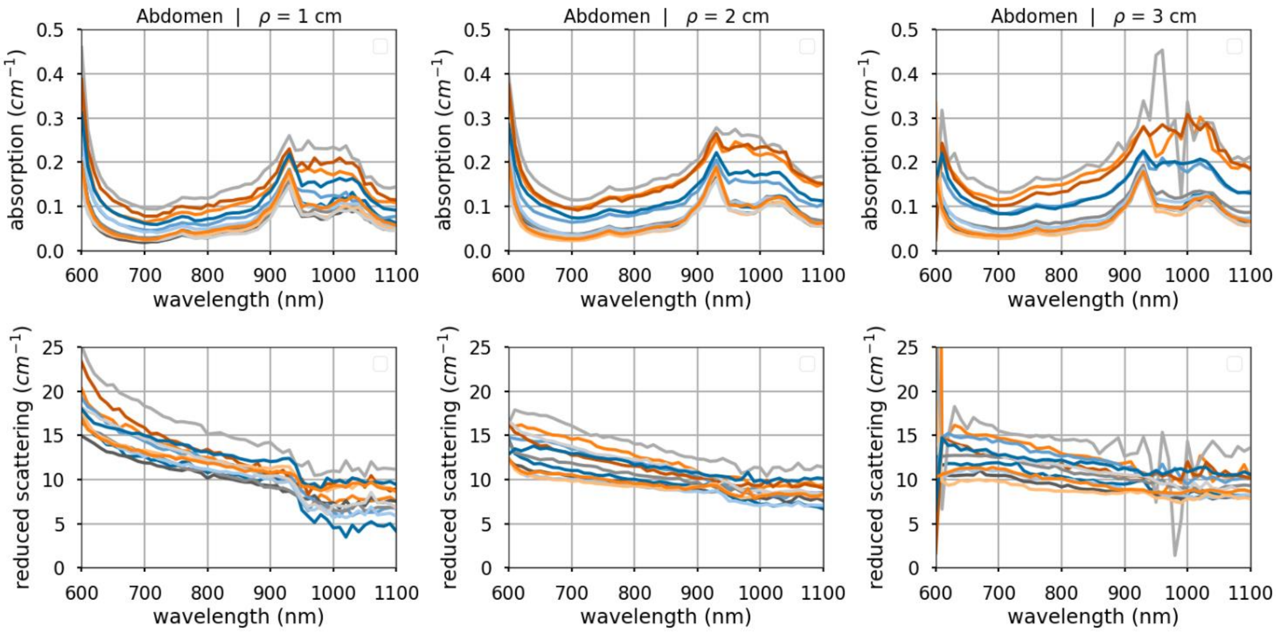

Figure 1 Inter-subject variation in the broadband absorption (top row) and reduced scattering spectra (bottom row) of the abdomen of 12 healthy *male* volunteers at three different source-detector distances.

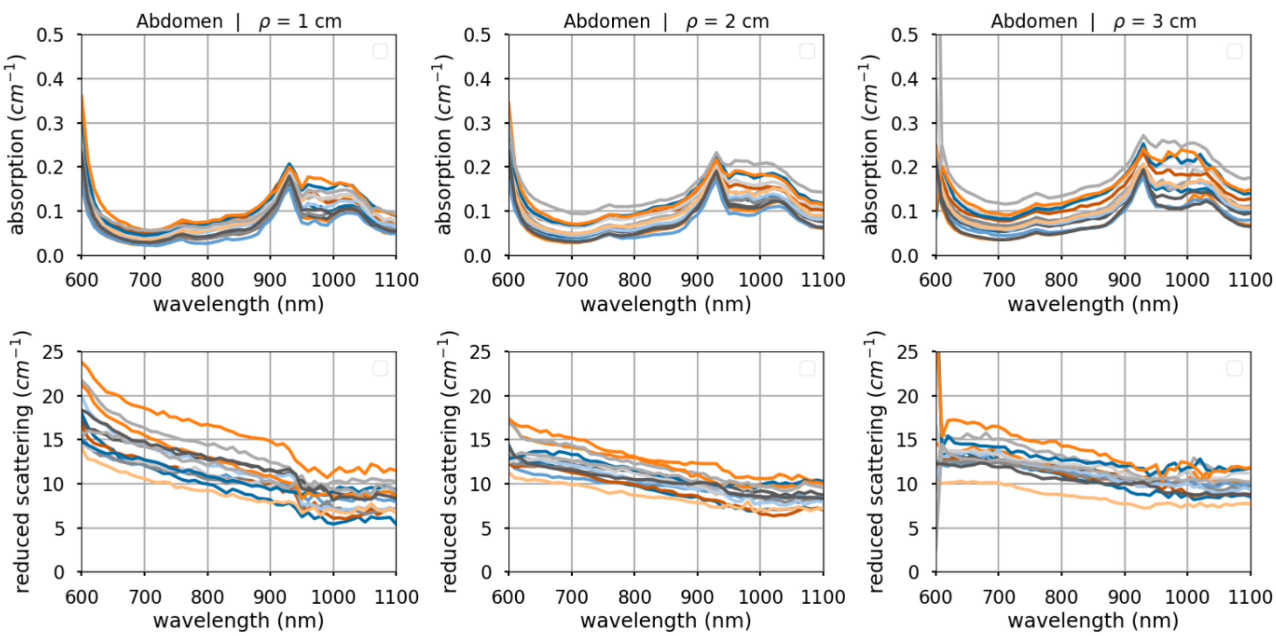

Figure 2 Inter-subject variation in the broadband absorption (top row) and reduced scattering spectra (bottom row) of the abdomen of 12 healthy *female* volunteers at three different source-detector distances.

3. RESULTS AND DISCUSSION

The resultant absorption spectra for the abdominal region for both subject groups (male and female) at all the source detector separations (ρ) are dominated by the lipid peak at 930 nm. Moreover, the increase in absorption observed over the entire spectral range with increasing ρ could be attributed to an increase in blood and water content in the deeper regions of the probed volume, *i.e.* the underlying muscle.

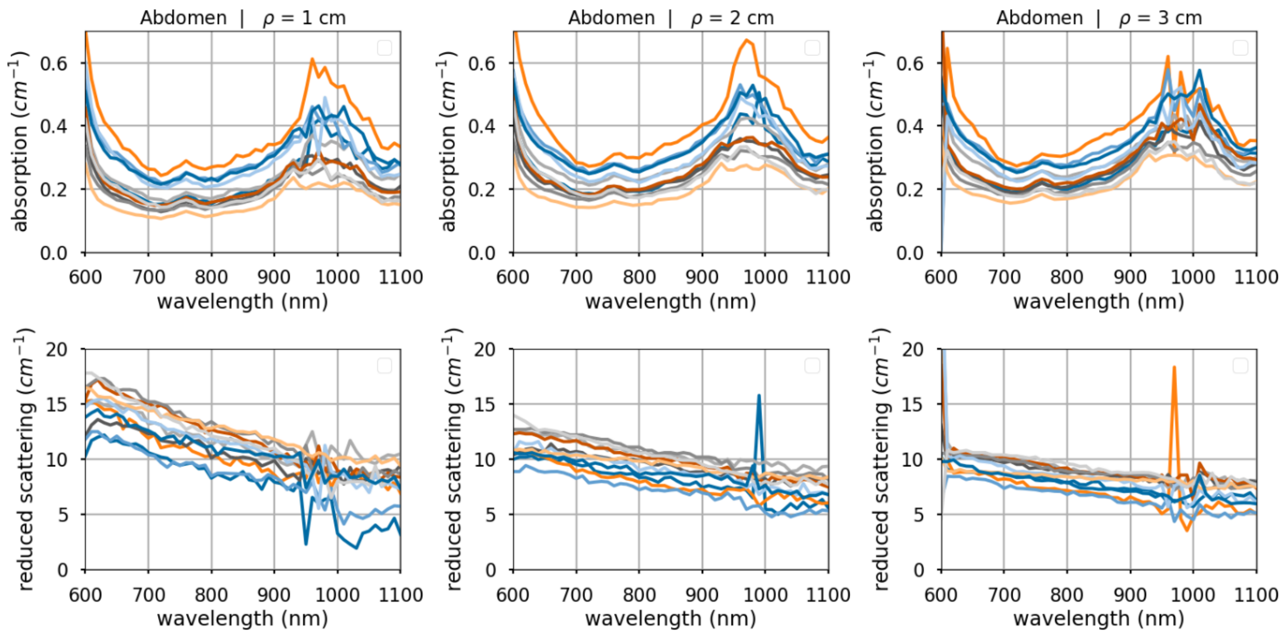

Figure 3 Inter-subject variation in the broadband absorption (top row) and reduced scattering spectra (bottom row) of the thigh muscle of 12 healthy *male* volunteers at three different source-detector distances.

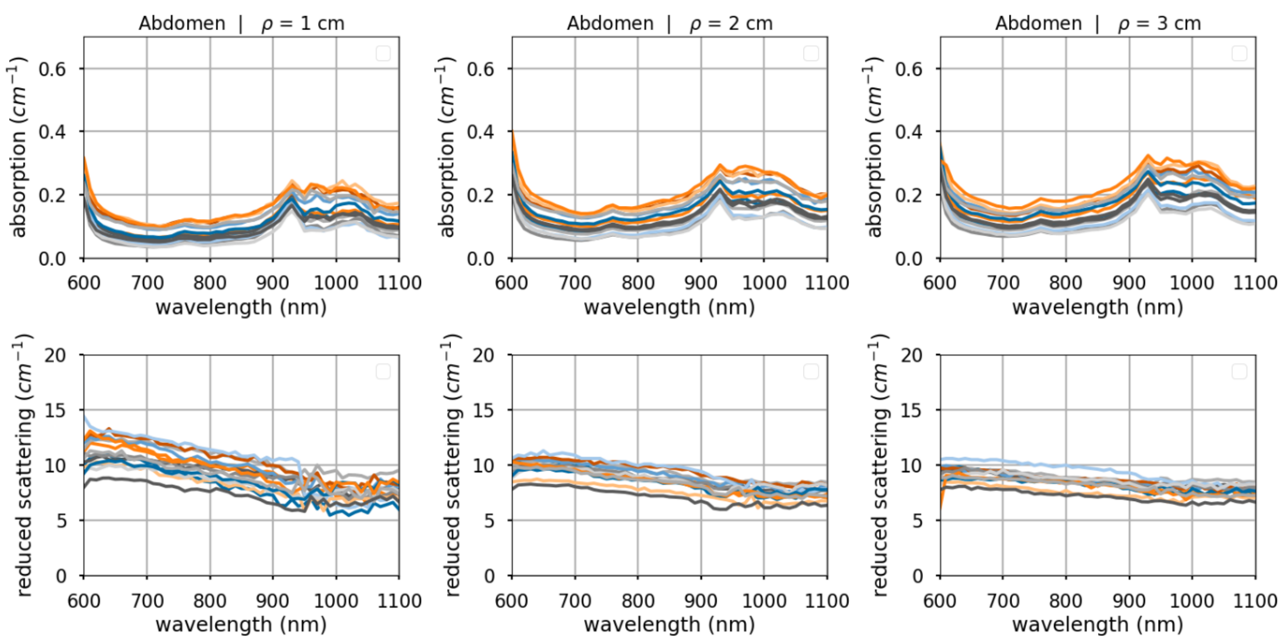

Figure 4 Inter-subject variation in the broadband absorption (top row) and reduced scattering spectra (bottom row) of the thigh muscle of 12 healthy *female* volunteers at three different source-detector distances.

Finally, the distinctive shape of the reduced scattering at ρ = 1 cm (larger slope, higher initial value) is assumed to be a consequence of the influence of the (collagenous) dermal layer on the recovered optical properties at short ρ. Thus, the three layers have a significant influence on the recovered optical property spectra at different ρ in the case of the abdominal region.

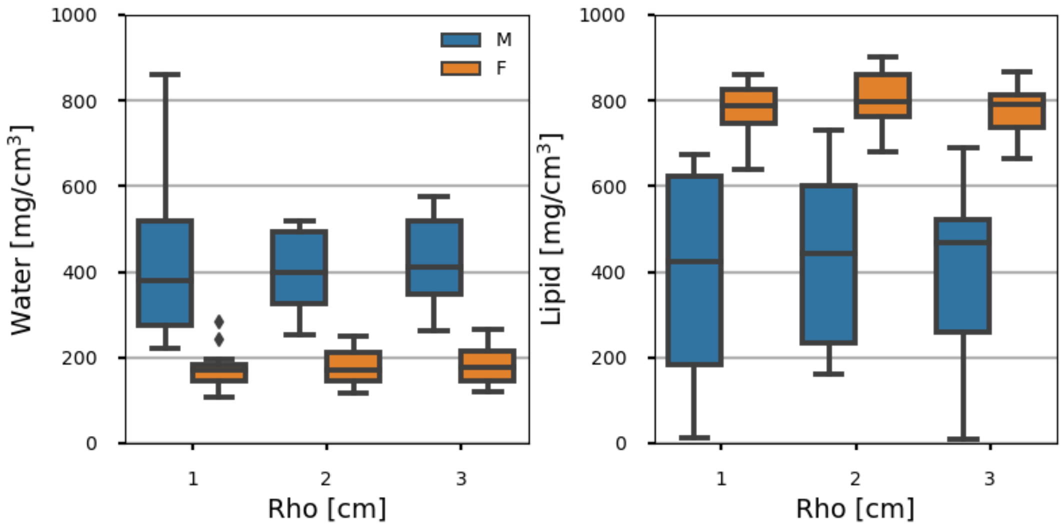

Figure 5 Box plots of the concentrations of the key tissue constituents (water and lipid) in the vastus lateralis region for both the populations at the different source -detector separations.

The results from the measurements on the (vastus lateralis) muscle of male subjects show significantly higher absorption in the red spectral region relative to the abdomen. In the male population, for all the three source-detector distances we observe a strong peak at 980 nm, corresponding to the water absorption, which often dominates lipid absorption at 930 nm. Differently, on average, apart from the contribution of hemoglobin at short wavelengths, the data on the female population resemble the spectrum of lipids, with major absorption at 930 nm and a secondary peak around 1020-1030 nm. This is further consolidated by the fact that the thickness of the fat layer in this region (measured using a sonograph and not presented here) is on an average lower for the male volunteers compared to the female ones. The absorption and reduced scattering spectra for women volunteers at source-detector distances of 2 and 3 cm is almost identical both in amplitude and shape, possibly suggesting that in this case the volume being probed at both these source-detector distances in mainly adipose (subcutaneous fat) and the underlying muscle is not effectively reached.

The concentrations of the tissue constituents like water, lipid and blood chromophores can be recovered by fitting the absorption spectrum to a linear combination of the extinction coeffient spectra[9]. Figure 5 presents the recovered concentrations of water and lipids at the thigh location for both the male and female populatoins at the three source detector distances. The results quantitatively support both arguments presented above namely the homogeneity in the results for the female population at the different inter fiber distances and the acqueos versus lipidic nature of the thigh muscle region of the male and female population respectively.

In conclusion, an *in-vivo* study was performed on healthy volunteers to understand the potential and limitations of using broadband diffuse optical spectroscopy to non-invasively monitor subcutaneous fat layer in the abdomen and skeletal muscle in the thigh. The insights obtained from this study will be used to design both optimized measurement protocol and data analysis methodology for a clinical study aimed at monitoring the physical frailty and muscle atrophy in elderly people.

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