Near-Infrared Reflectance Spectroscopy System for Noninvasive Estimation of Skin Hydration

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Abstract

In this study, a near-infrared reflectance spectroscopy method was developed for estimation of skin hydration. A clinical study was performed to compare skin moisture measurements of a total of 40 healthy volunteers by using two different methods: the developed near-infrared reflectance spectroscopy method and a commercially available skin hydration measurement device *DermaLab* by *Cortex Technology*. Skin moisture was measured at 3 spots on face and 9 spots on volar aspect of both arms for each of the volunteers. A comparison between results by optical and conductance based measurement systems is presented.

Skin moisture

Skin is the human body's largest organ that has many important functions to protect the body. One of them is the prevention of water loss. Skin consists of two main structural layers: epidermis and dermis. **Epidermis** consists of 5 sublayers (Figure 1), the outer of which, stratum corneum (SC), is the main barrier that **protects the body from dehydration**, as well as from other molecules (e.g. irritants) entering into the skin [1,2].

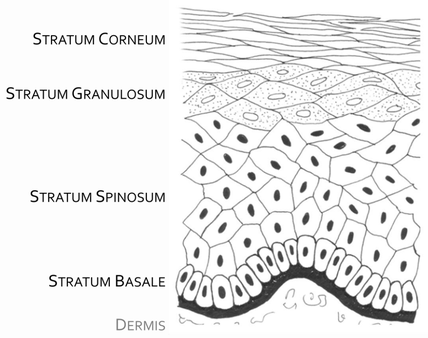


Fig.1 The five layers of epidermis [1]

Skin has its own **natural moisturizing mechanism** that keeps it moist. At the SG, keratinocytes are transformed into corneocytes that are the building blocks of SC. In this process, natural **body lipids** are released, and they are the main barrier that protects water passing out through the SC. On most body sites, SC consists of 12 to 16 cell layers, but it can vary from 9 cell layers at eyelids to more than 50 cell layers at soles [2]. There are three main processes **how skin moisturizers work** in order to help skin when its natural barrier has been irritated: attract water from dermis and bound it in the SC (glycerin), provide a physical barrier to reduce water loss (zinc oxide), provide occlusivity and smooth flaky skin cells (petrolatum) [3,4].

Experimental setup

Experimental setup consisted of a near-infrared spectrometer (Ocean Optics, *NirQuest 512*) in the spectral range of 900 nm – 1700 nm, Y-type water free (WF) optical fiber probe, and a tungsten-halogen light source *Thorlabs SLS201/M* with illumination spectrum between 300 and 2600 nm . Optical fiber probe consisted of 6 illumination fibers in a circle around 1 detection fiber in the middle. During measurements, room temperature was kept at temperature of 23°C.

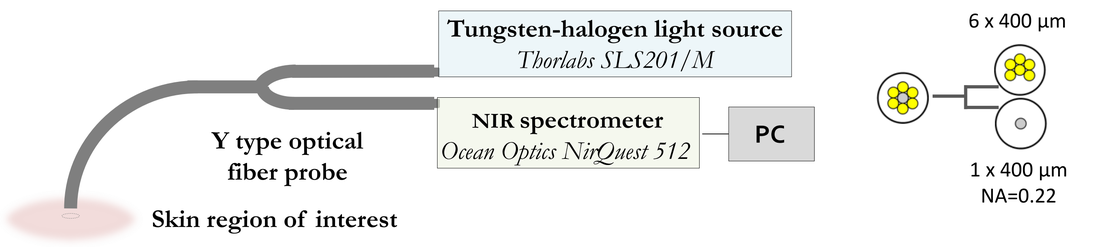
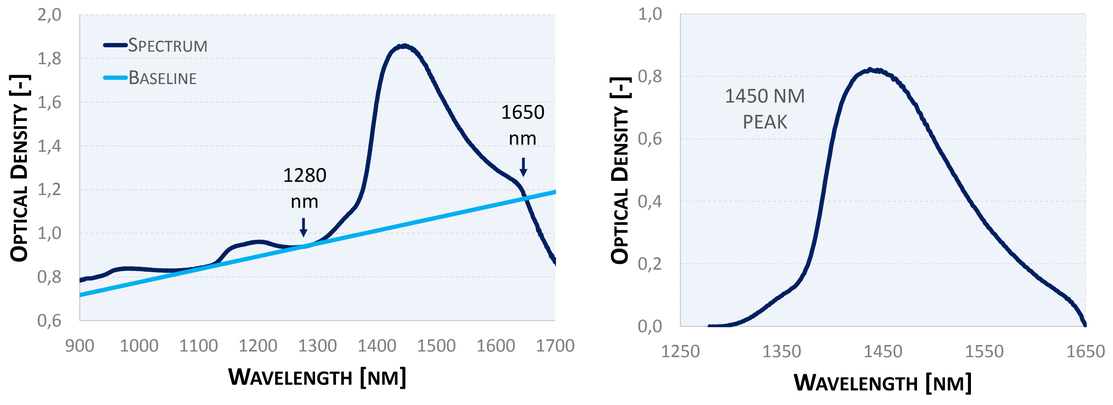


Fig.3 Experimental setup

Data analysis



$$OD(\lambda) = \log\frac{I_0(\lambda) - I_{dark}}{I(\lambda) - I_{dark}}$$ → **Baseline correction** for 1450 nm peak → Calculation of the **Volume Area** under the baseline-corrected peak

References

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NIR reflectance spectroscopy

Near-infrared (NIR) spectroscopy has a potential for noninvasive determination of skin moisture level due to high water absorption. Near-infrared reflectance spectroscopy can be used for estimation of skin hydration (water content in skin) due to high water absorption in this spectral range [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 [5]. Thus, the diffuse reflected light brings information from different layers of skin. The penetration depth is dependent on water concentration in skin.

Water absorption spectrum

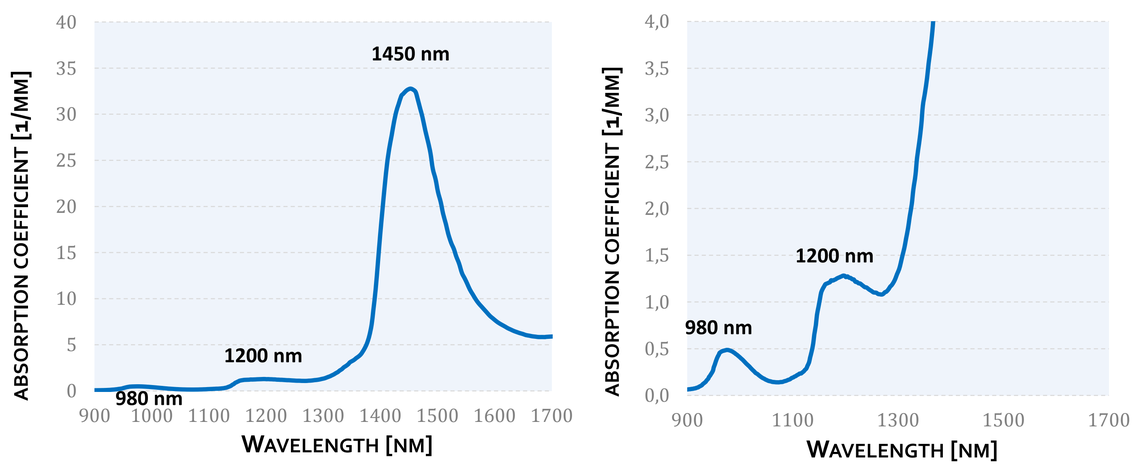
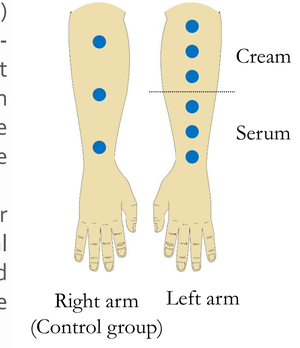


Fig.2 Absorption spectrum of water [6]

Clinical study

The goal of this study was to test short-term (30 minutes) and long-term (1 month) effect of a moisturizing cream X and serum Y on skin moisture level. For the long-term study, participants were using the moisturizing cream X on the proximal part of volar aspect of the left arm (closer to the elbow), and the moisturizing serum Y on the dorsal part of volar aspect of the left arm (closer to the palm) every day for one month. On the contrary, they were asked not to use any cream or serum on the volar aspect of the right arm for the whole month.

Measurements were performed by two different devices – the developed device for estimation of skin moisture level by near-infrared spectroscopy, and a commercial device *DermaLab* (by Cortex Technology) which estimates skin moisture level based on changes in skin conductance (with increased water volume fraction in skin, there is an increase in electrical conductance of skin).



Results

In total, results were divided in 5 groups for each device (10 groups in total), where each group consisted of skin moisture values for all 38 volunteers:

- Right arm (control) group in the beginning;
- Right arm (control) group 30 min / 1 month later;
- Left arm group in the beginning;
- Left arm cream group 30 min / 1 month later;
- Left arm serum group 30 min / 1 month later.

The following values were obtained for analysis of the results:

- The increase in skin moisture 30 min / 1 month later compared to the beginning of the measurement (in percent): $\boldsymbol{\Delta V}$;
- Standard error: $\boldsymbol{SE}$

30 minutes after

	NIR device	*Two-sample TTest*	*DermaLab*	*Two-sample TTest*
Control group	$\boldsymbol{\Delta V = +1,4\%}$ $SE = 0{,}7\%$	**NO** statistically significant difference	$\boldsymbol{\Delta V = -5\%}$ $SE = 1\%$	Statistically significant difference
Cream group	$\boldsymbol{\Delta V = +4,5\%}$ $SE = 0{,}6\%$	Statistically significant difference	$\boldsymbol{\Delta V = +7\%}$ $SE = 1\%$	Statistically significant difference
Serum group	$\boldsymbol{\Delta V = +3,4\%}$ $SE = 1{,}1\%$	Statistically significant difference	$\boldsymbol{\Delta V = +18\%}$ $SE = 3\%$	Statistically significant difference

1 month after

	NIR device	*Two-sample TTest*	*DermaLab*	*Two-sample TTest*
Control group	$\boldsymbol{\Delta V = +2,3\%}$ $SE = 0{,}6\%$	Statistically significant difference	$\boldsymbol{\Delta V = +32\%}$ $SE = 5\%$	Statistically significant difference
Cream group	$\boldsymbol{\Delta V = +1,9\%}$ $SE = 0{,}7\%$	Statistically significant difference	$\boldsymbol{\Delta V = +78\%}$ $SE = 13\%$	Statistically significant difference
Serum group	$\boldsymbol{\Delta V = +2,4\%}$ $SE = 1{,}0\%$	Statistically significant difference	$\boldsymbol{\Delta V = +49\%}$ $SE = 8\%$	Statistically significant difference

Conclusions

In conclusion, we can observe that *DermaLab* is more sensitive to small changes in skin moisture than the developed near-infrared spectroscopy device, and it is possible to evaluate the effect of cream and serum on skin moisture level 1 month after using them. However, by using *DermaLab* we also got results that we did not really expect – for the long-term study, there was a statistically significant improvement also for the control (right arm) group. Maybe it is due to the fact that some volunteers actually used moisturizing creams or lotions on the right arm even though they were asked not to, or maybe there were other factors affecting those results, for example, the outside temperature, physiological aspects etc.

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