Technical Note

Verification of a Skin Electrical Impedance Model for Evaluating Indicators of Skin Barrier Function of Older Adults

Osamu Uehara,[*, **] Yuya Funaki,[*] Takao Nakamura[**, ***, #]

Abstract Skin barrier function has been quantitatively evaluated through trans-epidermal water loss, which has been difficult to measure in clinical settings owing to environmental factors and the measurement time. The thickness and surface water content of the stratum corneum are important indicators of skin barrier function, and current methods for measuring these two indicators are also difficult to implement in clinical settings. Therefore, we developed a model based on skin electrical impedance to estimate the thickness and water content of the stratum corneum, enabling measurement and estimation of these two indicators in a short time. In this study, we verified this model implemented in a portable skin electrical impedance measurement device for estimating the thickness and surface water content of the stratum corneum of the skin in older adults. Thirty-four older individuals were studied. The measurement electrodes were placed in contact with the forearm skin, and an alternating signal of two frequencies was applied to measure the impedance, from which the thickness and surface water content of the stratum corneum were estimated in approximately 5 s. The correlation coefficients between the estimated and measured thickness and between the estimated and measured surface water content were 0.732 and 0.604, respectively. Furthermore, the root mean square errors of the residuals for the thickness and surface water content were 1.66 µm and 3.50 points, respectively, indicating that the model accurately estimated the thickness and surface water content of the stratum corneum, even in the skin of older adults.

Keywords: older adults, stratum corneum thickness, stratum corneum surface water content.

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1. Introduction

Impaired barrier function of human skin facilitates the penetration of various chemical substances and allergens into the body, causing itchiness, atopic dermatitis, and other problems [1, 2]. Skin barrier function is commonly evaluated by measuring the trans-epidermal water loss (TEWL [g/m^2/h]), which may also serve as an indicator

[*] Medical Engineering Laboratory, ALCARE Co., Ltd., Tokyo, Japan.

[**] Department of Radiological Technology, Graduate School of Health Sciences, Okayama University, Okayama, Japan.

[***] Department of Radiological Technology, Faculty of Health Sciences, Okayama University, Okayama, Japan.

[#] 2–5–1 Shikata-cho, Kita-ku, Okayama 700–8558, Japan.
E-mail: nakamura@md.okayama-u.ac.jp

of skin barrier function recovery [3–5]. Measurements of TEWL are easily affected by the environment and take a long time, making them difficult to apply in clinical settings. The stratum corneum is considered to be responsible for most of the skin barrier functions, and two factors—the thickness and the water content of the stratum corneum—play important roles.

High-precision measurements of the thickness and water content of the stratum corneum require the use of a confocal laser microscope and confocal Raman spectrometer, respectively. However, both of these devices are large, the measurement methods are complicated, and the measurement time is long, making them difficult to use in clinical settings.

Therefore, research has been conducted using electrical impedance method to calculate the thickness and water content of the stratum corneum, which are important factors in skin barrier function [6–8].

In the electrical impedance method, a harmless current is passed through the skin at two frequencies (500 Hz and 100 kHz), and the tissue resistance and capacitance are measured. We have verified a resistance–capacitance model of the thickness and surface water content of the stratum corneum implemented in a skin electrical

impedance measurement device for estimating the thickness and surface water content of the stratum corneum in adults [9]. Subsequently, we miniaturized the device and created a portable skin electrical impedance measurement device (PSID) (**Fig. 1**).

In this study, we verified whether this model is effective for estimating the thickness and surface water content of the stratum corneum in older adults by determining the accuracy of the PSID.

2. Measurement Methods

To verify the accuracy of the PSID, we enrolled 34 older adults (19 males and 15 females; mean age of 74.4 ± 5.2 years) who had no skin diseases. Measurements were taken at two test sites located near the center of the medial forearm (**Fig. 2**), with a total of 64 measurements. The electrodes on the measurement head of the PSID (**Fig. 3**) were placed in contact with the skin; measurement of the skin electrical impedance began 3 s later and was completed in approximately 5 s. The measured skin electrical impedance was used to estimate the thickness of the stratum corneum, denoted as T_E, and the surface water content of the stratum corneum, denoted as WC_{SE}. The thickness of the stratum corneum measured using a confocal laser microscope (VivaScope1500 Multi) was denoted as T_M, and the surface water content of the stratum corneum measured using a confocal Raman spectrometer (Model 3510 SCA) was denoted as WC_{SM}. Measurements were taken in a room maintained at a constant temperature of 21°C and relative humidity of 50%. The test site was first washed with water and then left to acclimatize for at least 15 min. This study was approved by the Ethical Review Committee of Okayama University Hospital (2211–042), and experiments were conducted in accordance with the Declaration of Helsinki, its revisions, and guidelines approved by the Ethical Review Committee. All participants provided written consent prior to the experiments.

3. Results

Figure 4a shows the relationship between the measured (T_M) and estimated thickness of the stratum corneum (T_E)

Fig. 1 Photograph of the portable skin impedance measurement device (PSID).
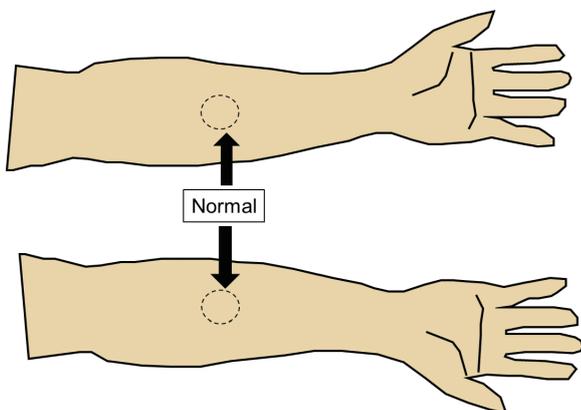

Fig. 2 Test sites at the center of the medial forearm.

Fig. 3 Electrode on the measurement head of the portable skin impedance measurement device (PSID).
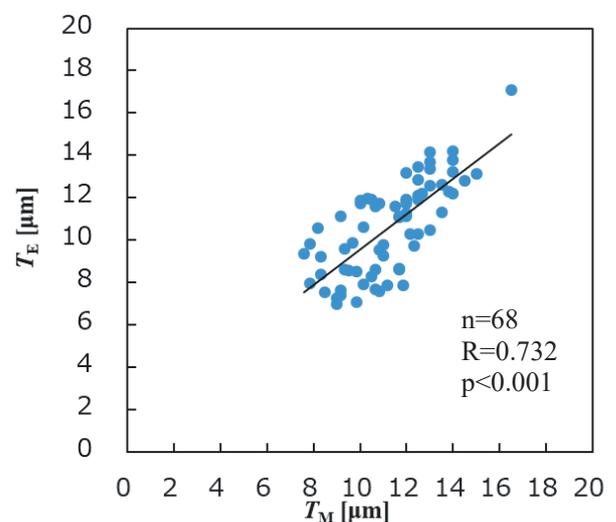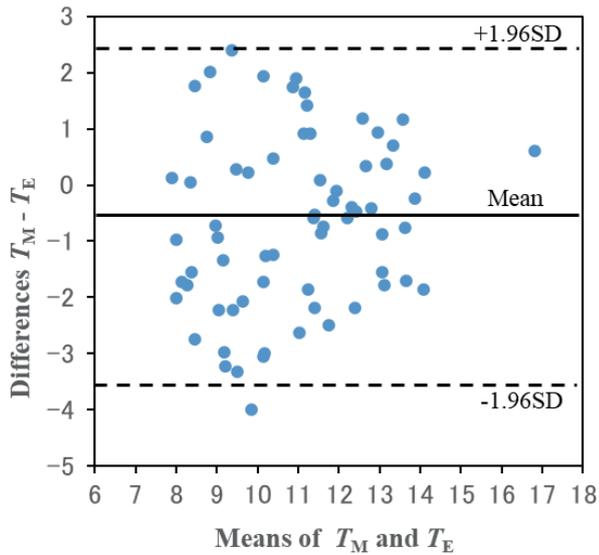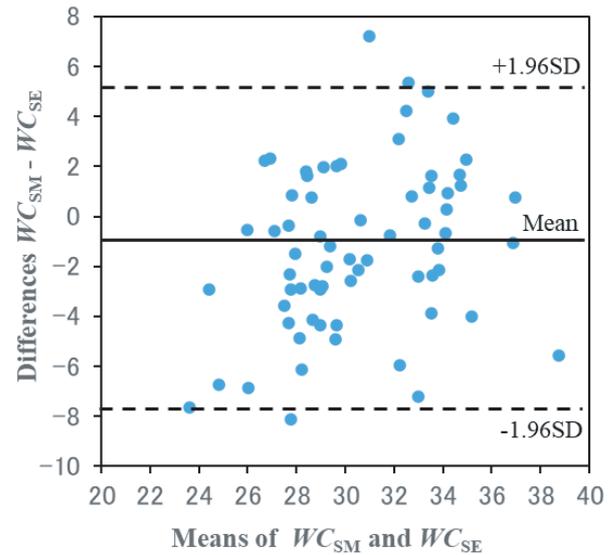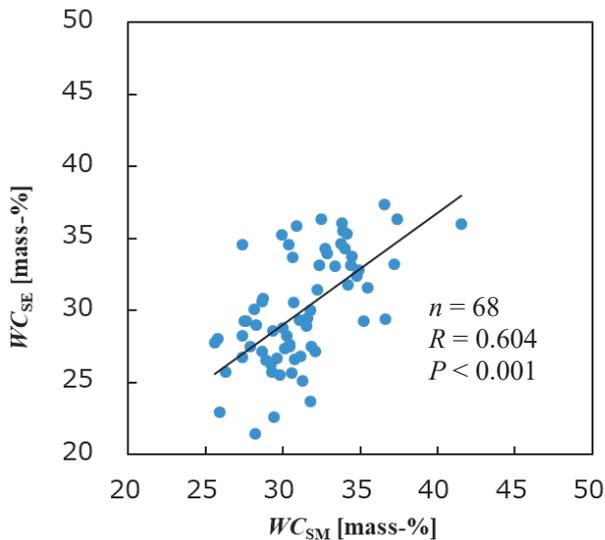

n=68
R=0.732
p<0.001

Fig. 4a Measured (T_M) and estimated thickness of the stratum corneum (T_E).

Fig. 4b Bland-Altman analysis of measured (T_M) and estimated thickness of the stratum corneum (T_E).

Fig. 5b Bland-Altman analysis of measured (WC_{SM}) and estimated surface water content of the stratum corneum (WC_{SE}).

4. Discussion

A strong correlation was observed between the thickness of the stratum corneum estimated using the PSID and the corresponding values measured using a confocal laser microscope in healthy older adults. Similarly, a correlation was observed between the surface water content of the stratum corneum estimated using the PSID and the corresponding values measured using a confocal Raman spectrometer. Uehara et al. [9] reported that the RMSE of the residuals for the thickness and surface water content of the stratum corneum were, respectively, 2.2 μm and 4.7 points in the fundamental data, and 2.3 μm and 5.4 points in the validation data. These values are larger than the corresponding values from the PSID measurements.

Figure 4b shows the Bland-Altman analysis of stratum corneum thickness, which revealed no significant proportional error, with a slope of 0.15. Only one data point for stratum corneum thickness fell outside the ±1.96 SD.

The Bland-Altman analysis of stratum corneum surface water content, as shown in **Fig. 5b**, exhibited significant proportional error with a slope of 0.303 ($p < 0.05$). The mean stratum corneum surface water content was approximately 30 mass-%, distributed within the range of 25 to 40 mass-%. At around 25 mass-%, the estimated value was approximately 1.5 mass-% lower. Furthermore, at around 40 mass-%, the estimated value was approximately 3.0 mass-% higher. Therefore, the influence of proportional error on stratum corneum surface water content can be considered minimal.

Additionally, three data points deviated from ±1.96

Fig. 5a Measured (WC_{SM}) and estimated surface water content of the stratum corneum (WC_{SE}).

using Pearson correlation coefficient. **Figure 4b** shows the results of Bland-Altman analysis between T_M and T_E. The correlation coefficient was 0.732 and root mean square error (RMSE) of the residuals was 1.66 μm. Furthermore, the mean difference ($T_M - T_E$) was −0.66, with +1.96 SD of 2.34 and −1.96 SD of −3.67. **Figure 5a** shows the relationship between the measured (WC_{SM}) and estimated surface water content of the stratum corneum (WC_{SE}) using Pearson correlation coefficient. **Figure 5b** shows the results of Bland-Altman analysis between WC_{SM} and WC_{SE}. The correlation coefficient was 0.604 and RMSE of the residuals was 3.50 points. Furthermore, the mean difference was −1.22, with +1.96 SD of 5.25, and −1.96 SD of −7.69.

SD in the analysis of stratum corneum surface water content.

These results demonstrate that stratum corneum thickness and surface water content can be estimated with the aforementioned accuracy using the PSID, even in the skin of older adults.

The accuracy of the PSID was evaluated using a sufficient number of measurements (a total of 64 measurements from 34 older men and women), confirming the effectiveness of the model in measuring the skin of older adults.

In future work, we will confirm whether the model for estimating the thickness and surface water content of the stratum corneum from skin electrical impedance is also effective for parts of the body other than the forearm. It will also be necessary to confirm whether this model is effective when medication has been applied onto the skin surface or when the skin has developed diseases such as senile xerosis.

5. Conclusion

In this study, we confirmed the accuracy of the PSID in measuring the skin of older adults. Because the PSID can quantify the thickness and surface water content of the stratum corneum of older adults within approximately 5 s, it appears to be a practical tool for use in clinical settings, potentially contributing to obtain new evidence for diseases such as senile xerosis.

Conflict of Interest

Osamu Uehara and Yuya Funaki are employees of ALCARE Co., Ltd. This study was conducted as a collaborative research project between Okayama University and ALCARE Co., Ltd. The measurement device used in this study was developed by ALCARE Co., Ltd., and experiments were conducted using the company's research facilities and equipment. Takao Nakamura has received collaborative research funding from ALCARE Co., Ltd. Study participants received compensation for their participation.

Osamu Uehara and Takao Nakamura are inventors of patents related to the measurement technology used in this study. The patent rights have been assigned to ALCARE Co., Ltd., and the inventors received only one-time compensation, with no ongoing personal financial benefit. The authors declare that these relationships did not influence the study design, data analysis, interpretation, or conclusions.

Ethics Declaration

This study was approved by the Ethical Review Committee of Okayama University Hospital (2211–042), and experiments were conducted in accordance with the Declaration of Helsinki, its revisions, and guidelines approved by the Ethical Review Committee. All participants provided written consent prior to the experiments.

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Osamu UEHARA

Osamu UEHARA received his master's degree in the University of Informatics and Engineering Departments, the University of Electro-Communications, Japan, in 2001. Since 2014, he has been a company member of ALCARE Co., Ltd. (Tokyo, Japan). Since 2023, he has been a visiting researcher at Okayama University. He is currently a visiting researcher at Okayama University. He has been studying on detection system of skin. He is a member of Japanese Society for Medical and Biological Engineering (JSMBE).

Yuya FUNAKI

Yuya FUNAKI received his M.E. in Engineering from the Tokyo Institute of Technology, currently called Institute of Science Tokyo, Tokyo, Japan, in 2014. Since 2014, he has been a company member of ALCARE Co., Ltd. (Tokyo, Japan). He is currently a researcher of Medical Engineering Laboratory Department. He has been studying on methods for evaluating skin.

Takao NAKAMURA

Takao NAKAMURA graduated from Graduate School of Natural Science and Technology, Okayama University and was also received the Ph.D. degree in 1992. From 1992 to 1994, he was a lecturer at Takamatsu National College of Technology, and subsequently a lecturer at School of Health Sciences, Okayama University in 1994. From 1995 to 1998, he worked as an associate professor. He was a visiting researcher at Linköping University, Sweden in 1996. From 1998 to 2016, he was an associate professor at Faculty of Health Sciences, Okayama University Medical School. Since 2016, he has been working as a professor at Department of Radiological Technology, Graduate School of Health Sciences, Okayama University. His research interests are bioelectric signal measurement, in particular measurement of bioelectrical impedance and its applications to biomedical engineering. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), Japanese Society for Medical and Biological Engineering (JSMBE), The Society for Nursing Science and Engineering and Japanese Society of Public Health (JPHA).