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In vivo Study of the Layered Structure on the Abdomen by Broadband Time-Domain Diffuse Optical Spectroscopy

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Abstract: We investigate the effect of depth heterogeneity in the abdomen by multidistance time-domain diffuse optical spectroscopy on 4 volunteers finding a higher water content in shallower regions, possibly due to fat heterogeneity and/or dermis contributions.
OCIS codes: (170.6935) Tissue characterization; (170.6510) Spectroscopy, tissue diagnostics (170.5280) Photon migration

1. Introduction

Among the key challenges of our society, food- and lifestyle-related morbidities like obesity, diabetes, and metabolic diseases are growing in relevance and impact on life quality and healthcare burden [1,2]. Diffuse Optical Spectroscopy and Imaging has been applied recently to the study of subcutaneous fat tissues, demonstrating increased water and blood content, together with reduced scattering following a 12-week calorie restriction [3].

In this paper, we exploit a Time-domain broadband Diffuse Optical Spectroscopy prototype [4], already validated in clinical studies [5], to investigate the effect of depth-heterogeneity on the non-invasive *in vivo* characterization of subcutaneous fat tissue. This preliminary study performed on 4 healthy volunteers will serve as the basis to understand the layered nature of the abdomen from the spectroscopic perspective, and identify the best experimental and analysis conditions for an upcoming wide clinical study on frailty.

2. Methods

The system is based on a broadband time-domain diffuse optical spectrometer, operated between 600 and 1300 nm. The source is provided by a supercontinuum fiber laser with 6 W overall power, generating few picoseconds pulses at 40 MHz repetition rate. Spectral tunability is achieved by dispersing the source with a Pellin-Broca prism and coupling the selected wavelength into an optical fiber. Wide spectral coverage is accomplished by two different detectors, a Silicon Photomultiplier (SiPM) [6,7] and a Hamamatsu InGaAs PMT. The diffuse time-of-flight photon temporal distributions were analyzed with the solution of the Diffusion equation under the extrapolated boundary conditions for a homogeneous medium.

We conducted a preliminary study on healthy volunteers to investigate the effect of the multi-layered structure of the abdomen on the spectral measurements. Four male volunteers were involved in the study spanning different ages, body mass indexes and thickness of the subcutaneous fat tissue. On each subject, we performed reflectance measurements in 2 positions (4 and 8 cm from the navel) at 3 source-detector distances (ρ = 1, 2, and 3 cm), spanning the 600-1100 nm range in steps of 10 nm. At each wavelength, 4 repetitions of 1 second each were acquired. Informed written consent was obtained from all subjects prior to the study.

3. Results and Discussion

Figure 2 shows the recovered absorption spectra for the 4 subjects for ρ=3 cm (left) showing the effect of the adipose thickness, and for ρ=1 cm (right) showing the effect of age. At the larger ρ, there is a clear contamination from the underlying muscle marked by an increased blood-related absorption for the thinner thickness d=0.3 cm which is progressively reduced for d>2.0 cm. Conversely, for ρ=1 cm there is a clear sign of superficial hydration which decreases upon increasing age. A first obvious explanation could be the contribution arising from the dermis, which is typically highly hydrated, and loses water with age. Yet, its thickness does not exceed few mm, thus it could contribute marginally even at the shortest ρ. Another explanation could be an uneven composition in depth of the adipose tissue itself, possibly richer in water in subcutaneous regions.

These trends are confirmed by a quantitative assessment of the absorption spectra in terms of the key tissue constituents, showing a decrease of total hemoglobin from 48 μM down to 10 μM upon increasing the adipose thickness, and a decrease of water from 500 mg/cm^3 down to 100 mg/cm^3 upon increasing age. Overall, these results are consistent with a simplified 3-layer model of the abdomen, composed of a superficial more hydrated dermis or first adipose layer, the bulk adipose tissue and the underlying muscle tissue.

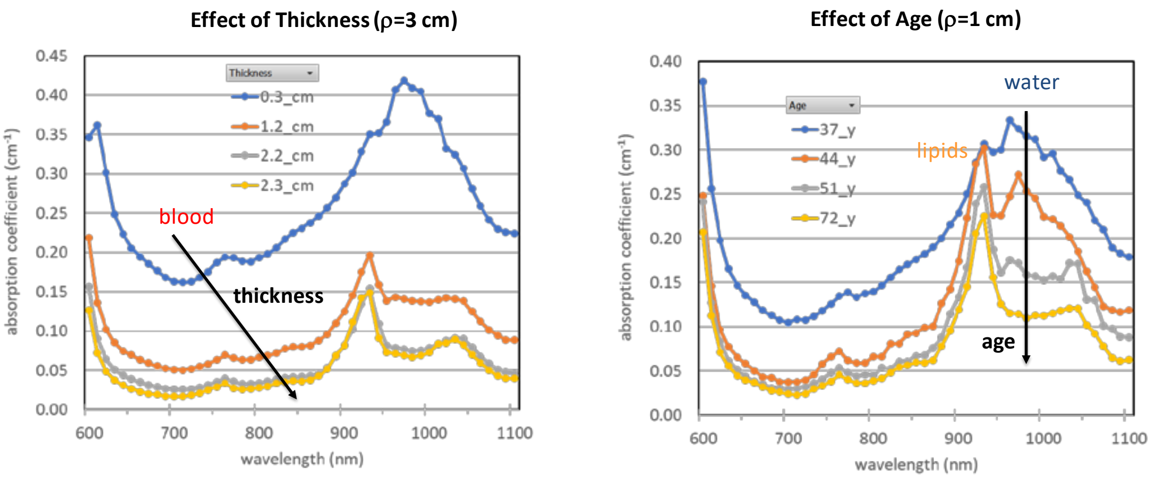

Figure 1. Absorption spectra from the 4 volunteers, showing the effect of adipose layer thickness (left) and age (right).

4. Conclusions

In conclusion, we have studied *in vivo* the depth heterogeneity on the abdomen by time-domain broadband diffuse optical spectroscopy. We have observed an obvious contamination from the muscle tissues whenever the subcutaneous fat layer is <2 cm. More unexpectedly, we observed also a clear sign of superficial hydration – either at the level of the dermis or of the upper fat tissue – which progressively decreases upon increasing age. Further analysis is in progress with multi-layered models to disentangle the contributions of different layers. These observations will be useful to draw the protocol for an upcoming clinical study to monitor the adipose fat organ. As future perspectives, the introduction of new photonics devices opens the way to deployment of compact and wearable health appliances for personal monitoring [9-12].

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