

Correlation between near infrared spectroscopy and electrical techniques in measuring skin moisture content

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Abstract. Near infrared (NIR) spectroscopy technique serves as an important tool for the measurement of moisture content of skin owing to the advantages it has over the other techniques. The purpose of the study is to develop a correlation between NIR spectrometer with electrical conventional techniques for skin moisture measurement. A non-invasive measurement of moisture content of skin was performed on different part of human face and hand under control environment (temperature 21 ± 1 °C, relative humidity 45 ± 5 %). Ten healthy volunteers age between 21-25 (male and female) participated in this study. The moisture content of skin was measured using DermaLab[®] USB Moisture Module, Scalar Moisture Checker and NIR spectroscopy (NIRQuest). Higher correlation was observed between NIRQuest and Dermalab moisture probe with a coefficient of determination (R^2) above 70 % for all the subjects. However, the value of R^2 between NIRQuest and Moisture Checker was observed to be lower with the R^2 values ranges from 51.6 to 94.4 %. The correlation of NIR spectroscopy technique successfully developed for measuring moisture content of the skin. The analysis of this correlation can help to establish novel instruments based on an optical system in clinical used especially in the dermatology field.

1. Introduction

The skin is composed of three structural layers with unique structure and function; stratum corneum (SC), epidermis, and the dermis [1]. The skin performs a wide variety of functions which the most important role to act as a physical barrier to the hostile external environment [2]. The outermost layer of epidermis, the stratum corneum (SC) is an important part in skin physiology and plays a vital role in the protection of humans [3] since it can act as the main protective barrier for skin to resists potential external mechanical, chemical and biological harmful effects [4]. The influence of the water content of SC on its mechanical properties has long been known. In 1952, Blank stated that water plays a preponderant role in the physical properties of the SC. The SC plays a vital role in maintaining life as a result of its water holding capacity and lipid content that functions in controlling the level of transcutaneous water loss [3][5]. It preserves the skin surface soft and smooth by binding the water even under very dry atmosphere [6]. Healthy and normal SC contains about 10-20 % water [7]. Failure of the SC to retain water induces dryness of the skin, producing a dry, scaly or rough skin surface.

Different non-invasive devices have been applied to evaluate the moisture content of the SC and other skin parameters for moisture determination as well as for detecting abnormalities in the skin [8]. The most popular technique is based on the measurement of electrical properties such as capacitance and alternating current [9]. Rosendal (1945), in the experiment showed that SC hydration was a



dominating factor for its conductive properties [10]. Since the last decade, the developments of electrical devices for assessing the water content of skin are based on the electrical properties, such as measurement of resistance, capacitance, conductance and impedance. The basic technique relies on the behavior of the SC as a dielectric material with a sufficient amount of direct current resistance to act as the material between the plates of a capacitor [11]. However, this technique has some limitations such as lack of a direct correlation between skin conductivity and water content besides the flow of current in subject to variations in ion movements and re-orientation of protein dipole moments [8]. The electrical devices are influenced by external humidity and temperature that require them to be retained at a constant humidity and temperature [12]. Besides, the electrical conductance devices can be affected by the amount of electrolyte that skin contains as well as by the contact area of the surface of the probe on the skin [12-13]. Alternatively, several current researches have proposed the application of NIR spectroscopy in measuring skin moisture [14-18].

NIR spectroscopy is a type of vibrational spectroscopy located in the wavelength range of 750 to 2500 nm between the red band of visible light and the mid infrared (mid-IR) region. The NIR signal (spectrum) is a consequence of the light absorption caused by molecular vibrations (overtones and combinations of fundamental vibrations) of hydrogen bonds like C-H, N-H, O-H and -SH functional groups [19]. In the NIR region, the O-H bands of water are very intensive which exhibit five absorption maxima at 760, 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), 1940 nm (due to combination of the O-H stretching band and the O-H bending band) [20-21]. Since 1983, a pioneering work conducted by Ellis and Bath on the analytical growth of the NIR spectra region has been carried out for the determination of water in gelatin by using its stronger absorption in the NIR region [22]. In 1980s, Norris et al. developed the first NIR spectroscopy for analysis of agriculture product [23]. Measuring oxygen saturation of hemoglobin is one of the most successful NIR spectroscopy applications in the field of biomedical engineering [9].

The NIR technology, from the last few decades, has accomplished numerous developments in many fields and has been regarded as the widely used analytical technique in various domains including the biomedical science analysis. This rapidly growing interest in the NIR spectroscopy lies in its benefits over other instrumental technique. It is because of the non-invasive and non-destructive character of this analysis; sample can be characterized by or without minimal sample preparation of demands. Another advantage is, as an analytical tools it is a very fast; provides spectra very quickly (one minute or less per sample) [21-22]. A number of detection surfaces and probes applied in measurement are occluded, therefore causes a false water build-up on the skin surface [24]. One of the significant advantages of NIR spectroscopy technique is for being a non-occlusive measurement [9].

The aim of this study is to develop a relationship (coefficient of determination, R^2) between NIR spectroscopy with conventional electrical techniques (as reference values) for skin moisture measurement to perform a comparative study on the moisture measurement accuracy (high value of R^2) when NIR technique is applied on 10 different individual. Besides, this study also perform comparative study on the measurement accuracy between NIR with two different electrical methods namely conductance (using Dermalab moisture probe) and capacitance (using Moisture Checker).

2. Materials and method

2.1. Subjects

A total of 10 healthy male and female volunteers (Malaysian) age between 21-25 years. They had neither a history nor the presence of any allergies and skin diseases. The subjects were acclimatized for at least 20 minutes in a temperature-controlled room with temperature 21 ± 1 °C and relative humidity 45 ± 5 % prior to the experiments.

2.2. Experimental design

A non-invasive measurement of skin hydration was performed on the left palm and right, forearm left and right, upper arm left and right, cheek left and right and forehead. The NIR spectroscopy technique (NIRQuest) was applied in the measurement of moisture content of skin to the nine different parts of human face and hand of each of the ten subjects (person). The conventional conductance (Dermalab moisture probe) and capacitance (Moisture Checker) techniques were used as reference values for the relative water content of the skin [21-22]. For each measurement, a 2 cm x 2 cm test site was applied with three replicated measurements and the average of every sample was calculated to represent the individual skin sample. The experiment was conducted in a closed room under controlled environmental conditions (temperature 21 ± 1 °C, relative humidity 45 ± 5 %).

2.3. Instrumentation

The NIRQuest (Ocean Optics, Inc. World Headquarters) spectrometer is a high performance InGaAs array detector as it covers the wavelength ranges between 900-2500 nm with the high sensitivity optical bench. The NIRQuest spectrometer is a low noise and low dark current and higher optical resolution 9.5 nm w/25 μ m slit. The advantages of the features make it an ideal instrument for analyzing the moisture content of the skin. The spectrometer consists of the light source HL-2000 tungsten halogen lamp with spectral emission in the wavelength region of 360-2000 nm. Reflection probe used in this measurement is R600-7-VIS-125F that covers the wavelength range between 400-2500 nm. To calibrate the reflectance spectrum of halogen lamp, a reference spectrum was taken with the WS-1-SL, a white diffuse reflectance standard. During the calibration process, the reflectance probe was placed perpendicularly on the top of the surface white diffuse reflectance standard. The experimental diagram for calibration of NIR system is illustrated in Figure 1.

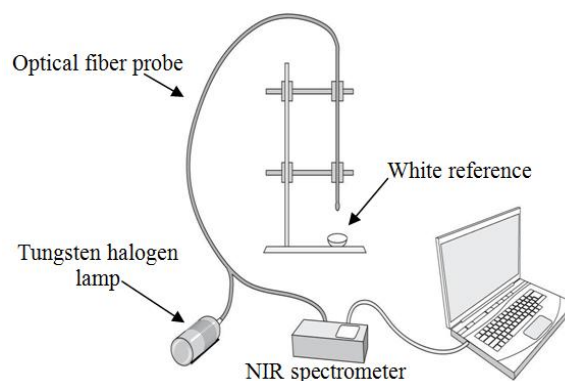


Figure 1. Schematic diagram for calibration of NIR spectroscopy technique.

The DermaLab[®] USB Moisture Module is manufactured by Cortex Technology, Hadsund, Denmark. The moisture probe constitutes an electrical impedance based device, operating at a single frequency of 100 kHz. It provides the information about the hydration state by measuring the conducting properties of the very upper layer of the skin, when subjected to an alternating voltage. This method is denoted as a conductance, measured in the unit of microSiemens (μ S) ranging from 0 to 1999 μ S with the resolution of 1 μ S. The moisture probe is a flat-faced which provides a relatively large contact surface and is ideal for normal skin measurement. The probe consists of a 13 mm sensor diameter with spring loaded action organized as a concentric.

The Scalar Moisture Checker MY-808S (Scalar Corporation, Japan) is designed based on measuring the capacitance value of SC hydration. The Moisture Checker functions give positive correlations between the water content and the dielectric percentage. Therefore, by measuring the dielectric, the percentage of the moisture of the skin can be measured. The Moisture Checker has a higher measurement accuracy that provides a higher correlation with actual moisture content in the skin. Measured values are displayed in percentages (%).

3. Result and discussion

In the analysis of electrical conventional instruments, relative water content of the skin for all examined subjects obtained by using Dermalab moisture probe from the range 14 to 1120 μS and Moisture Checker from 16.5 to 39.7%.

The spectroscopic measurement performed on the 10 subjects at nine different parts of face and hand. The reflectance spectra for the nine different parts of face and hand on normal skin are shown in Figure 2. The absorption peaks of water in skin located approximately at wavelengths 970, 1190, 1450 and 1900 nm. The samples of skin have clearly demonstrated the prominent bands associated with water content of the skin. In the near infrared region with the wavelength range between 900 to 2500 nm, four absorption peaks of water for skin moisture could be observed. However, the weak absorption band around 970 nm shown and has more effect of light scattering due to the shortness of wavelength.

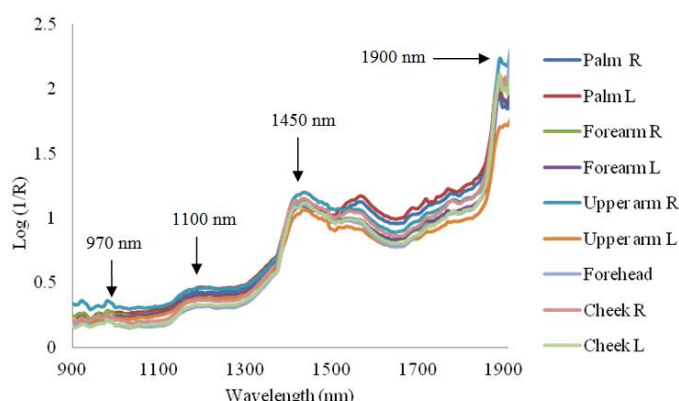


Figure 2. NIR Reflectance spectra of nine different parts of face and hand.

The analysis has been evaluated between the results obtained from different instrumental techniques and is focus to generate the correlation between NIR spectroscopy and electrical technique. NIR reflectance spectra and reference values were performed on the same sites and the correlation between the techniques were investigated. The value of R^2 of the ten subjects presents in Table 1.

Table 1. The experimental results conducted using a combination of four selected wavelengths (950-990 nm, 1100-1900 nm, 1400-1450 nm, 1870-1900 nm).

Subjects	Coefficient of determination, R^2 (%)	
	NIRQuest & Dermalab	NIRQuest & Moisture Checker
1	77.2	80.1
2	70.9	58.8
3	95.2	56.3
4	96.5	94.4
5	91.7	81.6
6	95.0	51.6
7	81.5	67.3
8	97.9	74.5
9	93.4	90.3
10	88.3	74.1
Average	88.8	72.9

From the experimental data summarized in Table 1, moisture content of skin determined by NIR spectroscopy technique correlated well with the electrical conventional techniques with the R^2 values range from 70.9 to 97.9 % (average of $R^2 = 88.8$ %) between NIRQuest and Dermalab moisture probe. Least accuracy has been observed for the correlation between NIRQuest and Moisture Checker with the R^2 values ranges from 51.6 to 94.4 % (average of $R^2 = 72.9$ %). The highest R^2 value has been generated efficiently produced linear relationship presented graphically in Figure 3 between NIRQuest and Dermalab moisture probe values ($R^2 = 97.9$ %), Figure 4 between NIRQuest and Moisture Checker values ($R^2 = 94.4$ %).

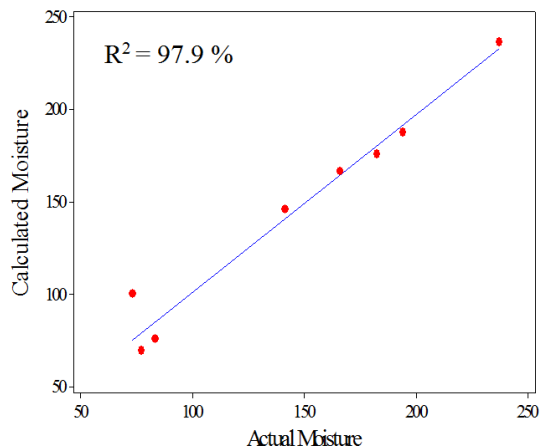


Figure 3. The scatter plot graph for the best correlation obtained between the values of NIRQuest spectrometer and Dermalab moisture probe (conductance).

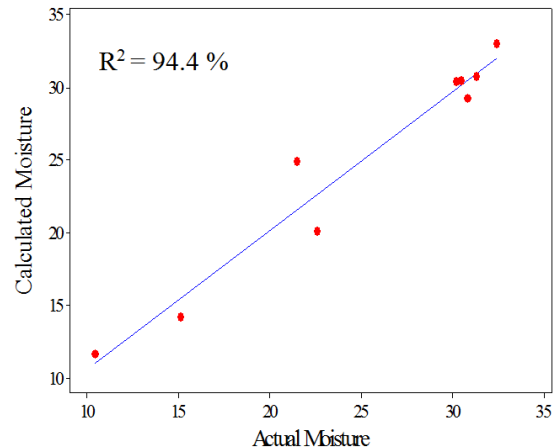


Figure 4. The scatter plot graph for the best correlation obtained between the values of NIRQuest spectrometer and Moisture Checker (capacitance).

The correlation between NIR spectroscopic and electrical conventional techniques successfully generated in measuring moisture content of the skin in addition to the advantages of NIR spectroscopy over the electrical techniques. The result from this study shows that measurement accuracy may vary from one individual to another. However, the deviation of accuracy is highly depended on the reference instrument. From this study, the higher consistency in measurement accuracy can be obtained when using conductance rather than capacitance technique as reference values.

The spectroscopic technique shows stability in the changes of temperature and relative humidity if compare to Dermalab moisture probe and Moisture Checker which is easily affected by environmental condition. The result obtained by using NIRQuest spectrometer is high in accuracy and precision due to low noise and dark current signal provide by the instruments. The most significant advantages is the non-occlusive measurement can be made by using spectroscopic technique, since the measurement can be performed without the interface of optical probe to be pressed with the skin surface.

4. Conclusion

This research has successfully generated correlation between NIR spectroscopy with conventional electrical techniques, Dermalab[®] USB Moisture Module and Scalar Moisture Checker. From the analysis of the entire research confirmed the ability of spectroscopic technique for practically used in quantifying moisture content of human skin. However, the accuracy of measurement may different when measured on different individual and when using different electrical methods as the reference values. In addition, the analysis of this correlation can assist to establish novel instruments based on an optical system in clinical application especially in the dermatology field.

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