Hydration of Human Stratum Corneum Studied In vivo by Optothermal Infrared Spectrometry, Electrical Capacitance Measurement, and Evaporimetry

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Optothermal infrared spectrometry (OTIS) is a recently introduced method for specific measurement, in vivo, of water in the skin. In the present study the method proved well suited to register the increase in water content in stratum corneum following application of emollients. The results were compared with those obtained with a commercial instrument, the Corneometer, and the two methods were found to match very closely. Neither method indicated any difference in hydration of normal skin between young and elderly women. Evaporimetry was used to detect any influence on the water barrier function of the skin following application of emollients; even though the water content of the skin was significantly higher after emollient treatment, the transepidermal water loss remained unchanged. (Received November 5, 1987.)

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The water content of stratum corneum is of importance for the appearance and function of the skin (1). Determination of the degree of hydration of the horny layer could prove useful in the investigation of factors contributing to or relieving ‘dry skin’, including xerosis in elderly people, and also in studies on the barrier function of the skin in health and disease.

Various methods have been tried for measuring the water content in skin (2). In the present investigation a recently introduced, specific method was used for studies in vivo, namely optothermal infrared spectrometry (OTIS) (2, 3). The stratum corneum water content and the effect upon it of emollients was studied in healthy women of two age groups. A non-specific electrical capacitance measurement (ECM) method was used for comparison (4, 5). The skin barrier function was studied by evaporimetry (6).

No difference in the water content of apparently normal skin emerged between young and elderly women. After application of an emollient the water content increased significantly, but no effect on the barrier function could be demonstrated.

MATERIAL

Test subjects

Three groups of volunteers were investigated: Group I, 8 young women from the clinical staff aged 18–23 years; Group II, 8 elderly women aged 70–76 years. Both groups took part in the study on the possible influence of age on the water content of normal skin. Group II also took part in a study on the effect of an emollient lotion. A third group, Group III, comprised 7 women aged 19–77 years (median 30), and was included in a study of the effect of emollient cream on the water content and barrier func-

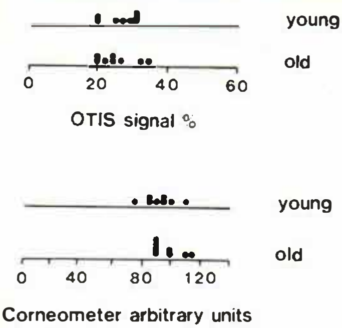

Fig. 1. Relative hydration in normal skin of 8 young women (Group I) and 8 elderly women (Group II) as measured by OTIS (20 Hz) and with the Corneometer. Individual mean values from the four test areas are plotted.

tion of the epidermis. All subjects were healthy and the skin of the volar aspects of the forearms appeared normal. Nothing but soap and water was applied to the test areas for at least 3 days before the study.

Test areas

The volar aspects of both forearms were used. The distal and proximal halves were separated by adhesive tape during the study involving emollients, to minimize the risk of contamination from treated to untreated control areas.

METHODS

Optothermal infrared spectrometry, OTIS

The technique is based on detection of heat generated in a sample owing to absorption of periodic monochromatic radiation with a wavelength of 1940 nm, where water has a highly specific absorption band (2, 3). The heat is conducted to a thin sapphire plate in contact with the skin and transparent to the radiation directed to the test area. The subsequent thermal expansion of the plate is transformed to an electrical signal by an annular piezo-electric crystal cemented to the periphery of the plate. The signal is fed into a lock-in amplifier and recorded on a pen-recorder. The probe is suspended in a spring-loaded counter-balance device, and the sapphire plate is placed in contact with the skin under light pressure.

The measuring time for each test area was limited to 1 min. Even during such a brief period, a small but steady increase in the optothermal signal, clearly due to accumulation of water caused by the occlusive effect of the probe, can usually be registered. A straight line was fitted to the recorded signal, and the fitted value after 30 s was arbitrarily chosen as representative of the water content. The registered value was recalculated to a 100% scale, in which the optothermal signal recorded with the sapphire plate in contact with pure water constituted the 100% level and the signal for the probe in air the zero level.

Two chopping frequencies were chosen, 20 Hz and 3 Hz. Theoretically, the higher frequency should cover a depth down to just under 30 µm (2, 3). If the thickness of the stratum corneum of the forearm is assumed to be no more than 10–15 µm, the higher-frequency recordings will reflect the hydration not only of the stratum corneum but also of the upper part of stratum spinosum, the water content of which is higher than that of stratum corneum. The lower frequency of 3 Hz would cover still deeper parts of the epidermis.

Electrical capacitance measurement, ECM

Measurements were made with the Corneometer CM 420 (Schwarzhaupt Medizintechnik GMBH 5000, Cologne, West Germany) (4). The electrical conductance of organic materials such as proteins in the stratum corneum is greatly influenced by the water content. Water also affects the capacitance, which increases with increasing hydration of the stratum corneum. The instrument includes a probe acting as a condensor, the capacitance of which is influenced by changes in the dielectric constant of the material in contact with the probe. The probe is held in contact with the test area at a standard pressure with the aid of a built-in spring mechanism. The signal is digitally displayed within 3 s, and is expressed in arbitrary units. The method is considered to reflect the degree of hydration in the deeper part of stratum corneum (7).

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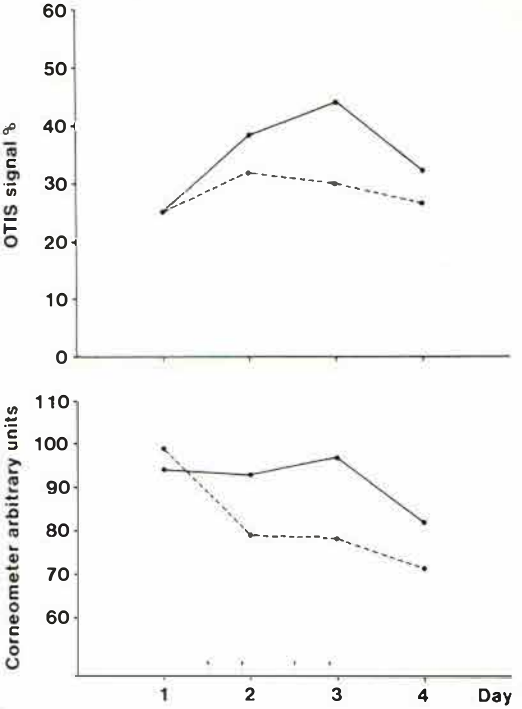

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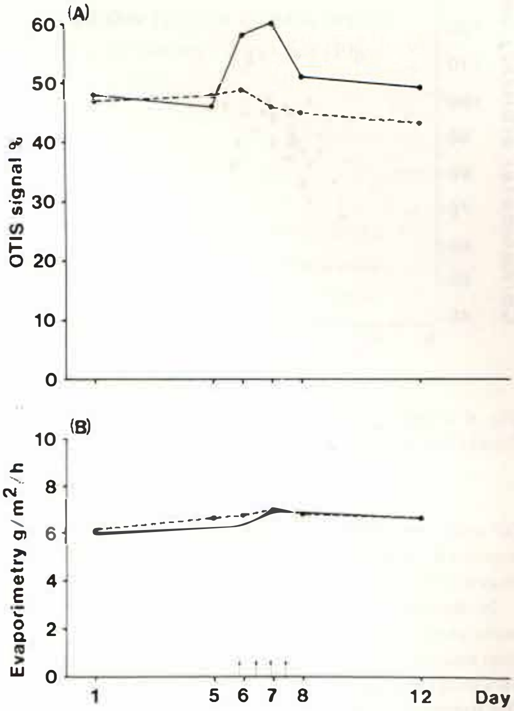

Fig. 2. The effect of emollient lotion on hydration of normal skin in 8 elderly women (Group II) determined with OTIS (20 Hz) and the Corneometer. Mean values for 2 treated and 2 control areas in each subject. Measurements were made once daily on days 1-4. Lotion was applied in the morning on days 2 and 3, 2 h before measurement, and on the preceding evening (*arrows*). ——, Emollient-treated skin; ------, untreated skin.

Fig. 3. (*A*) OTIS (3 Hz). The effect of emollient cream on hydration of normal skin in 7 women (Group III). (*B*) Evaporimetry. No effect on transepidermal water loss (TEWL). Mean values for 2 treated and 2 control areas in each individual. The measurements were made once daily on days 1, 5, 6, 7, 8, and 12. Cream was applied in the morning, 2 h before measurement, and in the evening on days 6 and 7 (*arrows*). ——, Emollient-treated skin; ------, untreated skin.

Evaporimetry

The transepidermal water loss (TEWL) or rate of evaporation was determined with the Evaporimeter EP1 (Servo Med AB, Stockholm, Sweden).

TEWL is assessed by determining the vapour pressure gradient in the water boundary layer surrounding the skin. This gradient, which is highly stable in the absence of forced convection, is proportional to the amount of water vapour passing through the boundary layer per unit time and area by evaporation from the skin surface (8).

The measuring unit of the probe is protected by an open cylindrical Teflon capsule which is placed over the test area. The TEWL value, expressed as $g/m^2/h$, was registered on a pen-recorder until a stable level was reached (usually within 1–2 min).

Study design

All measurements were performed by the same nurse, the subject resting comfortably on a couch in a quiet room. The test areas were first gently wiped with a dry cellulose swab. After at least 5 min rest the temperatures of the test areas were registered with a thermocouple thermometer (Ellab, type TE3). Each test area was then measured with the Corneometer (Groups I and II) or the Evaporimeter (Group III), after which the optothermal measurement was made. Before and after each optothermal measurement the values for pure water and air were registered.

The studies involving Groups I and II were made in December; the room temperature varied between

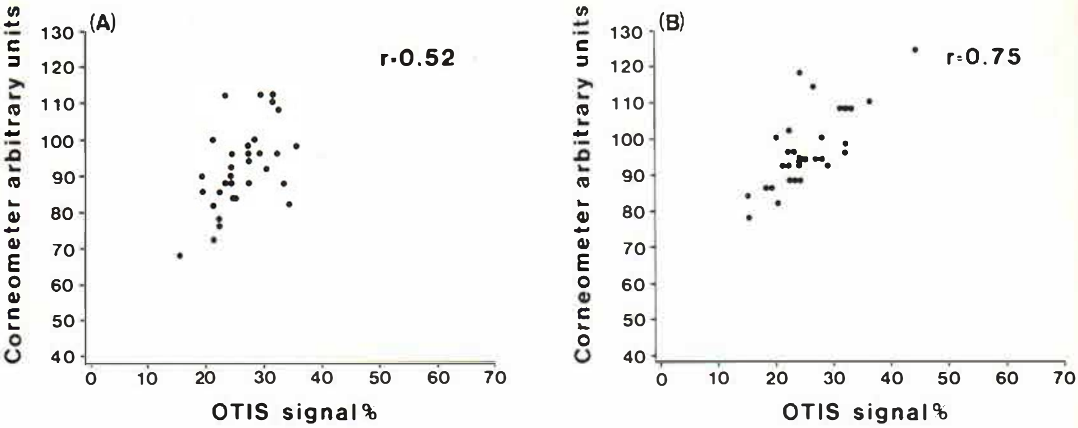

Fig. 4. Comparison of hydration values obtained by OTIS (20 Hz) and the Corneometer. (*A*) Group I. (*B*) Group II. Values for the 4 test areas in 8 individuals.

20° and 21° and the ambient relative humidity between 18% and 28%. The study involving Group III was made in April; the ambient temperature varied between 21° and 22° and the relative humidity between 10% and 22%.

In the study of the effect of emollient cream or lotion, two of the four test areas were treated and two were used as controls. In the study on Group II, measurements were made once daily on days 1–4. Lotion was applied in the morning on days 2 and 3, 2 h before measurement, and on the preceding evening. In Group III, measurements were made once daily on days 1, 5, 6, 7, 8, and 12. Cream was applied in the morning 2 h before measurement, and on the evenings of days 6 and 7.

Test substances

In the investigation of the effect of emollients, an oil-in-water cream (Decubal®) and a lotion (Decubal®, Dumex Ltd, Copenhagen, Denmark) were used.

Statistical methods

Student's unpaired *t*-test was used for comparison of water content of untreated skin in the two age groups. For assessing the effect of emollient treatment two-way analysis of variance was used.

RESULTS

Comparison of water content in normal skin in two age groups

No difference emerged between young and elderly women with regard to water content of normal skin, either by OTIS at 20 Hz or by ECM (Fig. 1).

Effect of emollients on water content of normal skin

In Group II, significantly higher values were recorded by OTIS at 20 Hz and by ECM in the lotion-treated areas, than in the control areas (Fig. 2). In Group III the effect of emollient cream was investigated by OTIS at 3 Hz (Fig. 3 A). The hydration showed a statistically significant increase at the first assessment 2 h after starting treatment, and a decrease on the day after stopping treatment.

Effect of emollients on skin barrier function

Evaporimetry showed that application of emollient cream did not influence skin barrier function of normal skin in Group III (Fig. 3B).

Comparison of OTIS and ECM

A comparison of the water content in untreated skin assessed with OTIS and ECM is made in Fig. 4. The concordance was higher in Group II ($r=0.75$), than in Group I ($r=0.52$) (Figs. 4A, 4B).

DISCUSSION

Various, largely non-specific methods have been used for the measurement in vivo of the water content of stratum corneum (2). The Corneometer responds to changes in the dielectric constant of the material studied; such changes influence the capacitance of the condensor which forms part of the probe. Water has a relatively high dielectric constant, which means that changes in water content of the material studied will greatly influence the capacitance—the higher the water content, the higher the capacitance registered. This method has recently been used in studies on the water content of atopic skin (5).

Optothermal spectrometry is presented as a new aid for dermatological research. In the present investigation it was employed as a specific detector of water, utilizing the specific absorption at 1940 nm (2, 3). The technique is derived from photoacoustic spectroscopy, both methods being based on the detection of heat generated in a sample by absorption of periodic radiation. OTIS is less sensitive than photoacoustic spectroscopy to environmental disturbances such as movements of the skin area tested, thermal expansion in the sample, and evaporation of water from it (2).

By varying the chopper frequency it is possible with OTIS to measure different thicknesses of the sample, an important feature in view of the increasing water content with increasing depth of the stratum corneum (9). Owing to the uneven distribution of water in the skin, however, it is not possible by means of OTIS to obtain absolute values for skin water content (2).

Although the strata covered by the two chopping frequencies chosen would also embrace both the stratum corneum and the upper parts of the stratum spinosum, our results indicate that the method is well suited to assessing hydration of the stratum corneum. This could be explained by the following two factors. Firstly, water in the layer closest to the probe, the stratum corneum, gives most weight to the integrated optothermal signal. Secondly, the water content of the stratum corneum is the only variable, the stratum spinosum being considered to remain constant under normal conditions (2). A still higher chopping frequency would be desirable when assessing the hydration of the stratum corneum proper, and this ought to be practicable, given some technical improvements in the probe.

Determination of the water content of stratum corneum could be of use when investigating factors contributing to or relieving 'dry skin', such as may occur in elderly people and patients with atopic skin. Subnormal water content in clinically dry skin of patients with atopic dermatitis has been described (5), whereas other, clinically normal skin areas in patients of the same category seem to have a normal water content (5, 10). Contradictory results, with findings of higher water content in unaffected skin of atopic patients compared with normal controls, have also been published, however (11). Scaly skin such as seen in certain dermatoses has been shown to have a subnormal water content (12, 13). In senile xerotic skin there seems to be only a moderately decreased water content in the stratum corneum, compared with normal skin (14). Pierard (15) maintains that 'dry skin' occurring in the winter is a misnomer, because he could find no lack of moisture in this condition. The subjective impression that the skin is dry seems to be very common among elderly people, and as many as 59% have been reported to have this belief (16).

However, little is actually known about this problem, although Potts et al. (17) found the water content in aged skin to be only moderately lower than that in the skin of younger people. Hegner et al. (18) showed some decrease in hydration of stratum corneum of the inner aspect of the arm with increasing age in adult women. Gloor et al. (11), on the other hand, were unable to show any distinct age dependency of the water content of stratum corneum.

In the first part of the present study we determined the water content of apparently normal skin in young and in elderly women. No difference in the hydration emerged with either OTIS or ECM.

Admittedly, subnormal hydration of stratum corneum in elderly people is conceivable, but the methods we have used are too insensitive to detect such a subtle difference from normal. It might be argued that with the thinning of the stratum corneum commonly believed to be a feature of ageing, the high water content of the stratum spinosum would make up the difference in the signal. However, the horny layer probably retains its thickness throughout life (19).

We have noted in a few experiments that the dehydration of the stratum corneum with an acetone–ether mixture causes a distinct decrease in the OTIS signal, which suggests that the method could also be used for evaluation of 'dry skin'.

We have recently shown, using OTIS, that an emollient cream can promote hydration of the skin (2). In the present study, the effect of an emollient lotion on the hydration of normal skin in elderly women was examined by the same technique, and the results were compared with those obtained with ECM. A significant increase was found with both methods.

OTIS and ECM are based on different principles. They may also register hydration at different depths in the epidermis, and thus could be influenced differently by the water profile of the stratum corneum. Moreover, any pathological or age-dependent change in the epidermis, whether qualitative or quantitative, could affect physical properties such as the dielectric constant. In ECM this constant is used indirectly to reflect the water content, whereas OTIS which is a specific method, would remain uninfluenced. Nevertheless the concordance between the methods in this study is fairly good. The higher concordance in Group II (Fig. 4 B) than in Group I (Fig. 4 A) could possibly be explained by the slightly greater interindividual variation in skin hydration in the elderly women. Gloor et al. (11) obtained similar results.

The effect of an emollient cream was tested in a third group of women, using OTIS at 3 Hz. The increase in water content was comparable to that resulting from application of an emollient lotion.

The degree of hydration of stratum corneum is of importance for the barrier function of the skin (20). Application of emollient cream, which led to a significant increase in the water content, did not affect TEWL, however, and therefore not the barrier function. Triebskorn et al. (7) found no correspondence between TEWL values and changes in the water content of the stratum corneum as measured by infrared spectroscopy. Our results indicate that a limited variation in the absolute water content of stratum corneum such as is achieved by emollients does not influence the rate of TEWL.

In conclusion, OTIS, which is a specific method for assessing water content, should prove valuable for determination of changes in hydration of stratum corneum in vivo.

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