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Infrared Spectroscopic measurement of skin hydration and sebum levels and comparison to Corneometer and Sebumeter

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ABSTRACT

Skin health characterized by a system of water and lipids in Stratum Corneum provide protection from harmful external elements and prevent trans-epidermal water loss. Skin hydration (moisture) and sebum (skin surface lipids) are considered to be important factors in skin health; a right balance between these components is an indication of skin health and plays a central role in protecting and preserving skin integrity. In this manuscript we present an infrared spectroscopic method for simultaneous and quantitative measurement of skin hydration and sebum levels utilizing differential detection with three wavelengths 1720, 1750, and 1770 nm, corresponding to the lipid vibrational bands that lie "in between" the prominent water absorption bands. The skin sebum and hydration values on the forehead under natural conditions and its variations to external stimuli were measured using our experimental set-up. The experimental results obtained with the optical set-up show good correlation with the results obtained with the commercially available instruments Corneometer and Sebumeter.

Keywords: Sebum, Sebum-water emulsion, Skin hydration, skin barrier function, Skin oiliness, Infrared spectroscopy, Optical diagnosis

1. INTRODUCTION

Skin hydration (moisture) and sebum (skin surface lipids) are considered to be important factors in skin health; a right balance between these components is an indication of healthy skin and plays a central role in protecting and preserving skin health [1]. Optimal balance between sebum and hydration levels provides the skin with a radiant, smooth texture and a natural pigmentation appearance, which is important from a cosmetic perspective. Hydration and sebum retaining ability of the skin is primarily related to the stratum corneum (SC). The SC plays the role of the barrier to water loss and is composed of the corneocytes and an intercellular lipid bilayer matrix. The efficacy of the barrier function is correlated with the biophysical parameters such as skin moisture and sebum content. The reduction in the efficiency of the barrier and moisture-maintaining functions of the skin result in easily dried, roughened skin which can be potentially more vulnerable to risk of infection. Good moisturizing creams have an optimal blend of the right barrier building, TEWL reducing lipids combined with a good humectant delivery system. Sufficiently hydrated epithelium remains flexible, lake of hydrations lids to brittle skin [2]. Viable bacteria that reach the cutaneous surface colonize it more readily, and fungi invade in more easily. Molecules move more readily through a hydrated SC [3]. Studies show that superficial lipids play an important role in the barrier function, creating a filter for interaction with the external environment. The SC is a multilayered tissue composed of corneocytes, surrounded by multiple planar lamellae sheets, enriched in ceramides, cholesterol, and free fatty acids (FFA). Double layers of such lipids in the liquid crystalline state will allow water to pass through the membrane more or less freely [4] and a cell membrane is therefore not a barrier to water. On the other hand, bilayers in the close packed crystalline (gel) state will effectively prevent the penetration of water molecules [5, 6]. The majority of the SC lipids will form crystal-(gel-) structures, hence provide a water tight enclosure. A random diffusion path in the inter-bilayer water sheath will occupy a comparatively long time compared to the vertical passage through a

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liquid crystalline area to reach the water sheath separating the past bilayer from the next one. It was estimated that if just a few percent of the inter-domain areas are transformed, e.g. by a penetration enhancer to form a vertical channel, the over-all effect on penetration may increase one or more orders of magnitude [7, 8]. Skin conditions such atopic dermatitis shows drop in skin hydration level reflecting in a drop of water holding capacity of the skin, increased transepidermal water loss (TEWL) and defective barrier function [9-11]. This disrupted balance can also be found in individuals suffering from psoriasis, eczema and ichthyosis vulgaris [12, 13]. This similarity in symptoms leads to complications with diagnostics, which often requires a biopsy, an invasive approach [14]. Nevertheless, these mentioned disorders show peculiar skin conditions with respect to the balance between hydration and oiliness. For example psoriasis shows dramatic decrease of hydration (~70%) and oiliness (~40-70%) levels [15], while eczema leads to minor water loss (few percent') combined with noticeable oiliness drop (~25%) [16, 17].

Lipid phase behavior in the stratum corneum is considered to be crucial for the skin barrier function [18]. Skin superficial lipids have been found to serve as water modulator in the stratum corneum [19]. Sebum keeps skin smooth and flexible by sealing and preserving moisture in the corneal layer and preventing evaporation and bacterial infections. The sebum excretion rate (SER) reflects the amount of sebum production and is closely related to the physiological activities of the sebaceous glands. This is important information in the pathogenesis of sebaceous glands disorders and pimple and acne. Excessive sebum production can cause clogged pores possibly resulting in blemishes. Sufficient amount of skin hydration and sebum makes the skin appear smooth, soft and supple whereas lack of moisture can cause the skin to look dull and cracked, appearing older. Thus, the water-sebum system determines the condition of the skin and can be used as an indicator of skin health.

For both medical and cosmetic purposes several independent biophysical methods and devices have been developed for monitoring and influencing the amount of sebum and water on the human skin. The commercially available moisture measuring instruments use capacitance or conductance methods. They however have several disadvantages such as sensitivity to environmental changes, the measurements are influenced by the amount of electrolytes, contact area, applied pressure. Moreover these devices use rigid probes which must be in contact with the skin [20-21]. Presently available sebum measuring devices based on grease-spot photometry and gravimetric analysis are tedious and time-consuming [22-24]. Moreover, they are not suitable for monitoring changes in the skin oiliness level over time and for visualizing the spatial distribution and heterogeneity of the skin superficial lipids level over the whole face. Different devices express the measured values in arbitrary units and until now there are no calibration standards reported to compare and correlate measurement values obtained with different devices used for measuring the same skin parameter. For instance, the electrical measurements of the capacitance of the skin using the capacitance method are expressed as arbitrary capacitance hydration units that are not directly related to real electrical units or to the water content of the horny layer.

In short, there is a need for quantitative and simultaneous measurement of skin hydration and oiliness. Development of a non-contact method for measuring skin hydration and sebum simultaneously will enable to assess the balance between these factors related to skin integrity and to select the appropriate skin care treatment and products.

To facilitate quantitative and simultaneous measurement of skin hydration and sebum levels, we developed an Infrared optical set-up using infrared absorption spectroscopy to estimate skin hydration and oiliness. The method utilizes differential detection between three wavelengths 1720, 1750, 1770 nm corresponding to the lipid vibrational bands that lie "in between" the prominent water absorption bands. The goal of this study is to show the feasibility of the method for measuring skin hydration and surface lipids in natural conditions and its variations to external stimuli.

2. MATERIALS AND METHODS

The experimental set-up utilizes differential detection with three wavelengths 1720, 1750, and 1770 nm, corresponding to the lipid vibrational bands that lay "in between" the prominent water absorption bands. We selected the spectral window around 1700 nm corresponding to high absolute values of the absorption coefficient and a high ratio of the absorption coefficient of sebum to the one of water and, simultaneously, a minimal influence of other skin chromophores such as melanin and blood (Fig.1). All lasers were coupled along the same optical path to illuminate the skin. Light backscattered from the skin was detected with a Ge detector and processed using a simple algorithm for estimating the amount of water and skin surface lipids based on Beer–Lambert's law for light propagation in turbid media. The wavelengths 1720 nm and 1750 nm are used for estimating the sebum content and 1750 nm and 1770 nm for the water content.

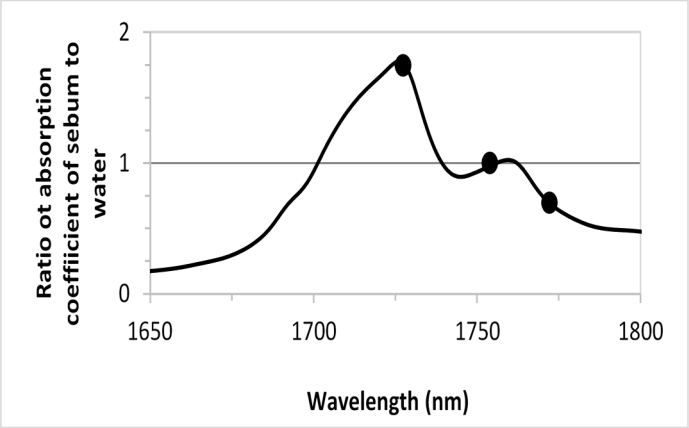

Fig.1 Ratio of absorption coefficient of sebum to water in the spectral band around 1700 nm (b). Dots represents the wavelength of light sources in the experimental set-up.

Water and sebum are mixed in various volume fractions ranging from 0-100% using an emulsifier (Triton-X 100). The sample consists of a mixture of sebum and water in different volume fractions relevant for skin physiological values and contain 5 volume % of emulsifier containing hydro- and lipophilic components to mix these two components. Emulsifiers such as Glycerin, Lecithin, Heptane, Triton-X 100 can also be used as emulsifiers. The preferred emulsifier is TRITON-X 100 because lower amount of emulsifier is required for mixing these two components and homogeneity of mixture. Initially, water and emulsifier are mixed and then sebum was added. Homogeneous and efficient mixing could be obtained by speed mixing. It is preferable to take sebum and water in a liquid phase (>35 ^{0}C), than cool down the mixture to a temperature lower than melting point of sebum (<33-35^{0}C) to avoid decomposition of solution. The mixture should be stored in closed jars in cold place to avoid evaporation of water and decomposition of the solution. By using two samples with sebum volume fraction of 0.2 and 0.6, the measured values of the combined or stand-alone devices could be calibrated using a linear approximation based on the set of calibration data stored in the device. We have applied 20 µg/cm^2 of sebum-water mixtures in different volume fractions on the skin to mimic different oily-dry skin conditions. We also measured the inter-and intra-individual variations in skin sebum and hydration levels and its variations to external stimuli [25, 26] using the optical set-up and compared these results with standard devices.

3. RESULTS AND DISCUSSION

To demonstrate the feasibility of the proposed method, we have prepared calibration samples in various volume fractions and measured the sebum-hydration levels using Sebumeter and Corneometer, which are standard devices used for measuring skin sebum hydration levels. There were 6 solutions prepared: 0, 20, 40, 60, 80 and 100 % of sebum. The mixture was uniformly applied onto the skin in amount of 20 µg/cm2 to replicate skin physiological conditions. The vertical axis corresponds to the estimated amount of water or sebum, while the horizontal axis corresponds to volume fraction of sebum in the applied sebum-water emulsion. Hydration measured with Corneometer and sebum measured with Sebumeter are also shown in the figure for comparison (Figure.2). The error bars represents the standard deviation of three measurements. The results show direct dependency of estimated sebum fraction on the concentration of sebum in the applied emulsion. The same behavior is observed for water concentration variations in the emulsions. The plot shows a linear relation between Corneometer and Sebumeter readings and the volume fraction of sebum until a plateau value is reached when the sebum level exceeds more than 80%.

Five types of skin according to their hydration and oilyness level are presented in the Figure 3. The horizontal axis shows hydration of the skin and the vertical axis shows the oiliness of the investigated skin area; solid symbols are reference measurements using commercially available instruments, and open symbols represents our experimental results. The measurement of the T-zone on the forehead measured under natural (not modified) conditions are shown in stars, other conditions were induced following standard methods.

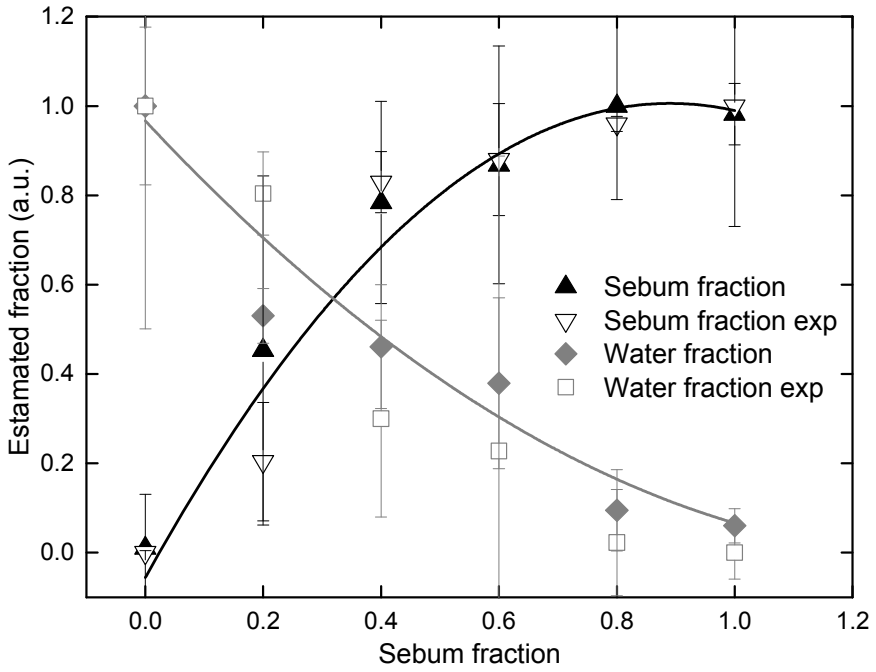

Fig.2: Volume fraction of sebum measured in-vivo using the optical set-up, Corneometer and Sebumeter for different water-sebum mixture samples.

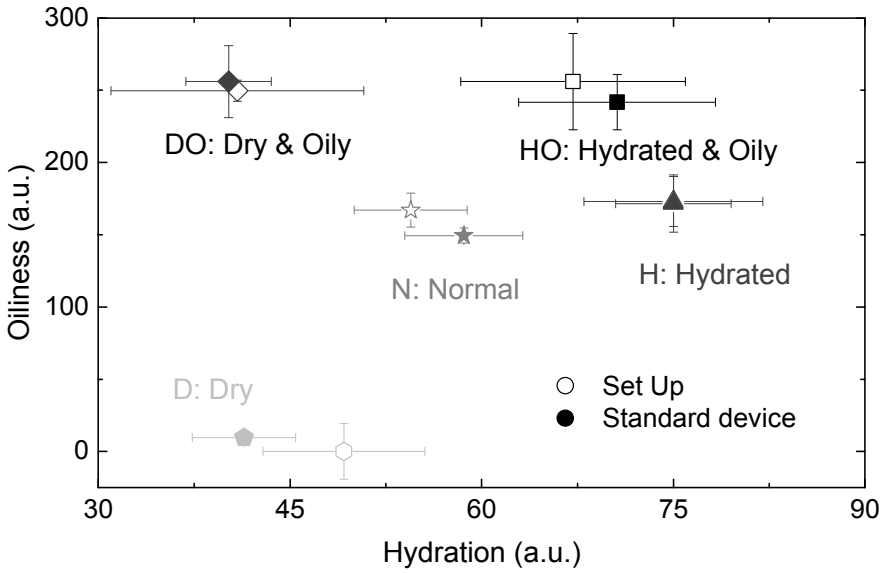

Fig.3: Mapping of various skin conditions on the forehead and its variations to different stimuli and comparison with Corneometer and Sebumeter.

The experimental results of our non-invasive infrared spectroscopic method to simultaneously determine skin surface lipids and hydration volume fractions show good agreement with the commercial instruments Corneometer and Sebumeter. One of the potential advantages of our method is that it is insensitive to the presence and variation of other skin chromophores such as blood and melanin. Hence our optical method can be applied independent of skin type. Moreover, the probe does not need to be in contact with the skin so that the reputed measurements can be performed on the same location without changing the skin conditions.

4. CONCLUSIONS

This study presented the feasibility of a home-built prototype based on infrared spectroscopy in the spectral region around 1720 nm utilizing the lipid vibrational bands that lie "in between" the prominent water absorption bands for measuring the hydration and sebum retaining ability of the skin. The natural and enhanced skin conditions measured on the T-zone on the forehead using our set-up showed good correlation with the reference measurements obtained using Sebumeter and Corneometer.

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