OPTICAL FIBER NEAR INFRARED SPECTROSCOPY FOR SKIN MOISTURE MEASUREMENT

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1. INTRODUCTION

Skin covers the entire human body and functions as shield from various types of external stimuli, damage and also from loss of moisture. The main characteristic factors for protecting the body and assisting in motion are the softness and pliability of skin. These factors are dependent on the amount of moisture available in the stratum corneum, which is the outermost layer of skin. Modification in the amount of water content of the stratum corneum may lead to significant consequences to the functional properties of human skin. It is essential to retain sufficient moisture in the stratum corneum for healthy skin since the water level in this superficial layer of the human skin are of the utmost importance in determining many of its properties . Many instruments have been developed for studying skin physiology and among these applications, measurements of moisture in stratum corneum or sometimes also referred as hydration is one of the fundamental in the study of biophysical properties and function of the skin barrier. The most well-established technique to measure water content in skin is based on measuring electrical properties such as capacitance and alternating current conductivity on the skin surface. . However, optical fiber near infrared spectroscopy technique has emerged as a popular substitute to conventional measuring methodology in various fields of study including environmental monitoring, agricultural and food product quality analysis and also in medical, particularly skin health analysis. This mainly due to the technique which is seen to be able to produce measuring instruments that are non-destructive, portable, low cost, fast and easy operation besides having high precision and reproducibility. The integration of optical fiber probe into the spectroscopy system has added the flexibility of measurement and the fiber design itself can serve into raising the efficiency of measurement. For skin moisture measurement, one of the advantages of applying optical measuring technique is that the interface of optical fiber probe does not necessarily have to be made to contact the skin surface. Therefore, non-occlusive measurements can be made. To cater for the increasing interest in the development of optical fiber spectroscopy system, this chapter will present the existing application of upper range of NIR (1100- 2500nm) and the possible application of lower range of NIR (700-1100nm) particularly 970nm in the measurement of skin moisture content.

2. OVERVIEW ON SKIN PATHOLOGY AND MOISTURE CONTENT

Human skin consists of epidermis and dermis and covers the entire body and function as protection from various types of external stimuli, damage and from moisture loss as well as assisting in motion through the skin softness and pliability. These characteristics are reliant on the amount of moisture available in the stratum corneum, the outermost layer of skin (epidermis) and are controlled by the barrier function that maintains adequate water content in the skin layer. Therefore, changes in the water content of the stratum corneum have important effects on the functional properties of human skin. To sustain a healthy skin, it is very important to maintain sufficient moisture in the stratum corneum. Stratum corneum is about 10-40µm thick and is composed of partially flattened and keratinized layers, except on palms and soles. It is also moderately dehydrated cells in a lipid matrix. Below the stratum corneum is the epidermis with about 100-200microns thickness. Below epidermis is the dermis with about 2-4mm thickness. Skin is more hydrated at the deeper layers. In general, the increase in tissue hydration rate can be influenced by the increase in relative humidity. If the health of the stratum corneum is not maintained during environmental changes, the efficiency of the barrier and moisture-maintaining functions of the skin may drop. Consequently, the skin will become easily dried, roughened and even more at risk to infection. Therefore, it is crucial to sustain adequate moisture in the stratum corneum for healthy skin. It is not necessarily to characterize dry skin as lacking in moisture. Dry skin is more often considered to have a rough and uneven surface that efficiently scatters light, leading to a dry and matte appearance of the skin. Climate, cleansing age or heredity may lead to normal dry skin. Water loss in skin can be reduced by applying moisturizer that function by creating a barrier to surface evaporation. This will create a smoother, softer feel to the skin and to improve the appearance of the skin. Skin moisture and thickness may vary according to anatomical body site, age, and gender and sun exposure. The thickness of the skin for adults may vary from a few millimeters at the eyelid until up to a centimeter at the foot sole. Majority of the current methods used for evaluating skin and diagnosing skin diseases are subjective, time consuming, expensive and invasive.

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Improvement in non-invasive and objective diagnostic methodology would be valuable from an economic point of view as well as to quality in health care. Abnormal changes in the skin are common indicator of many diseases. There is a growing interest in the development of non-invasive methods for diagnosing various illnesses through skin measurements. Since the last three decades, skin bioengineering is a growing field in coetaneous research. Various instruments have been introduced for skin physiological analysis and in experimental trials. The measurement of stratum corneum hydration is one of the primary importances in the study of the biophysical properties and function of the skin barrier. Two non-invasive skin characterization techniques suggested for the diagnosis and monitoring of various markers of diseases are near infrared (NIR) spectroscopy and skin impedance (IMP). These two techniques have been applied for diagnosis of neuropathy, blood glucose levels, microcirculation in patients with diabetes and radiotherapy induced erythema. NIR spectroscopy application for the measurement of water content in skin has long been developed. For clinical diagnostics and for the evaluation of the efficacy of cosmetics products, an exact water content measurement technique is required. For instance, an easy measurement method of water content is essential for atopic cases. NMR and IR to determine that at water content lower than 10%, the water present was tightly bound, most likely due to the polar sites of the proteins. At water contents in between 10-40%, they found less tightly bound water and suggested it was hydrogen-bonded to the protein-bound water. For water content greater than 50%, the water resembled the bulk liquid. The effectiveness of skin moisturizers is generally verified through indirect measurements of hydration such as high frequency electrical conductivity, TEWL (transepidermal water loss), biomechanical measurements and subjective clinical evaluations. However, all these techniques suffer from low precision and no well-understood relationship to water content.

3. SKIN MOISTURE MEASUREMENT

The skin moisture sensor design consists of two metal plates which are isolated by an isolating medium, called a dielectric, as a capacitor. When a voltage source is connected to the capacitor, electrons will start to flow from one plate over the terminal to the other plate. The capacitor will store the electric charge. The quantity of charge stored is called capacitance. The capacitance of the capacitor will increase when material is introduced between the capacitor plates. Vacuum has a dielectric constant less than 7 while water dielectric constant is approximately 81. Therefore, the changes in the amount of water in the measured skin lead to a modification of capacitance of the measuring capacitor. Probe is electrically isolated from the measuring electronics and hence eliminating the influence from ground capacitance and salty skin surface. Total electrical opposition to the flow of an alternating current is defined as impedance. Resistance (Rx), capacitance (Cx) and frequency (f) contribute to the impedance (Z) through the following equation

$$Z= (Rx^2 + [1/2\pi fCx]^2)^{1/2}$$

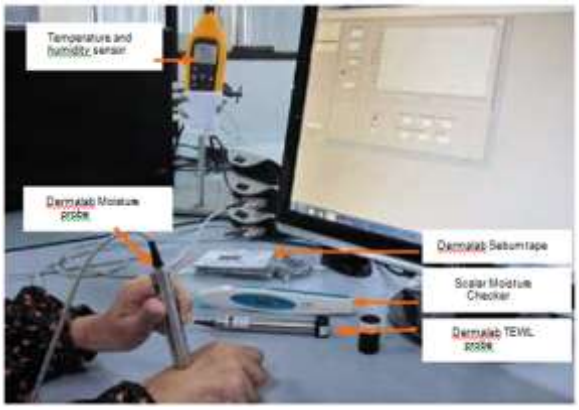

Fig. 1. Skin moisture measurement technique

Electrical conductance is measured when a constant frequency alternating current is applied to skin. The skin moisture is then calculated from the electric conductivity that is dependent on the water content of the skin. Conductance is identified to correlates well with the superficial portion of the stratum corneum even the electrical field on the stratum corneum is non-homogeneous. Moisture measurement using electric conductance devices are easily affected by the amount of electrolytes in the skin and by the contact area of the probe's surface on the skin. These devices are also influenced by external temperature and humidity. This requires the devices to be kept at a constant temperature and humidity. Besides, the amount of electrolyte that the skin contains can alter the conductance value with no regard to water content . Figure 2 shows the skin moisture distribution across a person right upper limb an Cortex Technologies suggested moisture content below 150µS as very dry, between 150-300 µS as dry and above 300µS as skin with sufficient amount of moisture. There is a non-linear relationship between electrical conductance and water content. However, this is depending on the binding state of water molecules. Berardescal stated that there has been regular in the literature to define three types of water according to their strength of binding to the keratin namely "tightly bound water" for water contents from in between 0% and 7%, "bound water" between about 7% and 35% and "free water " which is above 35%. This division is generally helpful and can be considered simplistic on the basis of more detailed theory. Due to the variation in water binding strength, there is no direct proportionality between total water content and electrical conductance. Substances or treatments that

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interact with the keratin-water network may modify conductance without changing the water content of the sample. Berardescal (1997) disagree with the approach to refer to the electrical "capacitance" of the skin without specifying the stimulating frequency and other

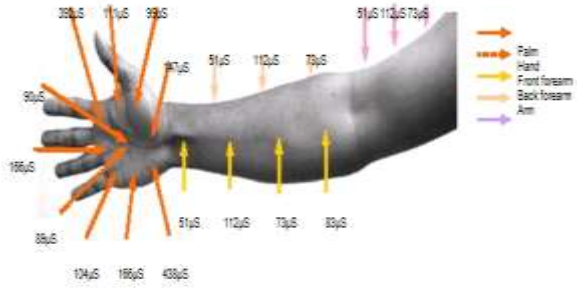

Fig. 2. Skin moisture distribution across a person right upper limb

experimental settings used to make the estimate. "Capacitance" term generally referred by many literatures in similar study is not actually electrical capacitance in the usual scientific and engineering sense since it is frequency dependent, in contrary to the true electrical capacitance. Derma lab moisture module has the capability of showing the result of moisture measurement in two ways, either a single instantaneous data or continuous measurement. For the continuous measurement where the probe is pressed onto the skin for a few cycle of measurement. The application of NIR spectroscopy through optical fiber probe has shown a promising solution to this problem since the measurement of moisture can be performed without the need for the probe to be in contact with the skin surface or with very minimum contact pressure.

4. OPTICAL FIBER NIR SPECTROSCOPY TECHNIQUE (1100-2000NM)

Near Infrared (NIR) spectroscopy technique are capable of providing information on constituent's concentration. NIR spectroscopy was first developed in the 1980s by Norris. Measuring oxygen saturation of hemoglobin is one of the most successful NIR spectroscopy applications in the field of biomedical engineering. There are also large interests of NIR application in non-invasive blood glucose measurement even though most of them are not clinically reliable until today. NIR region are the most prominent for water absorption bands. It allows direct moisture measurement at a certain range of wavelength. This is due to overtones and combinations of the fundamental vibrations that are active in the NIR range and taking place from hydrogen covalent bonds. Water spectrum dominating NIR spectra with overtone bands of the O-H bonds with peak absorption at 760 nm, 970 nm (due to the second overtone of the O-H stretching band), 1190nm (the combination of the first overtone of the O-H stretching and the O-H bending band), 1450 nm first overtone of the OH-stretching band and a combination band), and 1940 nm (combination of the O-H stretching band and the O-H bending band). Spectroscopic measurements are directly related to water content and can be represented by a classical Beer's Law relationship through the absorption of the hydroxyl moieties. The basic working relationship of the light attenuation can be stated by the exponential law of absorption. The differential absorption can be expressed as:

$$dI = - \alpha Io\, dx$$

Where α is the absorption coefficient and is a measure of the rate of loss of light from the direct beam due to the dissolved and suspended substance within the water and the water itself. It is an inherent optical property. Upon integration from 0 to x, gives the exponential law of absorption:

$$I = Ioe^{-\alpha x}$$

0 is the starting point of the light passage through the absorbing medium. X is the length of the medium or the distance of light travel through the medium. Io is the light intensity at point 0. Since the medium is a solution, the concentration, c is included. The absorbance of a sample is proportional to both concentration and the path length that light travels. Therefore, the equation becomes:

$$I = Io\, e^{-\alpha xc}$$

However, based on the above mentioned, the attenuation of the light is not entirely due to the absorption of light energy, but to some extent, it is also as the result of light scattered to the other side by the particles of the solution . Therefore, the equation can be rewritten as:

$$I = Ioe^{-[\alpha a + \alpha s]xc}$$

One of the advantages of the usage of optical techniques for water content measurement is its flexibility. Non-occlusive measurements can be made using NIR technique since it is not necessarily for the interface of probe light to be made in contact with the skin surface. Moreover, a single measurement point technique can be expanded to a two-dimensional area by using an image sensor with a series of spectral filters. Advantages that NIR spectroscopy has for biomedical applications

i. It is a non-invasive and non-destructive analytical technique.
ii. One can use fiber optics for in vivo measurements.
iii. It is possible to monitor not only the surface of biological tissues but also their insides.

because NIR light penetrate into the tissues. Study on the differences of the absorption spectra between free and bound water has been conducted by Martin (1995). Martin has successfully showed that the absorption spectra can distinguish four types of water in skin. Those are water associated with the lipid phase within the stratum corneum, bulk water below the stratum corneum, secondary water of hydration on stratum corneum keratin and primary water of hydration on stratum corneum keratin. Also

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in the work, Martin (1995) has experimentally obtained profiles of the measurement depth in diffuse reflectance spectroscopy. The system is the combination between a near infrared camera with a liquid-crystal tunable filter (LCTF) to acquire spectral images at multiple narrow wavelength bands. The proposed system produces two-dimensional skin hydration mapping system. This technique enables the reading of absorption distribution over the skin surface. The use of mid-infrared range of wavelength in attenuated total reflectance (ATR) spectroscopy is also an efficient technique to assess skin water content. The penetration depth of mid-infrared signal is much shallower than the NIR diffuse reflectance. This is because the ATR measurement utilizes evanescent wave that localizes on the surface of the ATR crystal. Good correlation between NIR absorbance and water content has been showed empirically through in vitro and in vivo technique. This is an additional advantage of NIR analysis over other measurements. Suh et al (2005) have conducted an experiment to evaluate water content in stratum corneum using a FT-NIR spectrometer with a fiber-optics probe. This technique is considered rapid and non-destructive.

5. OPTICAL FIBER NIR ANALYSIS AT 970NM

5.1 NIR reflectance spectroscopy

The range of NIR signal between 1100nm to 2500nm is commonly being suggested for biochemistry application, typically for quantitative analysis. Nonetheless, lower NIR region in between 700nm to 1100nm have also been used widely in physical analysis as well as in analytical chemistry. International Organization for Standardization has suggested LED with peak wavelength at 860nm to be used as illuminating radiation in water turbidity measurement. In fruits quality analysis, range of NIR wavelength in between 700-1100nm has widely been applied for the measurement of soluble solids content and acidity (Nicolai et al, 2007). This section presents an overview on spectroscopy skin analysis using lower range of NIR wavelength and the focus will be given particularly for wavelength at 970nm.The NIR spectral representation for different parts of body may be different due to the variation of skin thickness and surface roughness that will define the magnitude of diffuse and specular reflectance. To understand this further, spectroscopic implementation can be conducted on a person by collecting spectral signature from different part the person body. The spectroscopic instrumentations used for the measurement of Ocean Optics. The value of reflectance was measured using Spectrometer (650-1100nm). Other custom setup prior to the measurement includes integration time = 10ms, spectra averaged = 30 and boxcar smoothing = 1. Light source used was HL-2000 tungsten halogen lamp with spectral emission between 360nm to 2000nm and colour temperature of 2960K. The reflectance spectrum of the halogen lamp was calibrated using WS-1-SL, a white diffuse reflectance standard with above 99% reflectivity from 400-1500nm and above 96% reflectivity from 250-2000 nm. Reflectance probe used in this measurement is R600-7-SR-125F, a standard reflectance/backscattering probe with 6 illumination fibers around 1 read fiber. Each fiber has a core diameter of 600µm.

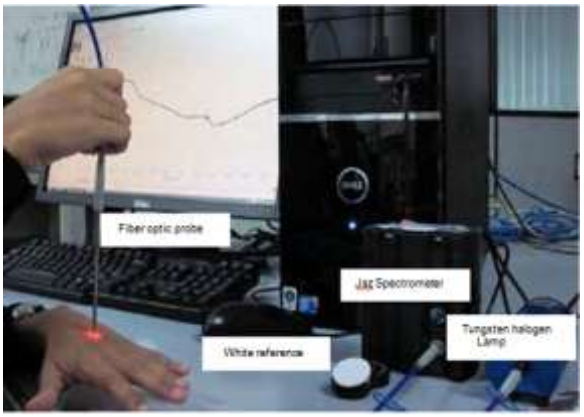

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Fig. 3. Spectroscopy experimental

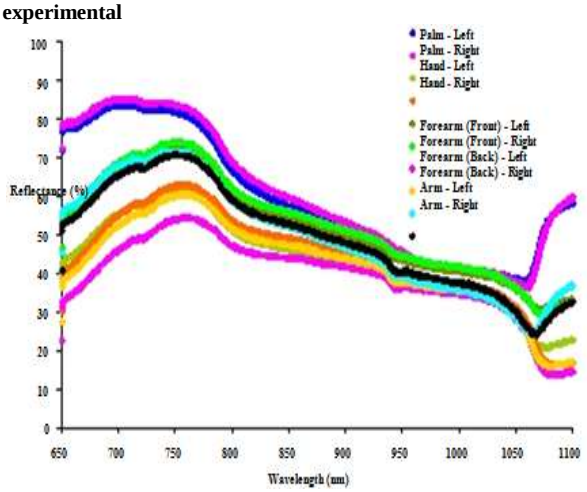

Fig. 4. NIR spectra from a person upper limb

6. CONCLUSION

This chapter has presented multiple experimental designs that are commercially available in the market such as impedance based design, within the clinical trial such as long NIR wavelength (1100-2500nm) and those that has possible venture into implementation such as lower range of NIR wavelength (970nm). The main aim of this continuous research is to be able to produce an optical fiber instrument that can minimize or to some extend eliminate any setback in the conventional implementation. Optical fiber NIR sensor has always be a promising technology as quantitative instrumentation for analytical science.

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