Non Invasive Measurement of Skin Hydration and Transepidermal Water Loss in Normal Skin

M. Mohamad, A. R. Msabbri, M. Z. MatJafri
School of Physics, Universiti Sains Malaysia,
11800, Penang, Malaysia.

Abstract—**Non invasive bioengineering techniques have been used to evaluate Stratum Corneum (SC) hydration and Transepidermal Water Loss (TEWL) in normal skin. Fifteen healthy volunteers aged between 21-27 participated in this study. We conducted a self skin evaluation questionnaire and a non-invasive measurement was performed on the palm, forearm, upper arm and forehead under controlled environment (temperature 21 ± 1 ^{0}C, relative humidity 45 ± 5%). Skin hydration was measured with a DermaLab® USB Moisture Module (Cortex Technology, Hadsund, Denmark) and Scalar Moisture Checker MY-808S (Scalar Corporation, Japan) while TEWL measurements were determined using a DermaLab® USB TEWL Module. The areas examined showed skin hydration and TEWL was differed depending on the anatomical sites. The correlations between the parameters were analysed. As a result, no significant correlations between TEWL and skin hydration capacitance were observed. A significant correlation was established between TEWL and conductance.**

Keywords-component; Stratum Corneum (SC); Skin hydration; Transepidermal Water Loss (TEWL)

I. INTRODUCTION

The skin, the largest organ of the human body, makes up approximately 16% of total body weight. Its major role is to prevent loss of water and protect other components of body to the environment besides protecting the body from variety of experimental insults [1]. Skin is composed of the epidermis, dermis and hypodermis. The outermost layer of the skin, the SC, is produced by the basal layer of epidermal.

The SC consists of about 20 stacked layers of dry and flattened dead bodies of epidermal cell; the corneocytes. The unique properties of SC with protein-enriched corneocytes and lipid-enriched intercellular bilayers make SC highly resistant to physical and chemical trauma [2]. The internal structure of the SC has been schematically described by the brick and mortar model. The corneocytes (bricks) are surrounded by the intercellular lipids (mortar). These lipids form multilayered structures within the SC which is important for water retention and as permeability barrier [3].

The SC plays an important role in maintaining life as a result of its water holding capacity and lipid content. Moreover, it acts as a barrier to protect the body from percutaneous absorption of xenobiotics, desiccation and from the insult of environmental conditions. The SC also keeps the skin surface smooth and soft by binding water even under very dry atmosphere [4]. Normal skin contains about 10-20% water near the SC surface. Failure of the SC to retain water induces dryness of the skin, producing a dry, scaly or rough skin surface. Hydration defined as the water content of the SC and intact barrier function is determined by measurement of the TEWL [5].

TEWL measurement is widely used in medical research and has become an important non-invasive tool in the dermatology and cosmetology fields [6]. TEWL is defined as the constitutive steady state water vapor loss from the skin surface, theoretically excluding desorption and sweat gland activity [7]. It is considered to be the result of passive diffusion of water from the hydrated layers of skin dermis and epidermis toward the superficial SC layer [8]. Compared with certain cases of skin disease, normal skin allows only small amount of water loss from the skin's surface. If there are pathological cases such as skin damage by a physical or chemical agent, the rate of water loss will be increased directly related to the degree of impairment [9].

Many different non-invasive devices have been proposed to determined skin hydration and TEWL. The developments of electrical instruments for assessing skin hydration are based on the electrical properties of the skin such as measurement of resistance, capacitance, conductance and impedance. The capacitance and conductance of the skin correlates and show similar behavior. When the probe is applied to the skin, the instruments used to record the value of capacitance and conductance correlate directly with the hydration of the skin. Increasing the skin's hydration will increase its dielectric constant leading to an increase in the value of conductance and capacitance [10].

There are five available electrical devices for assessing the hydration state of the skin based on capacitance or conductance method: DermaLab® USB Moisture Module (Cortex Technology, Hadsund, Denmark), Corneometer CM 820 and CM 825 (Courage & Khazaka, Koln, Germany), Nova DPM 9003 (Nova Technology Corporation, Gloucester, MA, USA) and Skicon 200 (I.B.S., Hamamatsu-shi, Japan).

The assessment of TEWL can be performed using various techniques which is the closed chamber method, open chamber method and ventilated chamber method. Today, the open chamber method is widely used in medical research and has proven to be more useful and form the basis of commercially available instruments. The first commercialized instrument based on the open chamber evaporation gradient method was the Servo Med Evaporimeter. Recently, a new and improved version of an open chamber TEWL probe was introduced by Cortex Technology (Hadsund, Denmark). It is capable of measuring TEWL accurately and reliably [9].

978-1-4673-4617-7/12/$31.00 ©2012 IEEE

Few studies have reported regional differences relating to stratum corneum water content and TEWL [6, 11-18]. Therefore, the purpose of this study is to measure the variations of the skin hydration and TEWL on healthy subjects in relation to differences in anatomical sites using newly developed instruments. The second objective of this present research is to find the correlations between these parameters.

II. Materials and Method

A. Subjects

A total of 15 healthy male and female volunteers between 21- 27 years of age with an average of 24 years were involved in this study. They had neither a history nor presence of allergies and skin diseases. A skin type evaluation was performed through a questionnaire. The subjects were acclimatized for at least 15 minute in a temperature-controlled room (temperature 21 ± 1 ^{0}C, relative humidity 45±5%) prior to the experiments. The study has been approved by The Human Research Ethics Committee, Universiti Sains Malaysia.

B. Study Design

This study included a self skin evaluation questionnaire about lifestyles and skin care habits. A non-invasive measurement of skin hydration was performed on the palm, forearm, upper arm and forehead using recommendations of published guidelines [13]. The TEWL was recorded on the same site of skin hydration, and complied with the guidelines proposed by Rogiers [6]. For measurement of SC hydration, a 2cm x 2cm test site was applied with five replicates measured for each skin site. The experiment was conducted in a closed room under controlled environmental conditions (temperature 21 ± 1 ^{0}C, relative humidity 45 ± 5%). The result was analyzed using Minitab Statistical Software.

C. Instrumentation

The skin hydration was assessed using the DermaLab® USB Moisture Module and Scalar Moisture Checker MY-808S. The Dermalab moisture probe is manufactured by Cortex Technology, Hadsund, Denmark. The moisture probe constitutes an electrical impedance based device operating at single frequency 100 kHz by measuring the conducting properties of the very upper layer of the skin, when subjected to an alternating voltage. This method is referred as a conductance measurement in the unit of microSiemens (µS) ranging from 0 to 1999 µS with the resolution 1 µS. The moisture probe is a flat-faced probe which provides a relatively large contact surface and is ideal for normal skin measurement. The probe consists of a 13mm sensor diameter with spring loaded action organized as a concentric ring [19].

The Scalar Moisture Checker MY-808S (Scalar Corporation, Japan) is designed based on measuring capacitance value of SC. The Moisture Checker functions give positive correlations between the water content and the dielectric percentage [20]. So by measuring the dielectric, the percentage of the moisture of the skin can be measured. The Moisture Checker has a high measurement accuracy that provides a higher correlation with actual moisture content on the skin. Measurement values were displayed in percentages (%).

TEWL was evaluated using a DermaLab® USB TEWL Module based on Nilsson's Vapor Pressure Gradient Estimation Method [21]. Water loss as measured by the TEWL Dermalab is an open chamber probe consisting of a cylinder which is placed perpendicular to the skin's surface. Within this chamber, there are sensors that are set at two fixed distances above the skin's surface. The vapor pressure gradient can be determined from the temperature and relative humidity readings are obtained from these two levels of sensors [9]. The evaporation rate follows Fick's Law of Diffusion, indicating the quantity being transported per a defined area and period of time. The results were expressed in grams per square meter per hour (g/m^2/h) [22].

III. Results

The mean value of capacitance, conductance and TEWL on the palm, forearm, upper arm and forehead are presented in Table I. The forehead showed the highest capacitance than the forearm and upper arm. The least capacitance value was observed on the palm. Conductance on the palm tended to be higher than that of others, while the lowest values were obtained on the forearm and upper arm. The highest TEWL value was detected on the palm, followed by the forehead. Slightly different values were observed on the upper arm and forearm.

A P-value less than or equal to 0.05 were considered as statistically significant [16]. In the study, no significant correlations were noted between TEWL and the skin hydration as measured by the skin capacitance parameter (r = 0.22, P = 0.086) as shown in Table II. However, significant correlations were obtained between the instrumental skin parameter TEWL and skin conductance (r = 0.69, P < 0.001).

TABLE I. Mean Values of Capacitance (Scalar Checker), Conductance (Dermalab) and TEWL (Dermalab) at Different Anatomial Sites

Part	**Biophysical Parameter**		
	Capacitance (%)	***Conductance (µS)***	***TEWL (g/m²/h)***
Palm	29.3	457.6	46.7
Forearm	31.9	72.8	6.3
Upper arm	32.6	65.0	6.7
Forehead	35.2	156.9	15.1

TABLE II. Correlations between (Scalar Checker), Conductance (Dermalab) and TEWL (Dermalab)

Parameter/Parameter	***r***	***P - value***
TEWL/ Capacitance	0.22	0.086
TEWL/ Conductance	0.69	< 0.001

IV. DISCUSSION

In this present study, skin hydration capacitances were 29.3% on the palm, 31.9% on the forearm, 32.6% on the upper arm and 35.2% on the forehead (Fig. 1). Few studies have been published on the variability of skin hydration in relation to differences in anatomic sites [13-18]. The capacitance of the skin showed the highest values on the forehead, while the lowest skin hydration values were detected on the palm. Tagami et al. [14] have conducted an in vivo experiment by using electrical instruments. These authors have reported the same trend of skin hydration capacitance.

Skin hydration as measured by the skin conductance parameter on the palm was 457.6 µS, 72.8 µS on the forearm, 65.0 µS on the upper arm and 156.9 on the forehead. It was highest on the palm. Conti et al. [16] have reported the higher skin hydration values on the palm and forehead whereas the lower values were found on the forearm and upper arm. These results were contradicted with the measurement of capacitance where the palm has the lowest value of skin hydration. This discrepancy could be due to technical aspects such as the type of probe surface, distances between the electrodes and integration depth profile on the skin which vary when comparing with different technology [23].

The variability assessment of TEWL with different anatomical sites has already been reported by the authors [6, 11-12, 15-17]. The highest TEWL value was recorded on the palm (46.7 $g/m^2/h$), followed by the forehead (15.1 $g/m^2/h$), the upper arm (6.7 $g/m^2/h$) and the forearm (6.3 $g/m^2/h$). This finding agrees with the previous studies [15-17] and the ranking of TEWL values of different anatomical sites is as follows: palm > sole > forehead = post auricular skin = nail = dorsum of hand > forearm = arm = thigh = chest = abdomen = back [11].

Considering all parts together, no significant differences between the skin hydration capacitance and TEWL were observed (Fig. 2). Significant correlations however existed between TEWL and hydration of the SC as measured by skin conductance. When TEWL was plotted against conductance combining all parts together, a significant linear correlation was demonstrated (Fig. 3).

The correlation between the SC hydration states in normal skin with TEWL is a matter of debate [16]. Literature data are contradictory; some authors observed an inverse relationship between TEWL and skin hydration [24], while others found no correlation between these two instrumental skin parameters [16, 18]. However, Loden et al. [18] have reported that in some areas of normal skin such as in the hand and arm, the TEWL tended to increase with increasing skin hydration. This discrepancy could be due to a reduction of diffusional resistance of the SC by the occlusion.

ACKNOWLEDGMENT

This project is sponsored by Universiti Sains Malaysia Research University (Grant no. 1001/PFIZIK/811153).

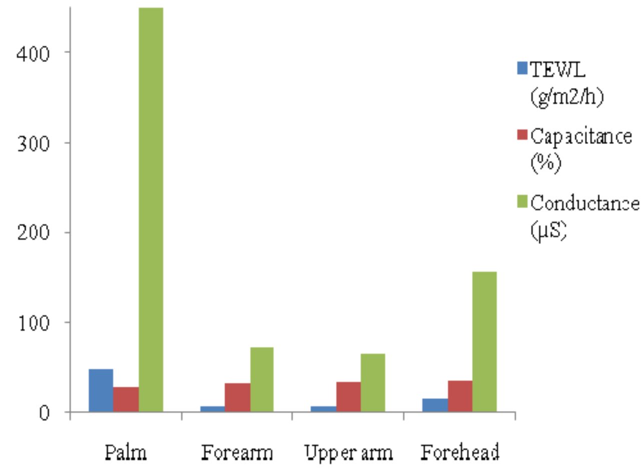

Figure 1. Differences of mean values on palm, forearm, upper arm and forehead.

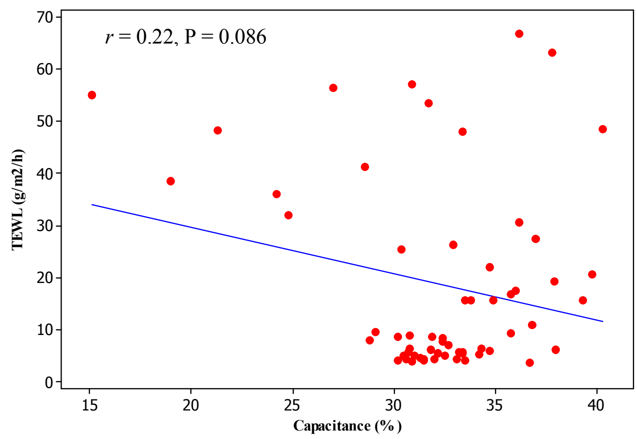

Figure 2. Relationship between TEWL and Capacitance.

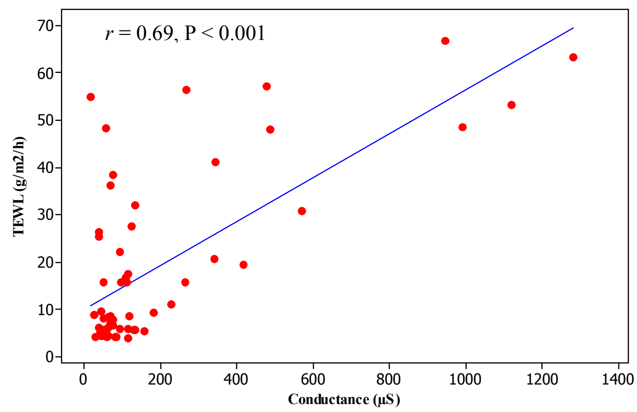

Figure 3. Relationship between TEWL and Conductance.

REFERENCES

[1] R. R. Wickett and M. O. Visscher, "Structure and function of the epidermal barrier," American Journal of Infection Control, vol. 34, pp. S98-S110, 2006.

[2] Loden Marie, "Transepidermal water loss and dry skin," J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach (Eds.), Bioengineering of the Skin. Water and theStratum Corneum (second ed.), CRC Press, Boca Raton, pp. 171−186 (Chapter 15), 2005.

[3] Edwards Chris, Mark Ronald, "Hydration and atopic dermatitis," J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach (Eds.), Bioengineering of the Skin. Water and theStratum Corneum (second ed.), CRC Press, Boca Raton, pp. 323−334 (Chapter 26), 2005.

[4] Hachiro Tagami, "Stratum corneum cell layers," Miranda A. Farage, Kenneth W. Miller, Howard I. Maibach (Eds.), Textbook of Aging Skin, Springer, pp. 337-384 (Chapter 37). 2010.

[5] Gabard Bernard, "Testing of ffficiacy of moisturizers," J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach (Eds.), Bioengineering of the Skin. Water and theStratum Corneum (second ed.), CRC Press, Boca Raton, pp. 211-236 (Chapter 18), 2005

[6] V. Rogiers, "EEMCO Guidance for the Assessment of Transepidermal Water Loss in Cosmetic Sciences," Skin Pharmacology and Physiology, vol. 14, pp. 117-128, 2001.

[7] Van der Valk P.G.M, Kucharekova M., Tupker R.A. " Transepidermal water loss and its relation to barrier function and skin irritation,"J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach (Eds.), Bioengineering of the Skin. Water and theStratum Corneum (second ed.), CRC Press, Boca Raton, pp. 97-104 (Chapter 8), 2005.

[8] B. Sotoodian and H. I. Maibach, "Noninvasive test methods for epidermal barrier function," *Clinics in Dermatology,* vol. 30, pp. 301-310, 2012.

[9] Gary L. Grove, Charles Zerweck, "Hardware and measuring principles: the computerized Dermalab transepidermal water loss probe,"J. Fluhr, P. Elsner, E. Berardesca, H.I. Maibach (Eds.), Bioengineering of the Skin. Water and theStratum Corneum (second ed.), CRC Press, Boca Raton, pp. 275-286 (Chapter 22), 2005.

[10] S. H. Hamed, B. Altrabsheh, T. Assa'd, S. Jaradat, M. Alshra'ah, A. Aljamal, H. S. Alkhatib, and A.-M. Almalty, "Construction, in vitro and in vivo evaluation of an in-house conductance meter for measurement of skin hydration," *Medical Engineering & Physics*, in press.

[11] J. Pinnagoda, R. A. Tupkek, T. Agner, and J. Serup, "Guidelines for transepidermal water loss (TEWL) measurement," *Contact Dermatitis,* vol. 22, pp. 164-178, 1990.

[12] S. Lopez, I. Le Fur, F. Morizot, G. Heuvin, C. Guinot, and E. Tschachler, "Transepidermal water loss, temperature and sebum levels on women's facial skin follow characteristic patterns," *Skin Research and Technology,* vol. 6, pp. 31-36, 2000.

[13] E. Berardesca, C. European Group for Efficacy Measurements on, and P. Other Topical, "EEMCO guidance for the assessment of stratum corneum hydration: electrical methods," *Skin Research and Technology,* vol. 3, pp. 126-132, 1997.

[14] H. Tagami, M. Ohi, K. Iwatsuki, Y. Kanamaru, M. Yamada, and B. Ichijo, "Evaluation of the Skin Surface Hydration in Vivo by Electrical Measurement," *J Investig Dermatol,* vol. 75, pp. 500-507, 1980.

[15] A. B. Cua, K. P. Wilhelm, and H. I. Maibach, "Frictional properties of human skin: relation to age, sex and anatomical region, stratum corneum hydration and transepidermal water loss," *British Journal of Dermatology,* vol. 123, pp. 473-479, 1990.

[16] A. Conti, M. E. Schiavi, and S. Seidenari, "Capacitance, transepidermal water loss and causal level of sebum in healthy subjects in relation to site, sex and age," *International Journal of Cosmetic Science,* vol. 17, pp. 77-85, 1995.

[17] R. Darlenski and J. W. Fluhr, "Influence of skin type, race, sex, and anatomic location on epidermal barrier function," *Clinics in Dermatology,* vol. 30, pp. 269-273, 2012.

[18] M. LodÉN, H. Olsson, T. AxÉLl, and Y. W. Linde, "Friction, capacitance and transepidermal water loss (TEWL) in dry atopic and normal skin " *British Journal of Dermatology,* vol. 126, pp. 137-141, 1992.

[19] DermaLab® USB Users Manual, Cortex Technology Hadsund Denmark pp-6

[20] Shirai and Y. Yamamoto, "Examination of amount of moisture of adult female's forearm epidermal stratum corneum with two kinds of impedance sensors," in *13th International Conference on Electrical Bioimpedance and the 8th Conference on Electrical Impedance Tomography*. vol. 17, H. Scharfetter and R. Merwa, Eds., ed: Springer Berlin Heidelberg, 2007, pp. 165-167.

[21] Nilsson, GE, "On the measurement of evaporative water loss", Linkoping University Medical Dissertations No. 48, 1977, Linkoping University.

[22] R. Darlenski, S. Sassning, N. Tsankov, and J. W. Fluhr, "Non-invasive in vivo methods for investigation of the skin barrier physical properties," *European Journal of Pharmaceutics and Biopharmaceutics,* vol. 72, pp. 295-303, 2009.

[23] P. Clarys, A. O. Barel, and B. Gabard, "Non-invasive electrical measurements for the evaluation of the hydration state of the skin: comparison between three conventional instruments - the Comeometer®, the Skicon® and the Nova DPM®," *Skin Research and Technology,* vol. 5, pp. 14-20, 1999.

[24] P. Thune, T. Nilsen, I. K. Hanstad, T. Gustavsen, and H. Lövig Dahl, "The water barrier function of the skin in relation to the water content of stratum corneum, pH and skin lipids. The effect of alkaline soap and syndet on dry skin in elderly, non-atopic patients," *Acta dermato-venereologica,* vol. 68, pp. 277-283, 1988.