STSM REPORT

STSM Application number: COST-STSM-BM1205-20181

STSM Grantee: Maciej Wróbel

STSM title: "Fabrication and measurements of a novel material for scattering optical tissue phantoms"

Home Institution: Gdańsk University of Technology

Host Institution: University of Oulu

STSM period: 16-22.05.2014

STSM purpose:

Fostering collaboration between biophotonics research groups from Gdańsk and Oulu and the development and characterization of new materials for optical phantoms. Revision and finalization of the manuscripts of scientific papers.

Description of the work carried out during the STSM:

The STSM was focused on three main points: Fostering future collaboration on shared scientific goals carried out in parts in both the Home and Host institution; revision and correction of a manuscripts which are the results of our ongoing collaboration; fabrication of scattering tissue-mimicking phantoms and spectroscopic and OCT characterization of their optical properties (scattering and absorption coefficients, anisotropy factor).

Extensive research in the area of optical sensing for medical diagnostics requires development of tissue phantoms with optical properties similar to those of living human tissues. Development and improvement of in vivo optical measurement systems requires the use of tissue phantoms with known characteristics, which are mainly used for calibration of such systems and testing their performance. Nevertheless, they must accurately simulate specific tissues they are supposed to mimic. Most tissues possess a multi-layered structure, with specific optical properties of each layer. Likewise, the tissue phantoms must reflect such structure with variable parameters of the corresponding layers.

Research carried out during STSM consisted of the development of a multi-layered phantoms with optical properties (scattering coefficient μ_s, absorption coefficient μ_a, and scattering anisotropy factor g) corresponding to the human head model layers, that is: skin, skull, gray and white matter of the brain tissue. The phantom is intended for use in noninvasive diffusive near-infrared spectroscopy (NIRS) of human brain. Optical parameters

of the fabricated phantoms are reconstructed using spectrophotometry and inverse adding-doubling calculation method. This research is the extension of previous studies but now focused on material research for more accurate modeling and fabrication of said scattering phantoms.

Description of the main results obtained:

With diffuse NIRS of the brain as the intended purpose of the phantom, only the knowledge of the absorption coefficient μ_a, and the reduced scattering coefficient μ_s' is required for the diffuse regime of light propagation, where μ_s' has the physical sense of a reciprocal of the mean free path of the phantom travel through the scattering media. The following equation is used to calculate μ_s':

$$\mu_s' = \mu_s(1 - g),$$

where μ_s is a scattering coefficient, g is a scattering anisotropy factor. In order to mimic the reduced scattering coefficient of tissues, phantoms were made with PVCP as a matrix material and ZnO nanoparticles as a scattering agents. Thus, theoretical calculations of the required concentrations of ZnO nanoparticles on grounds of Mie theory of scattering were employed. Then, the series of 0.5-mm-thick tissue-mimicking phantoms for skin, skull, gray and white matter, with these calculated ZnO concentrations were manufactured. Their optical properties as compared with the theoretical predictions and the values of real tissues from literature data are shown on the Figure 1.

In order to know the optical properties of phantoms, the values of total reflectance, total transmittance, collimated transmittance, refractive index, and sample thickness were measured. Total reflectance, total transmittance and collimated transmittance were measured using OL-750 spectrophotometer system (Optronic Laboratories, USA) with Si high-sensitivity detector module OL 750-HSD-300 (wavelength 0.25-1.1 μm) and integrating spheres. The refractive index was measured using a DR-M2/1550(A) multi-wavelength Abbe refractometer (Atago, Japan). Spectral-domain Optical Coherence Tomography system Hyperion (Thorlabs, USA) was used to confirm refractive index measurements at 930-nm wavelength. Thickness of the phantoms was also measured using OCT (resolution in air: 5.8 μm). The optical properties of phantoms (μ_a, μ_s, μ_s' and g) were then reconstructed using inverse adding-doubling algorithms.

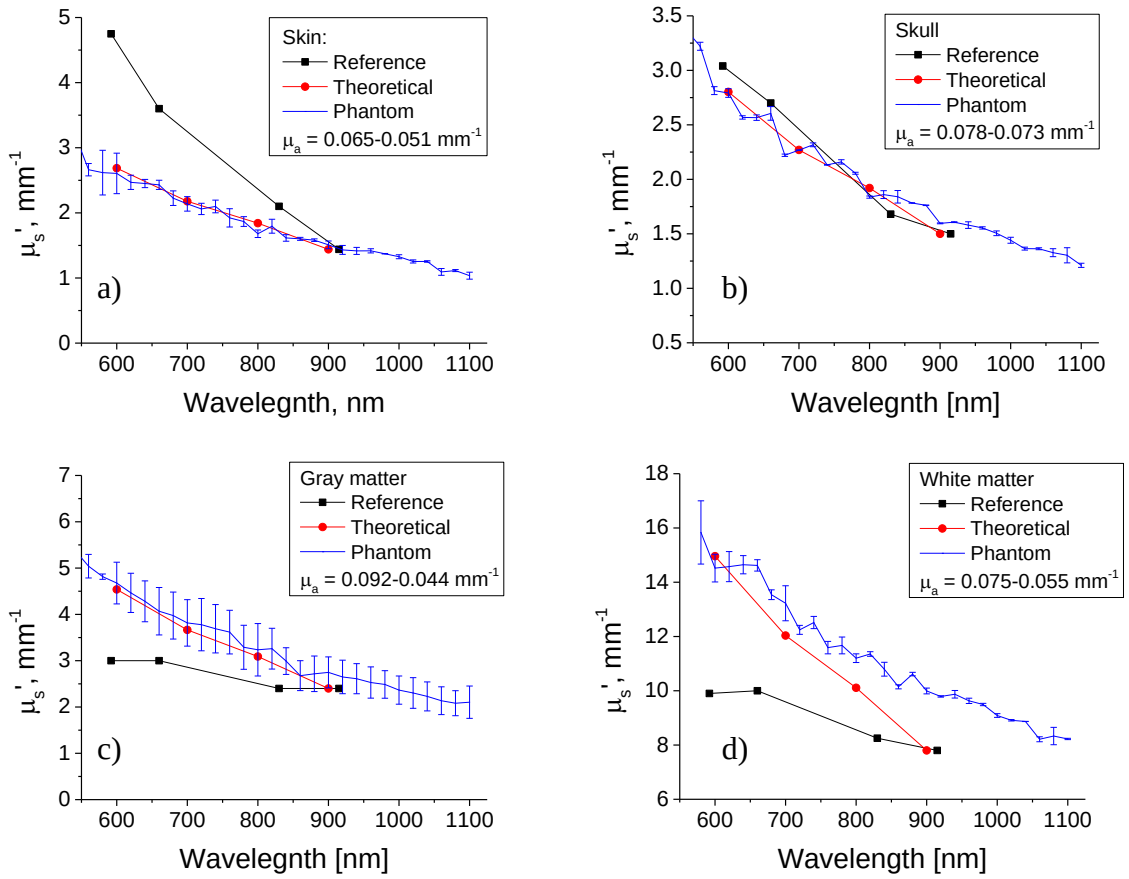

Figure 1. Reduced scattering coefficients of tissues from reference, linear extrapolation based on the single-scattering phantom, and results of measurements of fabricated phantoms, simulating skin (a), skull (b), gray matter (c) and white matter (d). Measured μ_s' for phantoms matches the theoretical values.

This STSM helped to gain more knowledge and know-how of accurate mimicking of optical properties through modeling and creation of the phantoms, along with improvement in the technological fabrication process.

Mutual benefits for the Home and Host institutions:

This STSM mission allowed for the completion of a step in the ongoing research collaboration between the biomedical optics groups from Department of Metrology and Optoelectronics, Gdańsk University of Technology and Laboratory of Optoelectronics and Measurement Techniques, University of Oulu on tissue-mimicking phantoms for noninvasive optical diagnostics. In Oulu the phantom research is focused on noninvasive NIRS measurements of brain, while in Gdańsk the phantoms are intended for noninvasive optical blood and skin composition detection methods.

Future collaboration with the Host institution (if applicable):

Future collaboration will continue between Host and Home institution in this research area as both parties agreed on the continuation of said research. Future endeavors will be carried out in the direction outlined during this mission, which include: refining the fabrication procedure of presented PVCP-ZnO phantoms and development of new materials for this purpose which closely match optical parameters of the tissues, mainly the g parameter, and development of phantoms with capillaries for blood flow.

Foreseen journal publications or conference presentation expected to result from the STSM:

This STSM will yield two journal publications, which are currently under the review process:

1. M.S. Wróbel, A.P. Popov, A.V. Bykov, M. Kinnunen, M. Jędrzejewska-Szczerska, V.V. Tuchin *"Multi-layered tissue head phantoms for noninvasive optical diagnostics"*, Journal of Innovative Optical Health Sciences.
2. M.S. Wróbel, A.P. Popov, A.V. Bykov, M. Kinnunen, M. Jędrzejewska-Szczerska, V.V. Tuchin *"Measurements of fundamental properties of human skin phantoms"*, Measurement.

Confirmation

We would like to confirm the successful completion of the STSM titled *"Fabrication and measurements of a novel material for scattering optical tissue phantoms"* carried out by Maciej Wróbel within the Optoelectronics and Measurement Techniques Laboratory at the University of Oulu from 16.05.2014 to 22.05.2014. His actions are in agreement with the contents of this report, and have yielded the finalization of research in the form of journal publications.

.....

Alexey Popov, D.Sc.(Tech.)
Host

Matti Kinnunen, D.Sc.(Tech.)
Head of the Optoelectronics and Measurement Techniques Laboratory,
University of Oulu