Characteristics of skin admittance for dry electrodes and the measurement of skin moisturisation

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Abstract—*The properties of skin admittance were investigated with the intention of applying them to skin moisturisation measurement. Skin admittance is determined by measuring relative permittivity and the resistivity of the stratum corneum, and by contact ratio between dry electrode and stratum corneum. It was found, however, that the contact ratio is the predominant factor producing the change of skin admittance induced by changes in the water content of skin. To measure skin admittance, the following conditions were found to be appropriate: (a) frequency of about 100 kHz; (b) concentric electrodes, the diameter of the measuring (inner) electrode being about 5 mm, and (c) an electrode pressure of about 100 g cm^{-2}. Based on these optimal conditions, a system for measuring skin admittance was constructed. All measuring procedures were automated. Experimental observations made with this system have indicated its usefulness for the measurement of skin moisturisation.*

Keywords—*Bioimpedance, Dehydration measurement, Skin admittance, Skin moisturisation*

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1 Introduction

THE STRATUM corneum consists of layers of dead cells, and is in a highly dried state compared with other tissue cells in the living body. The water content of the stratum corneum is influenced by changes in environmental humidity. However, it is necessary for the stratum corneum to contain appropriate moisture to exert its primary functions as the skin. Thus, the measurement of moisturisation is attracting much attention in the diagnosis of dermatological diseases and in the field of cosmetic sciences. In response to such demands, various methods for the objective measurement of the moisturisation of the stratum corneum have been developed and used (QUATTRONE and LADEN, 1976). For example, there are, *in vitro*, gravimetric, scanning calorimetric and mechanical techniques, and, *in vivo*, transpirometry, low-magnification photography and scanning electron microscopy. Photoacoustic emission spectroscopy (PAS) (CAMPBELL *et al.*, 1977) has also been applied. There is, however, no satisfactory method at present.

The electrical resistance or impedance of the skin at a low frequency has been used as the index of moisturisation in some method (CLAR *et al.*, 1975; CAMPBELL *et al.*, 1977; YAMAMOTO *et al.*, 1978; SERBAN *et al.*, 1981). However, ions rather than water in the skin largely influence the result, leaving problems in its general use. TAGAMI *et al.* (1980), on the other hand, developed a method for *in vivo* moisturisation measurement of the stratum corneum utilising the skin admittance measured with a radio frequency current of 3·5 MHz, and instruments conducted on the basis of this idea have been widely used. The main advantage of this method is the relatively small influence of ions compared with the use of the impedance in a low-frequency range, for example 0–100 Hz. There seem, however, to be some problems even in this excellent method; namely, the relationship between the skin admittance and the electrical properties of the stratum corneum is not yet fully clarified, particularly in relation to the justification of the use of a radio frequency of 3·5 MHz, and the method for achieving a close contact between a small dry electrode and the surface of the skin also appears to have some technical problems.

In the present study, problems such as those described above are discussed based on experimental observations, and the conditions required for the measurement of skin admittance to estimate skin moisturisation are made clear. Based on these findings and discussions, the design and composition of a practical instrument are described. Moreover, some data obtained with the instrument are presented to demonstrate its reliability.

2 Methods for the measurement of skin admittance

Two dry electrodes are placed on the skin, the surface area of one of these electrodes being more than ten times greater than that of the other. The electrode with a smaller

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area is a measuring electrode, while that with a larger area is an indifferent one. Electrodes have been made with flattened copper or brass without special surface treatment. The polarisation impedances of these metal electrodes decrease steadily with increasing frequency. Skin impedance is several orders higher than that of biological tissue such as muscle or blood, and so polarisation is no problem in this case.

If a current I(A) flows between the two electrodes when a sine-wave voltage E(V) is applied to the electrodes, the admittance Y(S) between the electrode and skin may be given by the following equation:

$$Y = I/E = |Y| e^{j\phi} \qquad (1)$$

Since the value of Y thus obtained primarily represents the admittance of the skin beneath the measuring electrode, this Y value is to be termed as the skin admittance in this paper. The term $|Y|$ will simply be written as Y in the following description, unless otherwise stated.

When dry electrodes are attached (compressed) to the skin, the skin admittance (first) increases rapidly, then the rate of increase gradually becomes slower. It has already been confirmed that the higher the admittance at a certain time during the above-mentioned time course, the greater is the relatively moisturisation in the stratum corneum (TAGAMI *et al.*, 1980).

It is also known that the slope of the rising curve of the observed admittance during a time range from 0·5 s to 10 s is invariable in the majority of different measurements. Therefore, as far as the relative content of skin moisture is concerned, it is not meaningful to consider what time point is to be employed for observation, but rather more important to make observations at the same point in time. We have thus employed the time point of 3 s after the attachment of electrodes (taking the time required for experimental procedures into consideration).

As mentioned above, this method is one of measuring the degree of skin moisturisation from the value of skin admittance and the absolute value of water content cannot be obtained.

3 Results and discussions

3.1 *Frequency characteristics of skin admittance*

For the purpose of the measurement of skin moisturisation, it is desirable to use the skin admittance at a particular frequency, which is barely influenced by ions but shows large variations with changes in the water content. Therefore the influences of water content and ions upon the skin admittance were experimentally investigated in relation to the frequency characteristics of the skin admittance.

The concentric electrode used comprised an inner electrode (5 mm diameter) and an outer passive electrode (10 mm inner diameter and 20 mm outer diameter) as shown in Fig. 6. The total pressure (see Section 3.2) applied to the electrode was adjusted to be 314 g (100 g cm^{-2}) with a coiled spring.

The results obtained from the skin of the forearm are shown in Fig. 1. The measurement was carried out on the forearm of a healthy subject after over 30 min of washing by tap water under the condition of room temperature 23°C and relative humidity 50 per cent RH. In Fig. 1, the normal represents the result for the natural (normal) skin condition, and the tap water and the NaCl indicate the results obtained by the following procedures: one drop of tap water or NaCl solution was dropped onto the ventral side of the forearm to be measured, wiped off 10 s later, and the electrode was attached 2 s after the wiping off. The stripping means that the stratum corneum was first removed by stripping 40 times with adhesive cellulose tapes, then one drop of tap water was placed in position and the electrode was attached.

The difference between (*a*) and (*b*) represents the change of skin admittance induced by a change in the water content of the stratum corneum. Differences between (*b*), (*c*) and (*d*) indicate the influence of ions in the presence of a sufficient amount of moisture. The value (*e*) corresponds to the upper limit of skin admittance, and the difference between the impedance ($1/Y$) of (*b*) and that of (*e*) represents the impedance of drenched (100 per cent moisturised) stratum corneum. Observed values from healthy normal skin under ordinary conditions may be close to the value of (*a*). To concentrate the effect of water and to avoid the influence of ions as much as possible, it is preferable to use the frequency zone which provides the greater differences between (*a*) and (*b*), but provides similar values of (*b*), (*c*) and (*d*). According to experimental data, the difference between (*a*) and (*b*), become slightly smaller with increasing frequencies, whereas differences between (*b*), (*c*) and (*d*) are very large in a low-frequency range and become smaller as the frequency is increased. Thus it is preferable to use frequencies higher than 10 kHz for moisture measurement.

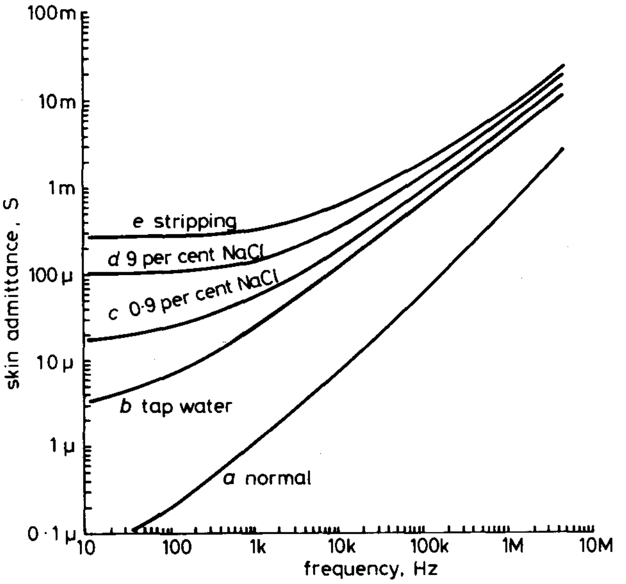

Fig. 1 *Frequency characteristics of skin admittance*

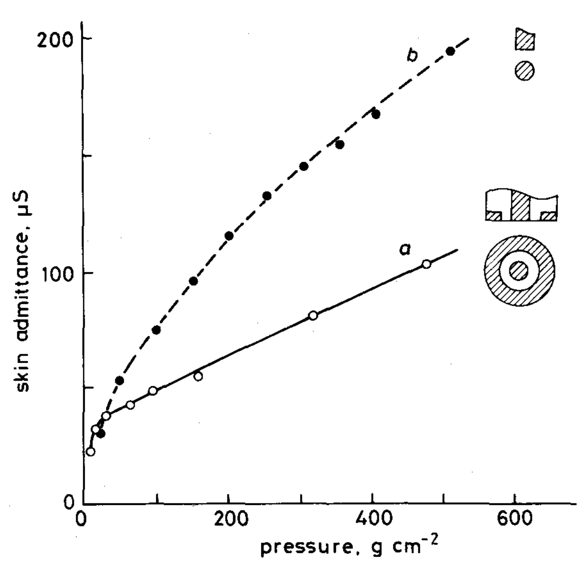

Fig. 2 *Pressure dependency of skin admittance*

3.2 *Electrode shape and the pressure applied to the electrode*

The relationship between the pressure applied to the electrode and the value of the skin admittance was then examined using electrodes with different shapes under the same conditions as before. As shown in Fig. 2, two types of brass electrode were tested, one having an insulator and a passive electrode around a measuring central electrode (Fig. 2*a*) and the other having independently placed measuring and passive electrodes as shown in Fig. 2*b*. The results obtained with these electrodes at 100 kHz are shown in Fig. 2. According to these observations, the electrode type (*a*) showed smaller changes in the admittance under increasing pressure, whereas in the case of the electrode type (*b*) it was found that the edge of the electrode invaded the skin to cause a focal compression. Thus electrode type (*b*) was judged to be inappropriate.

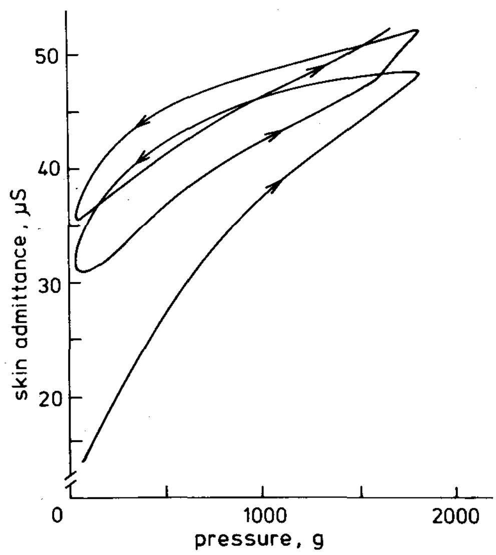

Fig. 3 *Lissajous' figure for skin admittance and contact pressure. Total area of measuring and passive electrodes = 3·14 cm². Pressure is expressed in g as the area is constant*

Fig. 3 shows the relationship between pressure P and skin admittance Y when the pressure for an electrode was periodically changed during 10 s under the conditions of 18°C, 54 per cent RH. After several cycles the Y/P relationship reached a steady state, indicating a strong influence of P upon Y in a manner similar to that shown in Fig. 2. Since the relative permittivity, the resistivity and thickness of the stratum corneum cannot be changed in response to periodical pressure changes, it may be inferred that changes in the degree of contact between the electrode and the skin are responsible for variations in the Y value.

3.3 *Surface area of electrodes*

Four concentric electrodes (as shown in Fig. 6) were prepared to make the surface area of the passive electrode about 10 times greater than that of the measuring electrode. The values of skin admittance measured with these electrodes at a frequency of 100 kHz under a constant contact pressure of $100\,\mathrm{g\,cm^{-2}}$ are shown in Fig. 4. The values shown are the mean of 12 observations from the forearm of the same subject.

If the admittance is determined by the resistivity and the relative permittivity of the skin surface, i.e. the stratum corneum, the value of the admittance is expected to be proportional to the surface area of a measuring electrode as shown later in eqn. 2. On the other hand, if the resistivity and the relative permittivity of deeper tissues, such as the dermis and muscles, determine the admittance, the value of the admittance should be proportional to the diameter of a measuring electrode as the result of current distribution in concentric electrodes (AIKAWA, 1959). The results shown in Fig. 4 indicate that the admittance is approximately proportional to the surface area of the electrode, suggesting very high dependency upon skin surface.

In Fig. 4, the values of standard deviations σ for Y are also shown. The greater was the electrode surface, the smaller were the value and the variation of Y. Thus the use of a measuring electrode with a large surface area may be expected to reduce the variation of the value of observed skin admittance. In practice, however, the size of a passive electrode consequently becomes too large, hence it becomes difficult to secure a sufficiently wide skin area at an individual region of the body. Therefore, the measuring electrode with a diameter of approximately 5 mm is thought to be appropriate.

3.4 *Skin hydration and contact ratio*

To what extent the skin admittance is affected by skin hydration was examined by observing the time course of changes in the admittance under several different conditions at 23°C, 60 per cent RH. The results thus obtained are shown in Fig, 5, in which curve (*a*) was that obtained by attaching a dry electrode on to normal skin surface, (*b*)

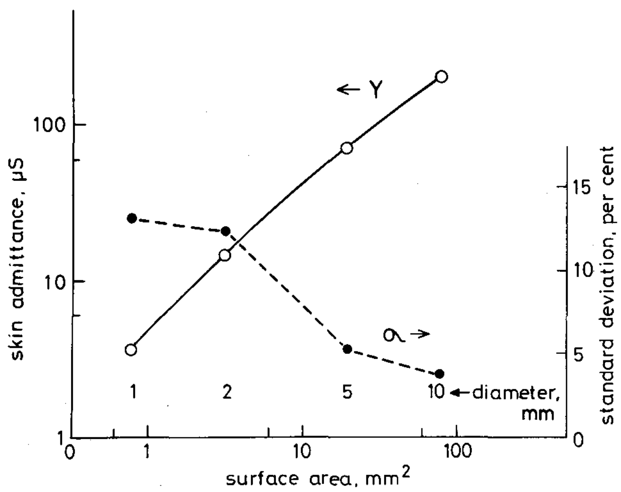

Fig. 4 *Skin admittances and their standard deviations for varied surface area of an electrode*

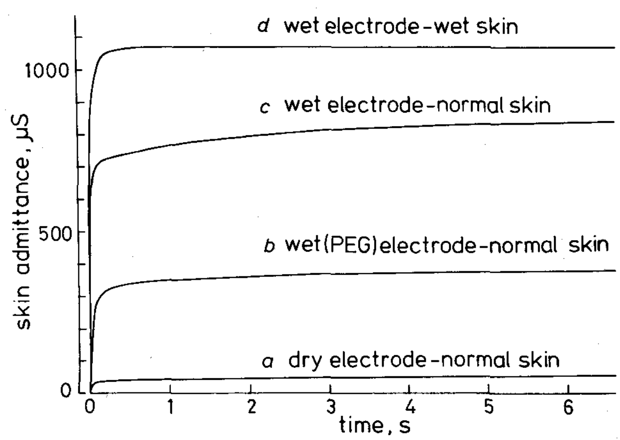

Fig. 5 *Time course of changes in skin admittance under various conditions*

attaching the electrode wetted with PEG (polyethylene glycol, molecular weight = 400) (CLAR *et al.*, 1975), (*c*) attaching the electrode moistened with water, and (*d*) attaching a water-moistened electrode onto the skin surface, which had also been moistened with water, for 10 min. It is known that PEG used for (*b*) does not markedly alter the skin hydration within a short period of time. Therefore a 7·5 times increase in Y from (*a*) to (*b*) in Fig. 5 is not due to a change in skin hydration but due to increasing the contact between the electrode and the skin, caused by the role of PEG (relative permittivity $\varepsilon_s \approx 10$) as a junction liquid. Namely, the air gap has been filled with PEG and the electrical connection between the electrode and the stratum corneum is improved because of the high value of ε_s. The high value of Y immediately after electrode attachment in (*c*) is also due to the function of water ($\varepsilon_s \approx 80$) as a junction liquid because water penetration in 0·2 s is small. In the case of (*d*), the contact might be as well as that in (*c*) or even greater because of softened skin. Therefore, the slowly increasing portion of the curve (*c*) after about 0·2 s is primarily due to the changes induced by progressive skin hydration in the relative permittivity and resistivity of the stratum corneum. This change due to hydration was only about 30 per cent even under such an extreme condition as (*c*), and it is very much smaller than the tenfold changes due to improving the contact.

The state of the contact is an element influencing the measured skin admittance to a major degree. Consider this in detail: a dry metal electrode is only partially in contact with the skin; therefore, normal skin admittance Y is very low compared with the skin admittance Y_0 obtained with the electrode having perfect contact with the skin. Now, we represent the degree of lowering of Y by η. Considering the skin admitted dependency on the skin surface under the electrode, i.e. the stratum corneum, from the results of Section 3.3, the skin admittance can be represented as follows:

$$Y = \eta Y_0 = \eta(1/\rho + j\omega\varepsilon)S_0/d, \qquad 0 \leqslant \eta \leqslant 1 \qquad (2)$$

where S_0 = electrode area, d = mean thickness of the stratum corneum, ρ, ε = resistivity, relative permittivity of the stratum corneum. From eqn. 2, the equivalent area contacting of the electrode and the skin is considered as $S = \eta S_0$. Then, η ($= S/S_0$) is named as the contact ratio. In Fig. 5, it can be said that the occurrence of a large change of Y without large variation of ε, ρ and d is due to the change of this contact ratio. The skin admittance change in an ordinary measurement also can be considered in the same way.

On the basis of the above observations, it may be said that changes in the intrinsic electrical properties of the stratum corneum with skin hydration only slightly contribute to variations in Y values observed from normal skin, whereas changes in the contact ratio caused by changes in skin hydration contribute predominantly to the variations in Y. Then, it can be said that this method is one of estimating the skin moisturisation by the medium of the contact ratio. However, the factor deciding the contact ratio is not only the skin moisturisation but also season, age, environmental conditions etc. Therefore measurement of the absolute water content of the skin is difficult.

4 Instrument for measurement of skin moisturisation

4.1 *Design of the instrument*

The experimental results described above indicated that the skin admittance is dependent upon the contact ratio between a dry electrode and the surface of the stratum corneum, and the contact ratio is related to the water content of the skin. The method for measuring the degree of skin moisturisation utilising the skin admittance, therefore, is based on this principle. Desirable conditions for skin admittance measurement may be summarised as follows:

(*a*) The measuring frequency should be higher than 10 kHz to minimise the influence of ions. However, if the frequency is too high, e.g. more than 1 MHz, the value of admittance becomes too large, and thus it becomes difficult to increase the surface area of an electrode. Moreover, the influence of stray capacitance is expected to be large. Thus, a frequency of about 100 kHz is most appropriate.

(*b*) The contact pressure applied to an electrode should be adjustable, and a pressure of about 100 g cm^{-2} is appropriate.

(*c*) Although dispersions in observed values of the admittance can be decreased by increasing the surface area of the measuring electrode, the diameter of the electrode is best kept to about 5 mm, otherwise it is difficult to place the electrode on a desired region of the skin.

It is known that the phase angle ϕ ($= \arctan B/G$) of the skin admittance Y ($= G + jB$) is quite large under a natural (normal) skin condition,* and it is capacitive ($B > G$). Therefore the change of the admittance in this state is most interesting and important for moisturisation measurement. When the skin becomes drier than normal, the phase angle is not largely changed, whereas the conductance G and the susceptance B are decreased. On the other hand, when the skin becomes much more moist than normal, the value of $|Y|$ ($= \sqrt{(G^2 + B^2)}$) increases and the phase angle decreases simultaneously. Thus, the increase of G becomes outstanding. This tendency occurs markedly when the skin is moistened with water. Therefore, as a parameter for the skin moisturisation, B or C is appropriate when the moisturisation is relatively low, while G is more suitable in the case of high moisturisation. However, since it is troublesome to use two parameters separately, the absolute value of the admittance, i.e. $|Y|$, may be used as an unified parameter for extensive use. For this reason, the value of $|Y|$ was employed in the present study.

4.2 *Construction of the instrument*

4.2.1 *Electrode and circuits.* As shown in Fig. 6, the electrode used was a concentric type, the diameter of the inner measuring electrode being 5 mm, and the inner and outer diameters of the surrounding passive electrode being 10 mm and 20 mm, respectively. The space between these two electrodes was filled with epoxy adhesive resin, and the tip to be contacted with the skin was finished to be flat by gold plating. The electrode element was pulled out of

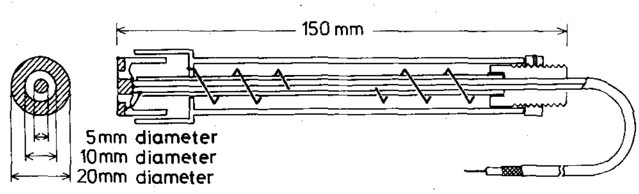

Fig. 6 *Concentric electrode as constructed*

* *According to actual observation, ϕ = 70–80° at f = 100 kHz–3·5 MHz.*

the mantle by the constant tension of a coil spring. This force was about 314 g, which was equivalent to $100\,g\,cm^{-2}$. When the electrode is being attached to the skin, it stays slightly pushed into the mantle, thus producing a constant pressure. If the pressure on the skin is too large, the electrode will retract before damage occurs.

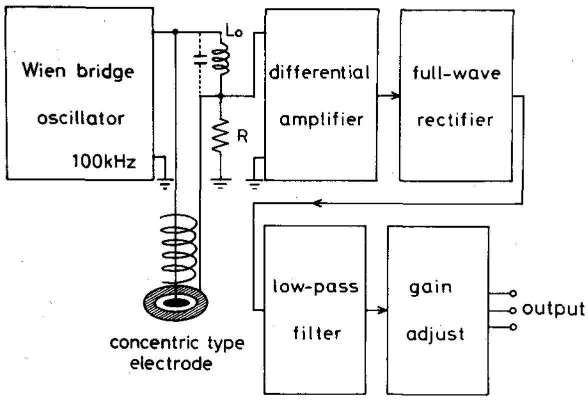

Fig. 7 *Circuit diagram of the admittance measuring system*

The block diagram of the admittance measuring circuit is shown in Fig. 7. A two-electrode method with a constant voltage source was employed. A sinusoidal wave voltage (100 kHz, 2 V) was applied by a Wien bridge oscillator to the electrode, and the current produced was detected with the resistor R ($10\,\Omega$) and amplified by the differential amplifier. The capacitance (160 pF) in the cable and electrode could be compensated by L_0 (about 20 mH). The signal was passed through the full-wave rectifier and the low-pass filter (cutoff frequency = 5 Hz), and converted to the DC signal proportional to the skin admittance. Such DC signals were passed through the gain adjuster and input to the analogue-to-digital convertor.

4.2.2 *Data processing system.* The block diagram of the entire system for data processing is illustrated in Fig. 8. The admittance measuring circuit described in Section 4.2.1 and the 12-bit analogue-to-digital convertor were each on one card board, and they were stored in a microcomputer (PC-9801, NEC), as the standard set of PC-9801, were also used.

Only the attachment of the electrode onto the skin required manual operation. All other procedures were automatic. Fig. 9 shows an example of observed data displayed in colour. When a new series of observations is to

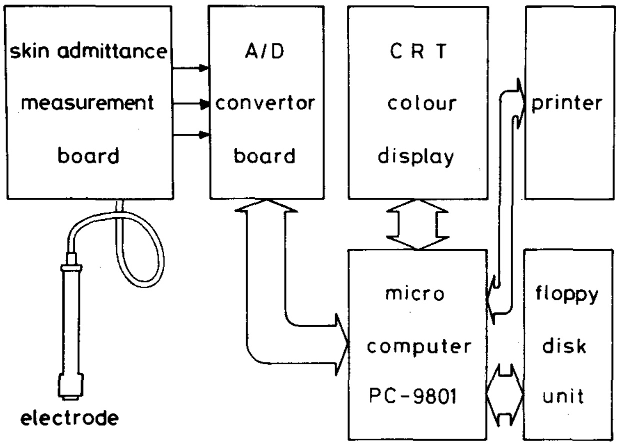

Fig. 8 *Block diagram of the admittance measuring system*

be started, we call the program and input various measuring conditions, the subject's name and the site of measurement through the keyboard to keep the computer in a standby state. As soon as the electrode is attached to the skin, automatic sampling starts at 10 ms intervals for 4 s. Upon the termination of sampling, the data are displayed in colour in a form of the time-course curve. With this display, one may confirm whether the measurement was properly made or not. If the result displayed is judged to be erroneous, entire results can be cancelled by keyboard command. After the measurement is repeated up to preset times, the mean value and its deviation at every observation time are displayed graphically, and the mean value with deviation at 3 s after the electrode attachment is also displayed. These data can be printed or stored on a floppy disk.

4.3 *Examples of observed data*

4.3.1 *The influence of ions.* It has already been confirmed that the influence of ions on the skin admittance is very large in low-frequency ranges and nearly constant in a frequency range from 10 kHz to 3 MHz. However, since the influence of ions is a very important matter, further investigations were made using the instrument constructed.

Multiple measuring points were set on the ventral side of the forearm of a subject. The site (*a*) was in the normal skin condition, (*b*) was that moistened with tap water, (*c*) was that moistened with 0·9 per cent NaCl solution and (*d*) was that moistened with 9 per cent NaCl solution. For each of (*b*), (*c*) and (*d*) one drop of the solution was placed on the spot, wiped off 10 s later with a piece of gauze, then the electrode was attached 2 s later, and the admittance measured 3 s later was employed. A C–C measuring unit (IB-354, IBS, measuring frequency 3·5 MHz) was used in

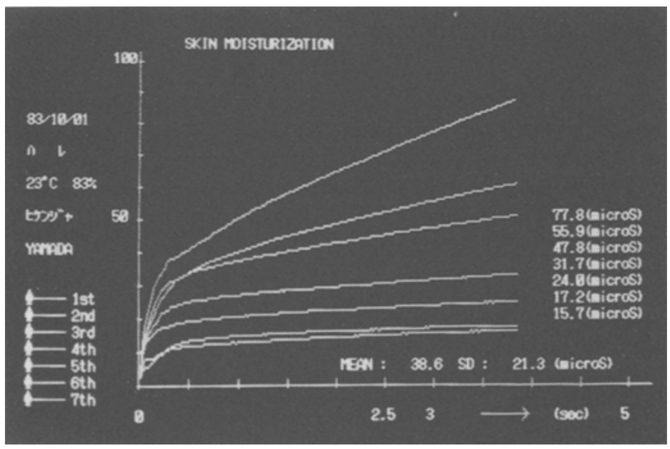

Fig. 9 *Example of the data displayed in colour*

addition to the main instrument (measuring frequency 100 kHz). In the case of measurement with 3·5 MHz frequency, the result was expressed in terms of capacitance (pF) and conductance (μS). For the purpose of comparison, these values were converted to admittance.

Table 1 shows the results thus obtained. The difference between (*a*) and (*b*) was large, whereas differences between (*b*), (*c*) and (*d*) were not so large. The influence of ions relative to that of water may be reflected by a ratio of $(Y_d/Y_b)/(Y_b/Y_a)$. This ratio was 0·07 at 100 kHz, and 0·26 at 3·5 MHz, indicating that the use of 100 kHz was more advantageous. Since normal skin is supposed to contain relatively low concentrations of ions, the result shown in Table 1 may be said to be within an acceptable range.

Table 1 Effects of ions on skin admittance

Condition	Y	100 kHz n	100 kHz $Y \pm SD$ (μS)	100 kHz Y/Y_a	3·5 MHz n	3·5 MHz $Y \pm SD$ (μs)	3·5 MHz Y/Y_a
(*a*) normal	Y_a	12	$34 \pm 4·4$	1	18	112 ± 75	1
(*b*) tap water	Y_b	5	796 ± 35	22	10	549 ± 64	4·9
(*c*) 0·9 per cent NaCl	Y_c	11	874 ± 97	25	11	610 ± 93	5·4
(*d*) 9 per cent NaCl	Y_d	10	1130 ± 114	33	11	711 ± 84	6·3

4.3.2 *Changes during dehydration processes.* Human skin becomes dampish and smooth immediately after washing with water or bathing. The water content of skin is obviously increased under such a condition. The water contained in the stratum corneum, however, vaporises rapidly, and the original equilibrium state with the environment is restored. The process of the uptake of water by skin is called hydration, and that of the loss of water is called dehydration. The relationship between the skin admittance and the skin moisturisation was then examined utilising these hydration and dehydration processes.

The ventral side of the forearm of each of several subjects was dipped into 42°C warm water for 5 min, then wiped off with gauze, and the time course of changes in the skin admittance was measured. This series of experiments was carried out in winter, under a condition of 20°C and 40 per cent RH. The result obtained is shown in Fig. 10. The skin admittance was markedly increased by hydration and decreased with the progress of dehydration. Thus it could be confirmed that the skin admittance is strongly correlated with the water content of skin.

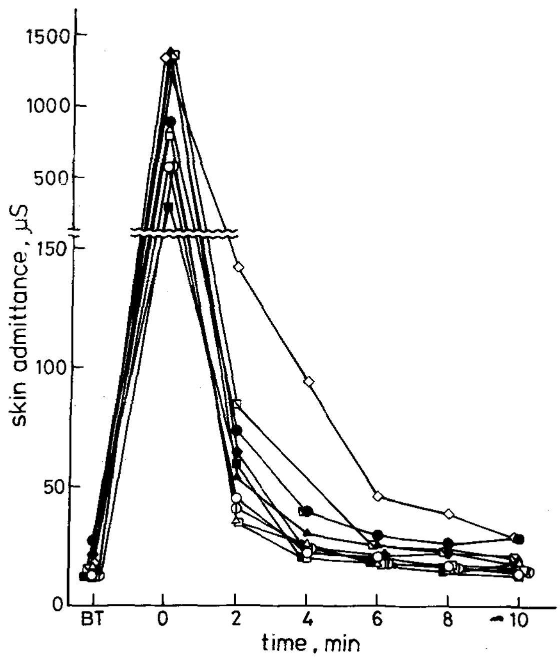

Fig. 10 *Changes of skin admittance during the process of dehydration*
BT: before treatment

4.3.3 *Changes due to different circumstances.* It is our common experience to notice that the skin becomes dry or moist depending upon environmental conditions. However, since such influences of circumstances on skin moisturisation have not been studied in detail, we carried out some experiments on this matter. The ventral side of the forearm of healthy subjects was equilibrated with the atmosphere of 21°C, 40 per cent RH, then it was inserted (at $t = 0$) into a thermohydrostat chamber of 21°C, 80 per cent RH. Fig. 11 shows the change of skin admittance induced by this humidity change. According to Fig. 11, the admittance was changed with a time constant of about 2 min, and a steady state was achieved 5 min later.

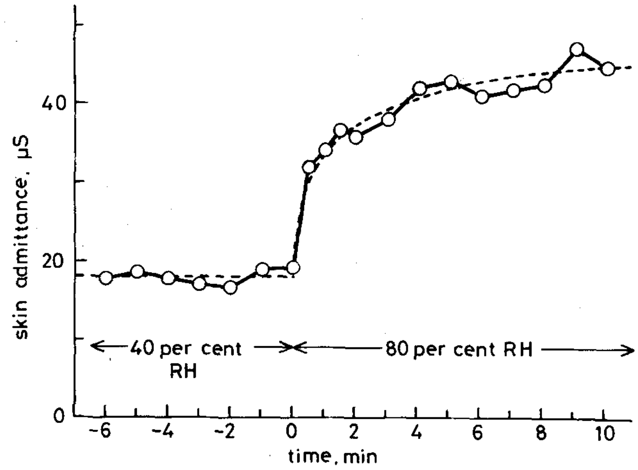

Fig. 11 *Response of skin admittance to an environmental change*

In another experiment the temperature was kept constant while the humidity was changed, and the admittance at the steady state was measured. Fig. 12 shows the results obtained from four subjects. In the range 35–65 per cent RH the admittances gradually increase with increasing relative humidity. In the range 65–80 per cent RH, the admittances rapidly increase and show much variation between subjects. However, these results indicate that the increase of the admittance induced by increasing environmental humidity reflects the rise in the moisturisation of the skin.

5 Summary

The properties of skin admittance were investigated from a standpoint of applying it to skin moisture measurement, and the following results were obtained:

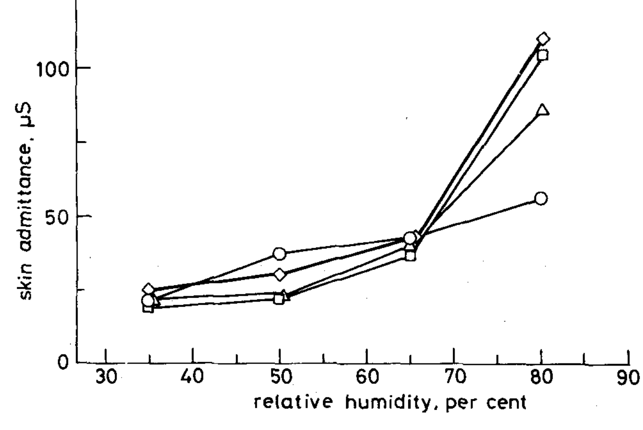

Fig. 12 *Variation of skin admittance with environmental changes*

(*a*) It is desirable to use a frequency higher than about 10 kHz for skin admittance measurement. However, the admittance becomes too large when the frequency is extremely high, and the size of the electrode cannot be increased too much. Therefore, a frequency of about 100 kHz is appropriate. The influence of ions upon the admittance was found to be much smaller in a frequency range higher than about 10 kHz in comparison with that in the lower frequency ranges.

(*b*) Since the admittance is largely influenced by the contact pressure for a dry electrode, the pressure should be adjustable. The most appropriate pressure was found to be $100\,\mathrm{g\,cm^{-2}}$.

(*c*) As far as variations in observed admittance values are concerned, the larger the surface area of a measuring electrode, the smaller the variation. However, taking the size of a passive electrode into account, we recommend a diameter of about 5 mm for a measuring electrode in practice.

(*d*) Skin admittance is primarily determined by the relative permittivity, the resistivity and the thickness of the stratum corneum and by the contact ratio between a dry electrode and stratum corneum. Among these, the contact ratio predominantly determines the changes of the admittance.

(*e*) The moisturisation measurement utilising skin admittance is based on the change of the contact ratio induced by differing the skin moisturisation.

(*f*) Based on the observations and considerations stated above, an instrument for the measurement of skin admittance was constructed. With this system measuring procedures were automatic, variations in observed data were reduced and the reliability of the result was improved.

Studies left for the future are:

(i) many standard levels of skin admittance are to be determined due to different measurements from normal skin under many different conditions

(ii) skin admittances in special circumstances such as cutaneous disease are to be confirmed.

References

AIKAWA, T. (1959) On the capacity of aperture type electrodes (in Japanese). *J. Inst. Elect. Eng. in Japan*, **79**, 751–756.

CAMPBELL, S. D., KRANING, K. K., SHIBLI, E. G. and MOMII, S. T. (1977) Hydration characteristics and electrical resistivity of stratum corneum using a noninvasive four-point microelectrode method. *J. Invest. Dermatol.*, **69**, 290–295.

CAMPBELL, S. D., YEE, S. S. and AFROMOWITZ, M. A. (1977) Two applications of photoacoustic spectroscopy to measurements in dermatology. *J. Bioeng.*, **1**, 185–188.

CLAR, E. J., HER, D. P. and STURELLE, C. G. (1975) Skin impedance and moisturization. *J. Soc. Cosmet. Chem.*, **26**, 337–353.

QUATTRONE, A. J. and LADEN, K. (1976) Physical techniques for assessing skin moisturization. *Ibid.*, **27**, 607–623.

SERBAN, G. P., HENRY, S. M., COTTY, V. F. and MARCUS, A. D. (1981) *In vivo* evaluation of skin lotions by electrical capacitance, II. Evaluation of moisturized skin using an improved dry electrode. *Ibid.*, **32**, 421–435.

TAGAMI, H., OHI, M., IWATSUKI, K., KANAMARU, Y., YAMADA, M. and ICHIJO, B. (1980) Evaluation of the skin surface hydration *in vivo* by electrical measurement. *J. Invest. Dermatol.*, **75**, 500–507.

YAMAMOTO, Y., YAMAMOTO, T., OHTA, S., UEHARA, T., TAHARA, S. and ISHIZUKA, Y. (1978) The measurement principle for evaluating the performance of drugs and cosmetics by skin impedance. *Med. & Biol. Eng. & Comput.*, **16**, 623–632.

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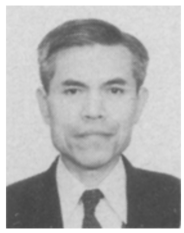

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