STSM REPORT

STSM Application number: COST-STSM-BM1205-010416-068539

STSM Grantee: Inga Saknite

STSM title: Near-infrared hyperspectral imaging of skin for determination of skin moisture

Home Institution: University of Latvia, Riga, Latvia

Host Institution: Norwegian University of Science and Technology, Trondheim, Norway

STSM period: 01/04/2016 – 30/04/2016

STSM purpose: The objective of this short term scientific mission was to obtain new experimental results of changes in skin moisture after application of moisturizing creams on skin *in vivo* by near-infrared hyperspectral imaging in an extended spectral range of 900-2500 nm.

Description of the work carried out during the STSM: One of the main reasons and achievements of this STSM is the development of a closer collaboration between our group at Biophotonics Laboratory, University of Latvia, and the group at Norwegian University of Science and Technology, lead by professor Randeberg, as both our groups work on spectroscopy and hyperspectral imaging of skin in the visible and near-infrared spectral ranges for different applications in skin diagnostics. During this visit, new experimental results of skin moisture changes over time after application of different moisturizing creams by near-infrared hyperspectral imaging (900-2500 nm) were acquired and analyzed. In addition, new model for estimation of skin hydration was developed and tested by experimental data. Monte Carlo simulations were performed to test the developed model and to better understand the effect of different optical properties on reflectance spectrum of skin.

Description of the main results obtained:

Near-infrared (NIR) spectroscopy has a potential for noninvasive determination of skin moisture level due to high water absorption [1]. However, there is still no golden standard technique for estimation of skin hydration by optical methods. Currently there are commercially available devices based on electrical properties of skin (mostly, conductance, capacitance) that are widely used by dermatologists and cosmetic industry for estimation of skin hydration but they are not considered to be the most reliable. Near-infrared light penetrates deeper in tissue than visible light. In the spectral range of 900 nm to 1700 nm, light penetrates up to 1 mm deep into the skin [2]. Thus, the diffuse reflected light brings information from different layers of skin. The penetration depth is dependent on water concentration in skin. Previously, our group at Biophotonics Laboratory, University of Latvia, has worked on near-infrared spectroscopy and imaging in the spectral range of 900-1700 nm. However, there is an even higher absorption of water in longer wavelengths up to 2500 nm, thus I wanted to acquire and analyze data in the extended near-infrared spectral range of 900-2500 nm. It was possible to do that at professor

Randeberg's laboratory at Norwegian University of Science and Technology. In addition, it was possible to acquire hyperspectral images of approximately 5x10 cm of skin with spectral resolution ~ 6 nm by hyperspectral imaging camera developed by *Norsk Elektro Optikk*. Although this visit mainly focused on research of changes in skin moisture after application of different moisturizing creams, water content of skin (skin hydration) could also be important for other diagnostic applications. During this visit, already existing experimental data of skin burns were also analyzed to monitor how skin hydration changes over time in burns with different severity.

During this visit, improvements in methodology for estimation of water content in skin were done. In the spectral range of 900-1700 nm, there are three water absorption maxima: 980 nm, 1200 nm and 1450 nm. In this study, the 980 nm maximum was not used because of the noisy signal at around 900 nm. For 1200 nm and 1450 nm maxima, baseline correction was done to afterwards calculate the volume area under the baseline-corrected maximum of water absorption (Fig. 1) [3]. Results of both maxima were later calculated and analyzed for comparison. Compared to 1450 nm, the 1200 nm maximum is more sensitive to absorption of lipids, as the lipid absorption at around 1200 nm is almost as high as that of water.

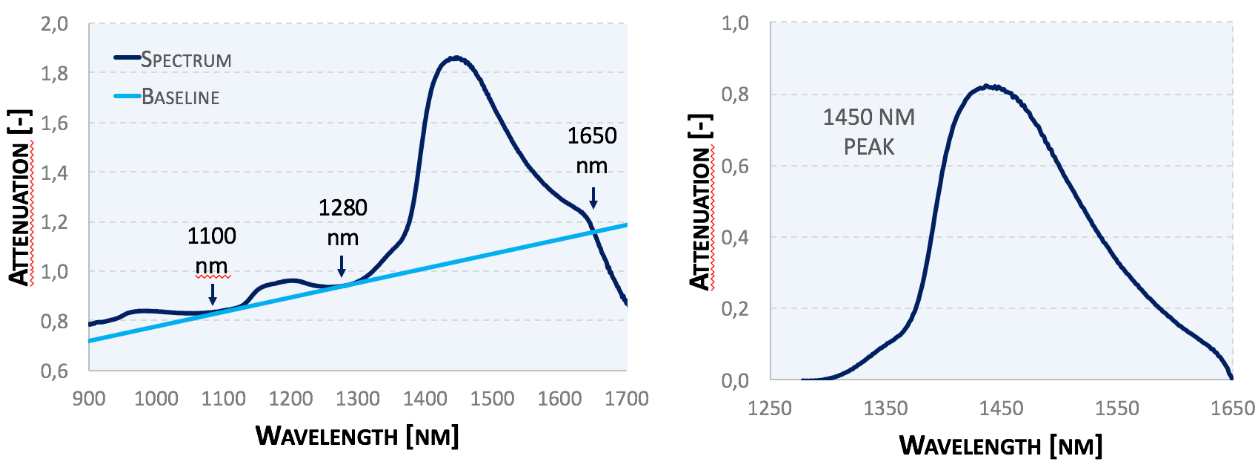

Fig. 1 Baseline correction of two water absorption maxima (to the left) and baseline corrected 1450 nm water absorption maximum (to the right).

In order to test the baseline correction method and better understand how different optical properties and different skin models affect the reflectance spectrum, Monte Carlo simulations were performed [4]. An example of how reflectance spectrum changes due to different water volume fraction in dermis is shown in Fig. 2. For this example, a 2-layer skin model was used: epidermis of thickness 0,1 mm and a constant water volume fraction of 7,5%, dermis of thickness 0,5 mm and water volume fraction changing from 10% to 100%. In the simulations, 1 million photons were launched, and Mie and Rayleigh scattering was included. When analyzing the simulation results, we can clearly see that for this chosen skin model volume area of 1200 nm water absorption maximum increases with an almost linear function to water volume fraction; however, it is not the case for the 1450 nm water absorption maximum – if the fraction of water in dermis is more than 30%, volume area remains almost constant with an increased water volume fraction (Fig. 3). Even though this is only one example of a particular skin model that was chosen similar to human skin properties, other examples showed similar results, and the main conclusion is that the 1450 nm water absorption maximum can be unreliable for estimation of skin hydration as it can get “oversaturated” when there is a high percentage of water in skin.

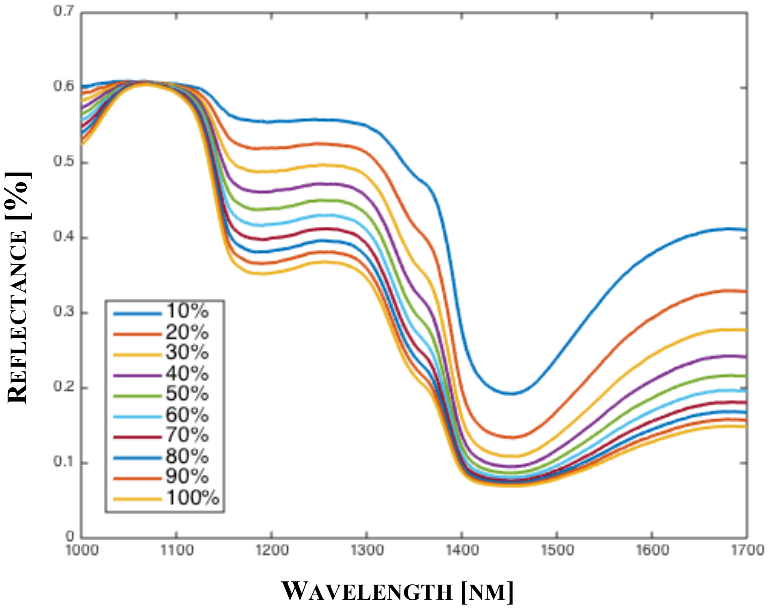

Fig. 2 Monte Carlo simulation results of how reflectance spectrum changes due to water volume fraction in dermis for a 2-layer skin model.

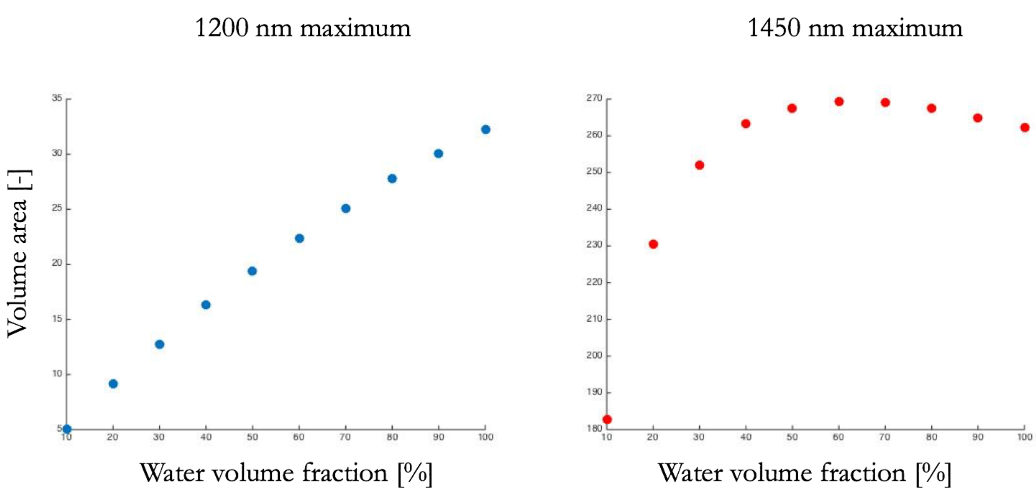

Fig. 3 Calculated volume area dependence on water volume fraction in dermis for 1200 nm and 1450 nm water absorption maxima.

New experimental results were obtained during this visit by using a push-broom hyperspectral imaging camera (*Norsk Elektro Optikk*) in the wavelength range of 900-2500 nm, spectral resolution ~ 6 nm, a halogen lamp as a light source and linear polarizers in front of the light source and in the camera to eliminate the specular reflectance. White reference tile was used to estimate reflectance values. *Matlab* software was afterwards used to analyze the hyperspectral image cubes.

Hyperspectral images of 4 different creams in a Petri plate were acquired over time for 4 hours. Reflectance values were transformed to normalized attenuation ($A = log\frac{1}{R}$). The 4 different creams were with a known lipid content except for one that was supposed to have very little amount of lipids, not specified of the actual percentage (Fig. 4).

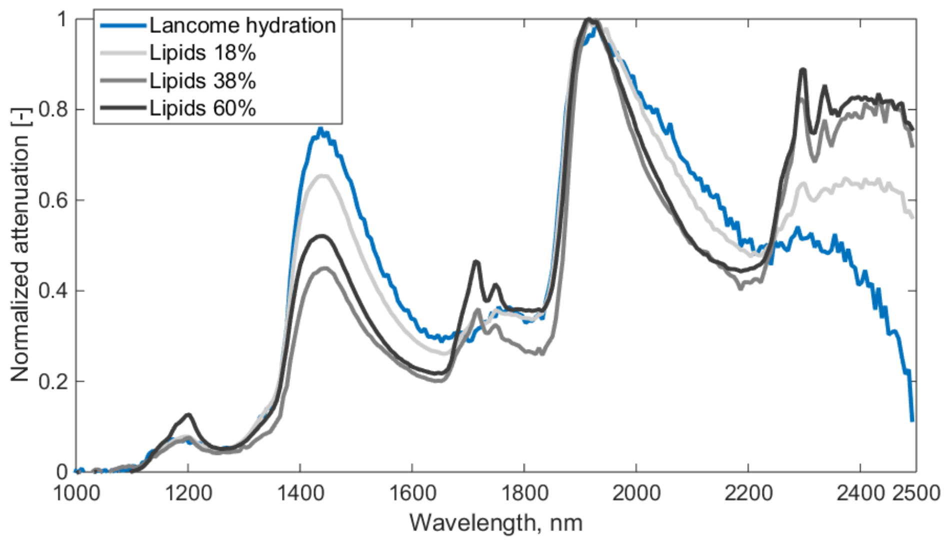

Fig. 4 Normalized attenuation spectra of creams with different lipid content.

An example of how attenuation spectrum of the cream with lipid content 60% changed over time is shown in Fig. 5. We can observe that the ratio of water absorption peaks (1450 nm and 1900 nm) and lipid absorption peaks (1200 nm, 1750 nm) is changing over time. That could mean that the cream put in a Petri plate outside of a concealed tube is losing its water content, or maybe there is some other effect that we see here.

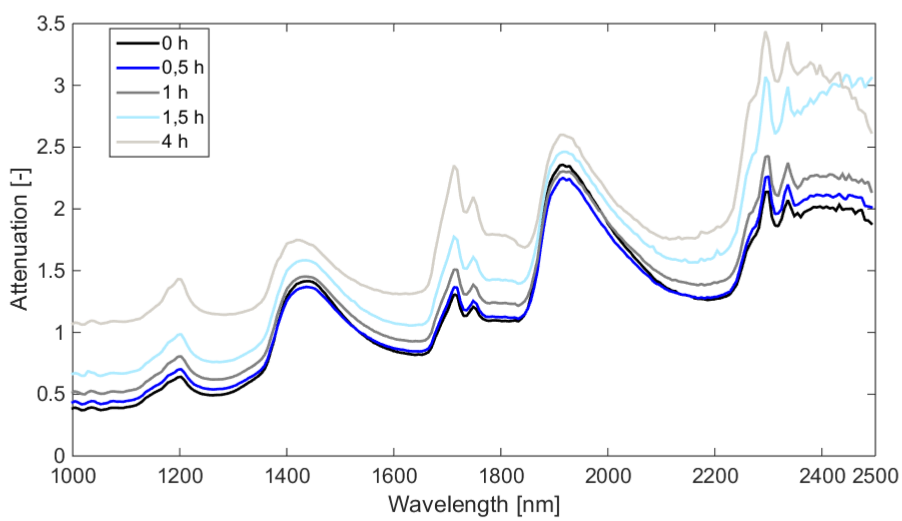

Fig. 5 Attenuation spectra of cream with lipid content 60% at different times after putting a layer of it on a Petri plate.

Results of how attenuation spectrum changes over time when all four creams are put on the skin of a hand (each cream at a different spot) were also acquired. An example of the results are shown in Fig. 6.

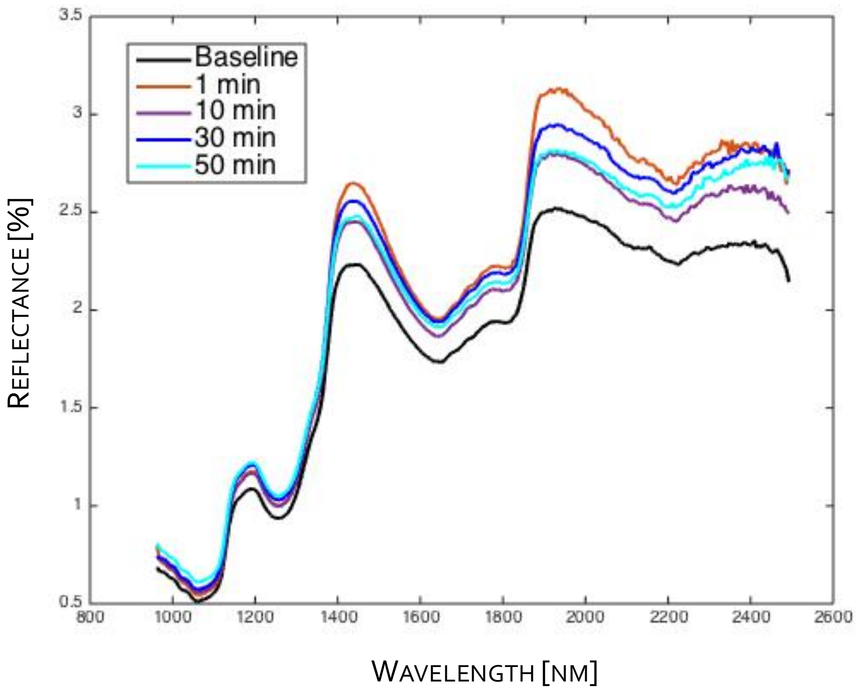

Fig. 6 Attenuation spectra of the cream with lipid content 60% put on forearm skin over time after application on skin surface.

References

[1] L. Rigal Bazin, Sturelle, Descamps, Leveque and L. Rigal Bazin, Sturelle, Descamps, Leveque, "Near infrared spectroscopy: a new approach to the characterisation of dry skin," *Ifscc*, vol. 209, no. August, pp. 197–209, 1993.

[2] a N. Bashkatov, E. a Genina, V. I. Kochubey, and V. V Tuchin, "Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000 nm," *J. Phys. D. Appl. Phys.*, vol. 38, no. 15, pp. 2543–2555, 2005.

[3] M. G. Sowa, J. R. Payette, and H. H. Mantsch, "Near-infrared spectroscopic assessment of tissue hydration following surgery," *J Surg Res*, vol. 86, no. 1, pp. 62–69, 1999.

[4] L. Wang and S. L. Jacques, "Monte Carlo Modeling of Light Transport in Multi-layered Tissues in Standard C Monte Carlo Modeling of Light Transport in Multi-layered Tissues in Standard C," University of Texas M. D. Anderson Cancer Center, 1998.

Mutual benefits for the Home and Host institutions: This visit resulted in very interesting new experimental results, new simulation results and learning of a new method for estimation of skin hydration. This visit was also full of interesting and useful discussions for everyone involved. This visit resulted in more results than previously planned.

Future collaboration with the Host institution (if applicable): We are already continuing our collaboration regarding the analysis of the experimental results by discussing them via e-mail correspondence, and will continue to do so as there are still some interesting issues we would like to understand. This visit also resulted in a better understanding of what the Home and the Host institutions do and how we could collaborate with each other in the future. It would be very interesting for me to visit this group some time in the future again, maybe for a bit longer period, to do a broad experimental study on skin hydration and how it changes by using different moisturizing creams, maybe even involving patients, and this kind of study and its results would benefit both groups, as well as the scientific community.

Foreseen journal publications or conference presentations expected to result from the STSM (if applicable):

This visit might result in two papers. We are planning to write and submit one paper on how skin hydration changes over time in burns with different severity. An idea for another paper came up during this visit, and this potential paper could thoroughly describe the methodology for analyzing skin hydration by reflectance spectroscopy or imaging of skin, also involving Monte Carlo simulations to model the interaction of near-infrared radiation and skin tissue.

STSM outcome form

STSM application number	Home institution & country	Host institution & country	BM1205 WG	Objective of the collaboration	Results of the collaboration
COST-STSM-BM1205-010416-068539	University of Latvia, Riga, Latvia	Norwegian University of Science and Technology, Trondheim, Norway	WG4	Near-infrared hyperspectral imaging of skin for determination of skin moisture	New model for estimation of skin hydration was developed and tested by experimental data, as well as by Monte Carlo simulations. New experimental results of skin moisture changes over time after application of different moisturizing creams by near-infrared hyperspectral imaging (900-2500 nm) were acquired and analyzed.

I acknowledge that the described short-term scientific mission (STSM) was successfully carried out in the conditions here specified. Prospects of potential further collaborations on topics related to estimation of skin hydration by near-infrared spectral range are expected in the coming months.

NTNU
Norwegian University of Science and Technology

Lise Lyngsnes Randeberg

Professor Lise Lyngsnes Randeberg
Norwegian University of Science and Technology
Trondheim, Norway
E-mail: lise.randeberg@ntnu.no