Compensation on Impedance of the Stratum Corneum

Ki-won Kim*, Han-yoon Choi*, Myeong-heon Sim*, In-cheol Jeong* and Hyung-ro Yoon†

Abstract – *This study aims at compensation of the skin moisture level using skin impedance and SR factor.* SR factor is related with the current diffusion into the skin layer. To efficiently analyze the current diffusion on the skin model, we used an electromagnetic simulation program called Ansys 10.0 Emag. We confirmed that the measured value decreases as the electric current gets more diffused to the layer below the horny layer. In order to conduct actual experiments based on the simulated result, we manufactured special electrodes with 24 pins by arranging 0.8mm-diameter electrodes every 0.5mm, in a 3 x 8 array. By simultaneously achieving both impedance value and SR value of skin with the manufactured electrodes, we compared the skin moisture level using the existing equipment to the skin moisture level applied using the skin impedance as well as the SR factor developed in this study. The correlation coefficient between the skin moisture level achieved from the existing equipment and the reference value was 0.615 ($p<0.01$), whereas the correlation coefficient between the skin moisture achieved from the regression equation in this study was 0.677 ($p<0.01$). Accordingly, it was confirmed that applying SR factor additionally improves the moisture level more precisely.

Keywords: Array electrode, Compensation of the skin moisture, Moisture of the stratum corneum, Skin impedance, SR parameter

1. Introduction

Dry skin is a symptom caused by a deficiency of moisture, and a state of destruction that commonly occurs to elderly persons whose sebaceous glands have decreased, chronic invalids whose supportive connective tissues are lost, or other patients who are dehydrated. Dry skin can primarily cause pruritus and discomfort, and may secondarily generate skin conditions such as infection or bedsores, as well as serious emotional disturbance including a feeling of uneasiness, anxiousness, or self-concept disturbance. 59~85% of the senior population experiences this skin related dilemma, and many patients actually suffer from varying degrees of dry skin. Nonetheless, patients tend to pay little or no attention to their dry skin condition, as they consider it to be a simple problem that can be solved without assistance from someone in the medical profession. Conversely, medical professionals do not usually take patients' skin conditions seriously, although such attitude may cause complications to arise. Therefore, it is required to develop a dry-skin examination method that measures the moisture level of skin, with a correct understanding of dry skin difficulties [1].

Existing methods for measuring the moisture level of skin include electrical measurements, infrared spectroscopy, microwave-propagation, heat conductivi-ty, photo acoustic spectroscopy, viscoelastic properties, friction, dye fluorescence, and topography [2]. This study applies the electrical measurement method that is widely used clinically, since it is noninvasive, simpler than other methods, inexpensive, highly mobile and reproducible[3].

The loss of moisture from the skin is prevented by the horny layer [4], which is the outermost layer of skin, with a thickness of 10~40um [5, 6]. In order to achieve precise results with electrical measurements, the electrode gap spacing needs to be as thin as the thickness of the skin to be measured.

Certain papers have reported that the contribution of tissues under the horny layer to the measured impedance value is no more than 10% when using the low-frequency energy below 1kHz, even if the electrode gap is as wide as 3mm [7]. However, even 10% can largely affect the total resistance because the impedance in the stratum lucidum and the subcutaneous fat layer is about 1,000 times lower than the horny layer. Accordingly, this paper presents a system that gives superior performance while maintaining the existing electrode gap spacing of

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several millimeters and produces an advanced regression equation.

2. Ansys Simulation

2.1 Method

The epidermis is a complex medium consisting of many layers (horny layer, stratum lucidum, granulation layer, etc.) with various impedances, thus it was expected that different impedance values from other tissues including the stratum lucidum would be mixed with the impedance on the horny layer by the diffusion of electric current. For efficient analysis, the finite element method was chosen. Ansys 10.0 Emag was used as the analysis tool. The skin equivalent circuit suggested by R. Ivanic [8] was used as the skin model for simulation. This model is simplified with the horny layer, the stratum lucidum, and the Equipotential line. Impedance in the stratum lucidum is 1,000 times less than in the horny layer, and even lesser in the next layer below, thus almost no resistance is considered to exist.

In order to identify the problem related to the range of electric current diffusion, we changed the thickness of the horny layer while fixing the impedance value in each layer. Simultaneously, we observed the voltage pattern on the skin surface.

2.2. Simulation Result

As results, it was discovered that a) less amount of impedance value was measured on the thinner horny layer, and b) the voltage drop Slope Ratio (SR, afterward) along the straight line between two electrodes has a correlation with the change of horny layer thickness (Fig. 1). Consequently, it is possible to compensate the regression equation for deducting the moisture level by simultaneously measuring both the magnitude of impedance and SR on the skin surface.

3. Animal Testing

3.1. Hardware

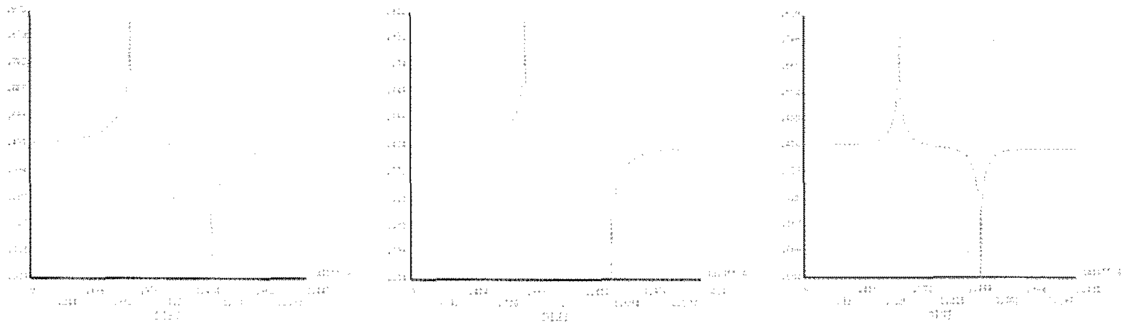
Based on the simulation results, we actually constructed custom hardware and special electrodes (Fig. 2). Although it was very convenient to observe the voltage drop pattern on the simulation, the existing 2-electrode method was insufficient to observe in the actual environment. Therefore, in this study we designed an Independent Array Electrode for sampling the voltages across two electrodes. This is not an existing 2-electrode-based electrode designed by R. Ivanic [8] or Norman F. [9], but an electrode in which each node is independent.

An 8-node array electrode was designed, in which 'node 2' and 'node 7' are the electric current electrodes. All electrode arrays from 'node 1' to 'node 8' measure voltages generated on the skin surface. Accordingly, 'node 2' and 'node 7' function as both current electrodes and voltage electrodes.

The diameter of each electrode cell is 0.7mm, and the gap spacing between electrodes is 0.5mm. The total length of the array electrode is 9.10mm, and the total width is 3.1mm. The gap spacing between current electrodes is 6mm.

The pressure applied to the skin while measuring the skin impedance may generate an error [10], thus a micro spring was mounted to each electrode cell to help reduce this from occurring. A single electrode array was segmented into 3 cells to allow it to adapt easily to leaning in all directions (Fig. 3).

Since the skin impedance reaches up to several MΩ



(a) (b) (c)

Fig. 1. Surface voltage graphs: changing the thickness of the horny layer in R. Ivanic's skin model to 30um (a), 20um (b), and 10um (c), by using Ansys (X axis: position along the length of skin surface that electrodes contact, Y axis: magnitude of voltage).

unlike bio-electrical impedance, we mounted a buffer on each electrode input terminal to increase the input impedance of the electrode.

Measured data are collected into the PC through DAQ board by National Instrument, and are simultaneously displayed with LabView 8.2 by the same company, as well as saved as a text file (Fig. 4).

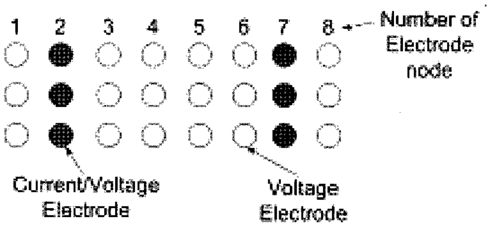


Fig. 2. Diagram of skin contact area of independent array electrode.

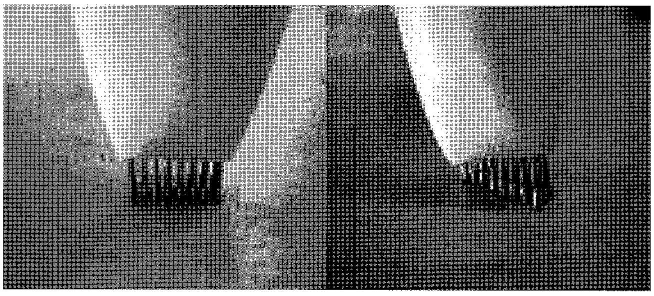


Fig. 3. The flexibility of electrodes mounted with micro springs.

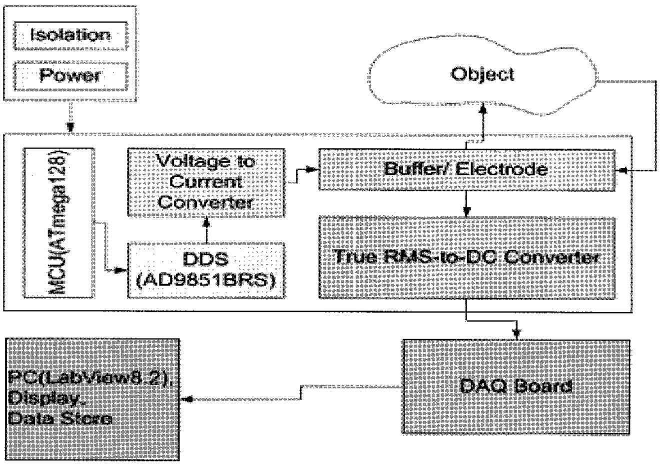


Fig. 4. Block diagram of the system.

3.2. Method & Result

In order to verify the benefit of SR factor suggested in this study, we compared the moisture level measured by existing equipment with the moisture level deduced by using the skin impedance magnitude from our own electrodes and the SR factor together (Fig. 5).

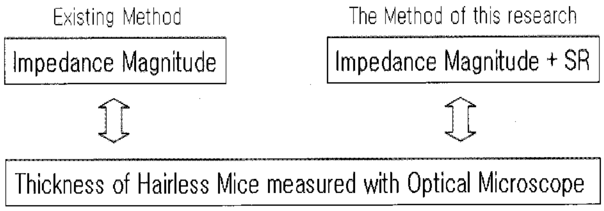


Fig. 5. Schematic of the experiment.

The existing equipment compared in this study is Aram Huvis's AramoTS (AH-AT-070192), which is widely used in measuring the moisture level of skin. For reference moisture level, we used the thickness of horny layer interrelated to the skin's moisture level, which was observed with an optical microscope [11, 12].

We chose hairless mice (SPF/VAF Outbred - Mice, CrljBgi:SKH1-hr) that are frequently used for monitoring skin conditions, as experimental subjects [6, 13]. Twenty out of 30 mice were used to produce the regression equation for measuring the moisture level of skin by using the equipment manufactured for this study. The remaining 10 mice were used to verify the regression equation produced. During the experiment, one mouse for producing the regression equation was dead, so it had to be excluded. Due to an error in the measurement, another mouse for producing the regression equation was excluded. Accordingly, data in 72 areas from 18 hairless mice in total were used to produce the regression equation.

After marking the target area of a subject, we measured the skin impedance value and the SR factor by using the electrodes manufactured. SR factor is defined as the ratio between "the average of the slope from node 2 to node 3 and the slope from node 6 to node 7" and the slope from node 3 to node 6. The achievement of SR value can be expressed as the equation (1) below.

$$SR = \frac{V_{node6} - V_{node3}}{\frac{(V_{node7} - V_{node6}) + (V_{node3} - V_{node2})}{2}} \quad (1)$$

Such measured data are automatically saved in the PC as shown in the block diagram above. To analyze results, voltage values saved in the text file from LabView 8.2 were represented with Excel in Microsoft Office 2003 (Fig. 6). X axis represents nodes of the 8-row array electrode, meaning the distance on the target surface. Y axis represents the magnitude of voltage. As shown in Fig. 6, the magnitude of voltage distribution decreased as the frequency of constant current increased. This graph presents the similar result to Ansys's result (Fig. 1) for the skin model simulated previously.

After measuring with the manufactured equipment, we also measured and recorded the moisture level of skin with the existing equipment. Skin tissues of subjects were

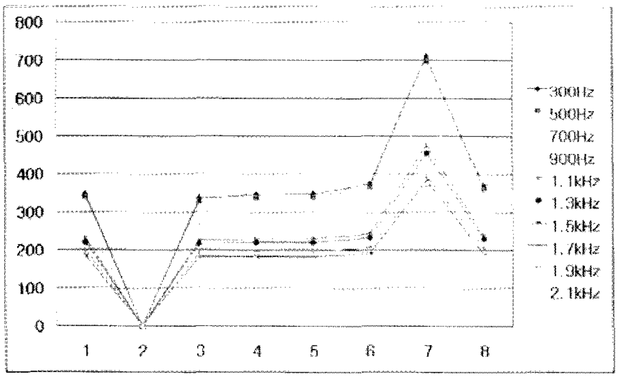


Fig. 6. Result of voltage distribution on the skin surface of hairless mice, regarding the constant current in 10 different frequency bands.

Fig. 7. A picture from the microscope with which the thickness of the horny layer of hairless mice was observed (zoom: 1000x).

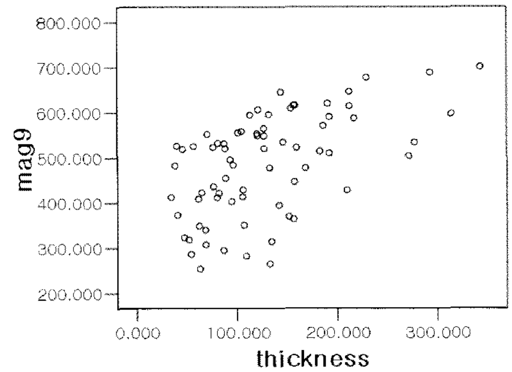


Fig. 8. Correlation between the thickness of horny layer and the skin impedance value.

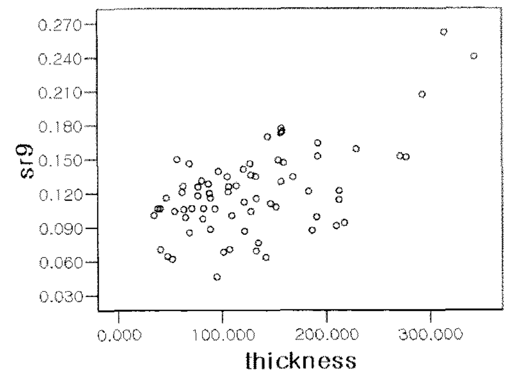


Fig. 9. Correlation between the thickness of horny layer and the SR factor.

collected and fixed immediately after completing all measuring process. Then we observed the skin tissues that went through the dyeing process with a 1,000x zoom optical microscope (Fig. 7). In order to measure the skin thickness, we used Motic Images Plus 2.0 ML that can be linked to the optical microscope for measuring the thickness of the desired area easily.

Considering the change of measured impedance values at each node according to the frequency, we repeated the experiments in 10 different frequency bands, at every 200Hz from 300Hz to 2.1kHz.

According to the data analysis result, we found a correlation of 0.544 ($p<0.01$) at 1.9kHz, between the increase of horny layer thickness due to the deficiency of skin moisture and the impedance value measured from the skin surface, and thus we confirmed that the impedance value is a useful factor in deducing the moisture level of the horny layer on the skin (Fig. 8).

In addition, the SR factor suggested in this study also increased as the skin thickness increased, showing 0.593 ($p < 0.01$) of Pearson's correlation coefficient at 1.9kHz (Fig. 9). Therefore, the SR factor is considered useful to deduce the moisture level of skin.

By using impedance magnitude values and SR values measured in 10 different frequencies as independent variables, we produced 10 regression equations that deduce the thickness of the horny layer correlated to the reciprocal of moisture level [11, 12]. Expression (2) is the regression equation that deduces the skin thickness at 1.9kHz, which shows the best performance among 10 frequency bands.

$$\begin{aligned}&\text{Skin thickness} =\\&(0.209\times \text{Measured Impedance Value 1.9kHz})\\&+(776.595\times \text{SR1.9kHz})-6.493\end{aligned} \quad (2)$$

By using the regression equation at 1.9kHz, we verified the impedance magnitude values against 10 independent hairless mice and the SR value-applied regression equation. We used SPSS 12.0 for the statistic analysis.

As shown in Table 1 and Fig. 10, we compared the moisture levels measured by both the existing equipment and the system manufactured in this paper, with the reciprocal of skin thickness observed by the optical microscope.

Table 1. Correlation comparison of skin moisture levels both from the method suggested in this study as well as from the existing equipment, with the reciprocal of horny layer thickness in hairless mice.

	Reciprocal of thickness of skin horny layer	
	Pearson's Correlation coefficient	Significant probability
Skin moisture level deduced in this study	0.677	P < 0.001
Skin moisture level deduced by existing equipment	0.615	P < 0.001

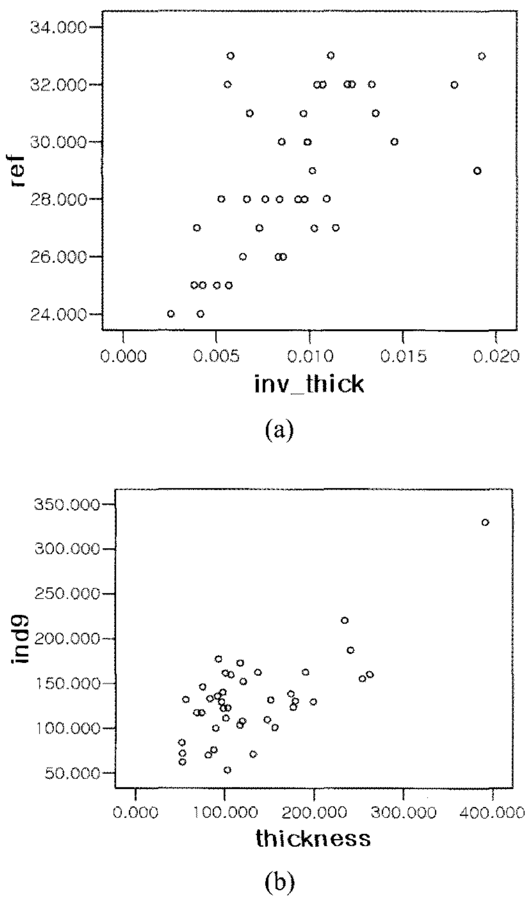


Fig. 10. Comparison of correlation between the skin moisture level by the existing equipment and the reciprocal of thickness (a), with correlation between the impedance magnitude and the skin moisture level (1.9kHz) applied with SR factor (b).

As results, the existing method shows 0.615 ($p<0.01$) of Pearson's correlation coefficient, while the system in this paper shows 0.677 ($p<0.01$) at 1.9kHz. Accordingly, it was confirmed that application of the SR factor additionally increases the accuracy of deduced moisture level in the pertinent frequency band.

4. Discussion

The phenomenon in Fig. 1 is due to the fact that the section of high current density covers more of the low-impedance areas, as moving from Fig. 1(a) to Fig. 1(c). Although the thickness of the horny layer decreases as the moisture level increases, accordingly the stratum lucidum gets closer so that the low impedance value in the stratum lucidum can get mixed. Therefore, it is necessary to compensate the measured impedance value as the thickness of horny value decreases.

If the impedance of the medium to be measured is basically singular, the SR pattern will decrease linearly. However, if the medium has two or more impedance components and there exist a substance that has lower impedance under that medium, the direction of current flow changes and thus the SR pattern on the surface changes as well (Fig. 11).

A characteristic is the flat area generated in the middle (Fig. 11). It gets closer to the horizontal plane as the horny layer gets thinner. By defining such ratio as SR factor, it is possible to improve the measuring result of moisture level.

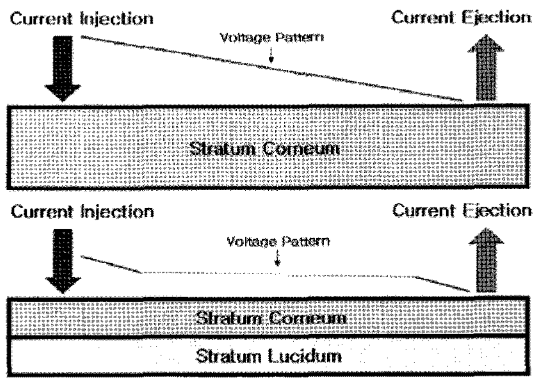


Fig. 11. Differences in SR tendency according the medium components.

5. Conclusions

This study is aimed at measuring the moisture level of skin more precisely. According to the analysis result with Ansys 10.0 Emag, we verified that the thinner horny layer tends to provide a smaller result value, being affected by the lower layer (stratum lucidum) that has high conductivity, even if the impedance value of the horny layer is the same. We verified that such phenomenon actually occurs by designing and manufacturing custom hardware, and defined it as SR factor for numeric representation.

We applied the impedance magnitude and the SR value to the regression equation for deducing the skin moisture level more precisely.

By comparing the moisture level achieved from the impedance magnitude to the moisture level achieved from the impedance magnitude together with SR factor, we verified that the correlation to the reciprocal of horny layer thickness was more precisely improved from 0.615 to 0.677.

Acknowledgements

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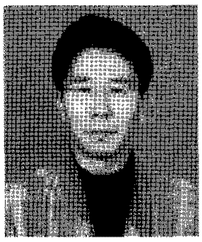

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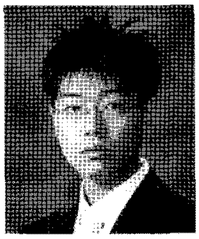

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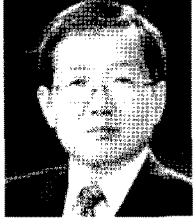

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