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Effect of exposure of human skin to a dry environment

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Background/aims: Changes in the skin conditions after exposure to low humidity have been generally experienced in everyday life, but there have been few reports to approach it—especially in healthy skin. We have examined the effect of low humidity on healthy human skin by using noninvasive measurement devices.

Methods: Skin conditions on the ventral forearm and the cheek before and after 3 or 6 h exposure to low humidity were evaluated by measuring skin surface conductance, skin surface capacitance and transepidermal water loss. Skin surface replicas were also taken before and after exposure and analysed for roughness parameters—Ra (arithmetic mean roughness value), Rz (10-point height), Sm (mean value of the profile element) and VC1 (anisotropy of skin furrows).

Results: There was a significant decrease of water content of stratum corneum at both test sites from the time points 0 h to 3 h and 6 h ($P < 0.01$) and transepidermal water loss from the time point 0 h to 6 h ($P < 0.05$). Regarding the roughness parameters, a significant increase of Rz in the directions of 45°/225° and 90°/270° to the body axis and Sm in the directions of 0°/180° ($P < 0.05$) on the forearm and VC1 ($P < 0.05$) on the cheek. The parameter Rz also showed a tendency to increase in the directions of 45°/225° ($P = 0.06$) on the cheek. A specific pattern of the changes to be related to the Langer's lines in the surface morphology was observed. The changes of skin surface pattern in our experiment lead us to consider that exposure to low humidity even in such a short period would be related to inducing aggravation of skin texture and the formation of fine wrinkles.

Conclusion: A short exposure of skin to a low-humidity environment induced changes in the moisture contents in the stratum corneum and skin surface pattern, which lead us to assume that a dry environment in our daily life would make fine wrinkles related to lack of water in the stratum corneum.

Key words: low humidity – moisture content – skin roughness – stratum corneum – human skin

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The skin is constantly exposed to various environmental stimuli, because it composes the outermost layer of the body. The skin has not only a barrier function against various stimuli but also a function to prevent the loss of water from the body. It is, therefore, obvious that environmental humidity greatly influences the skin conditions. Andersen et al. (1) studied the effects of dry air on the nasal mucus flow rate, nasal resistance, forced vital capacity, skin resistance and discomfort in eight healthy young men exposed to 9% relative humidity (RH) air for 27 h at 23 °C in an artificial climate chamber. There were no significant changes in the nasal mucus flow rate, showing no discomfort from the body surface, and skin resistance did not change. Reinikainen and Jaakkola (2) evaluated the effect of humidifying air on the dryness of the skin and mucosa, allergic and asthmatic reactions on 211 volunteers in a six-period trial by using both humidified and nonhumidified conditions. The dryness symptom score and allergic symptoms were significantly smaller during the humidified phase than during the reference phase. As described in these two reports, changes such as scabrousness or roughness are generally experienced in a dry environment, but they have rarely been examined from a dermatological viewpoint.

Recently advanced measurement devices have made possible various noninvasive examinations on the skin and provide more parameters to compare the human skin condition (3–9). This situation led us to consider examining human skin conditions with such devices and physiological parameters. Kajiwara et al. (10) examined the influence of airflow on skin physiological parameters. Skin temperature and water content in the stratum corneum were decreased after 60-min exposure of the face to an airflow, but the amount of recovered sebum was unaffected. They

considered that the amount of recovered sebum changes with the temperature, but it was unaffected by airflow velocity. This suggests that the airflow would promote skin damage in an ordinary environment within a couple of hours by causing skin dryness. In addition, Bernadette et al. (11) reported that a 3-h exposure to dry air (30% RH) significantly increased the roughness parameter of skin surface in patients with atopic eczema, whereas no significant change occurred in the controls. This indicates that a short exposure to dry air induces skin roughness in patients with atopic eczema. However, further studies are needed, because they examined only surface roughness as a parameter; they did not examine the changes in healthy individuals and they did not use a dry condition. In the present study, we investigated the effect of dry conditions on human skin by using noninvasive measurement devices.

Materials and Methods

Environmental condition
In the low-humidity environment, the temperature was kept at 24–25 °C and an RH of 10% monitored with a Thermohydrometer THR-VM (Shinei, Japan).

Subjects
In total, 12 healthy human volunteers—four males and eight females, 21–45 years old—without any indications of cutaneous pathology participated in this test.

Trial schedule
The volunteers were not allowed to use makeup on the day of the experiment. One hour before the first measurement, volunteers washed their test sites—that is, the left ventral forearms and the cheeks—with soap free of moisturizer. At the first measurement, the skin surface replicas were obtained from the ventral forearms and the cheeks with silicon (Si) rubber replica material for the 0-h measurement. Then, the test sites were washed once again with soap free of any moisturizer, so that nothing in the replica material affected the following instrumental measurement. No treatment was carried out on the surfaces retained before the instrumental measurements. Another 1 h after washing the skin, the subjects entered the low-humidity room. After about a 10-min rest, instrumental measurement for the time point of 0 h was performed in order to obtain the base value. The volunteers stayed in the room with the humidity maintained at around 10% RH for 6 h. Measurements after the exposure to a dry environment were made at the time points 3 h and 6 h. After the last measurement, skin surface replicas were taken, again.

Both the forearms and the cheeks were uncovered during the test in order to avoid any phenomenon of occlusion and to reach a stable balance of water exchange between the skin and the surrounding medium.

Prohibition
Hot drinks and foods were forbidden throughout the duration of the study.

Measurement devices
Moisture content
SKICON100 (IBS Co., Ltd, Japan) (3–5) was used for measuring the moisture contents in the stratum corneum. These devices are based on the conductance measurement of a fixed high-frequency current of 3.5 MHz. We analysed the averages of five measurements at each site.

Corneometer
The moisture content in the stratum corneum was also measured by using a Corneometer CM825 (Courage + Khazaka Electronic Gmbh, Cologne, Germany) (6, 7). This device is based on a capacitance measurement. We analysed the averages of three measurements at each site.

Transepidermal water loss
The transepidermal water loss (TEWL) was measured by using a Tewameter TM210 (Courage + Khazaka Electronic Gmbh, Cologne, Germany) (8). The average calculated from the data in a stable part of a 2-min measurement was used as a measurement value.

Skin surface pattern
The skin surface pattern was measured by observing the negative replica using Si rubber material. Two kinds of devices were used for analysis. One had a two-dimensional replica image analysis system that used optics and the other had a three-dimensional surface roughness analysis

system (12, 13) for scanning the roughness of the replica surface with a confocal laser.

Two-dimensional replica image analysis

Skin surface replicas were analysed with an image analyser (9). The replicas were illuminated from three directions, with 120 degrees between each pair of directions. The images 4×4 mm of replicas were degraded to pixels, and then the binary image of the skin relief was obtained. Though there are various parameters, we used VC1 in this report. The parameter VC1 is defined as the variation coefficient for the number of black dots in each 13×13 mesh composing the binary image, which shows the anisotropy of the skin furrows.

Three-dimensional surface roughness analysis

A conformal scanning microscope HD100D (Lasertec Co, Yokohama, Japan) was used in order to obtain three-dimensional profiles of the skin. The data were memorized and calculated in order to yield the roughness parameters—Ra, Rz and Sm (International ISO Standard, 4287: 1997). The parameter Ra (μm) is the arithmetic mean roughness value; it represents the arithmetic average value of the filtered roughness profile determined from deviations about the center line within the evaluation length.

$$Ra = (1/L) \int |y(x)| dx \qquad (1)$$

where L = the evaluation length and y(x) = the filtered roughness profile.

The parameter Rz (μm) is the 10-point height—that is, the average of the height of the five highest peaks plus the depth of the five deepest valleys over the evaluation length.

The parameter Sm (μm) is the mean value of the profile element width within a sampling length.

The analysis conditions were as follows: the evaluation length was 2.3 mm and the cutoff wavelength was 1.6 mm. Five arbitrary lines in the analysis area were selected. Then, the average of the five lines was used for the analysis. As shown in Fig. 1, roughness parameters were analysed in four directions of 0°/180°, 45°/225°, 90°/270° and 135°/315°. In each subject, the direction of 0°/180° was along the body axis at the cheek and along the forearm axis at the forearm.

Statistics

Statview 5.0 (SAS Institute, USA) was used for statistical analysis.

Results

Changes in the physiological parameters on water content

Figure 2 shows the chronological change in moisture content in the stratum corneum of the forearms by using SKICON100 and Corneometer CM825. Figure 3 shows the chronological change in moisture content in the stratum corneum of the cheeks by using SKICON100 and Corneometer CM825.

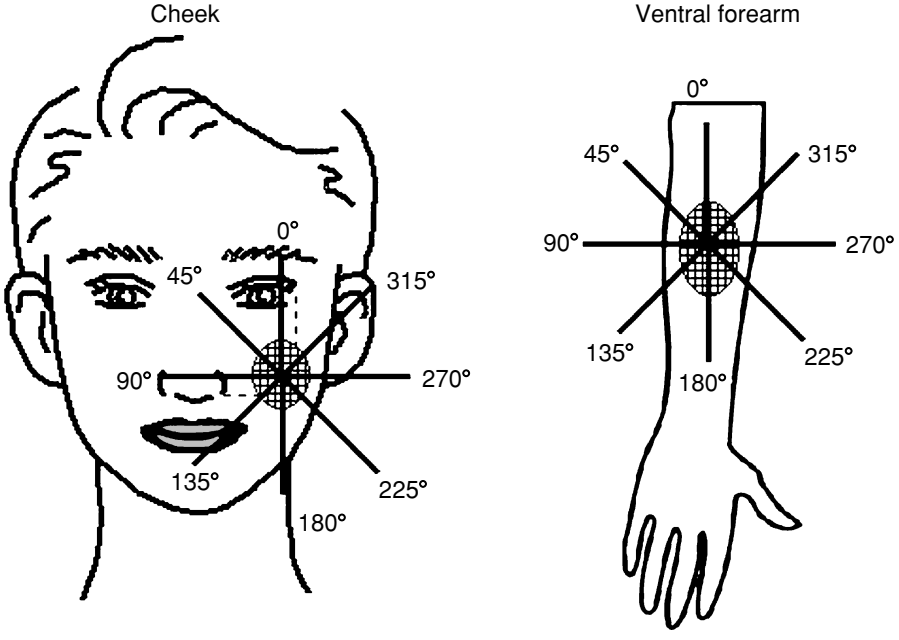

Fig. 1. Direction of analysis of replica roughness parameters (Ra, Rz, Sm) were statistically analysed in four directions. For example, the parameters analyzed at 0° were defined as Ra0, Rz and Sm0.

Concerning the change in moisture content in the stratum corneum, the values of SKICON100 significantly decreased at both test sites from the time points 0 h to 3 h and 6 h with $P < 0.01$, whereas no significant difference was observed in the values of Corneometer CM825. In addition, the value of SKICON100 in the forearm had a tendency to decrease from the time point 3 h to 6 h. In the cheek, there was a significant decrease from the time point 3 h to 6 h ($P < 0.05$).

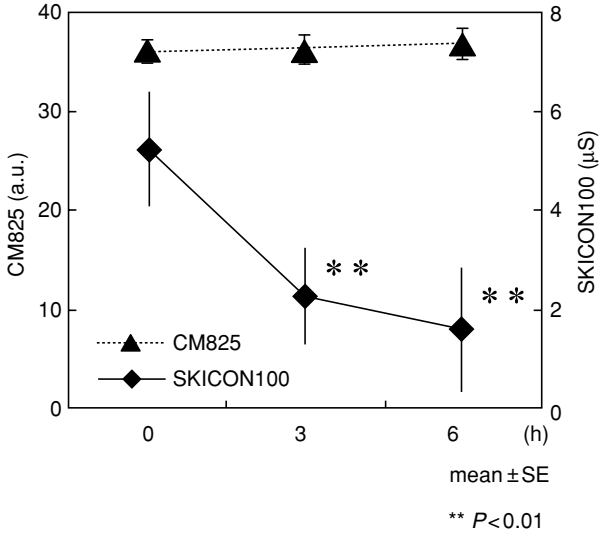

Fig. 2. Change in the moisture content in the stratum corneum on forearm. The moisture content was obtained by SKICON100 and CM825 at 0, 3 and 6 h after start of low humidity treatment.

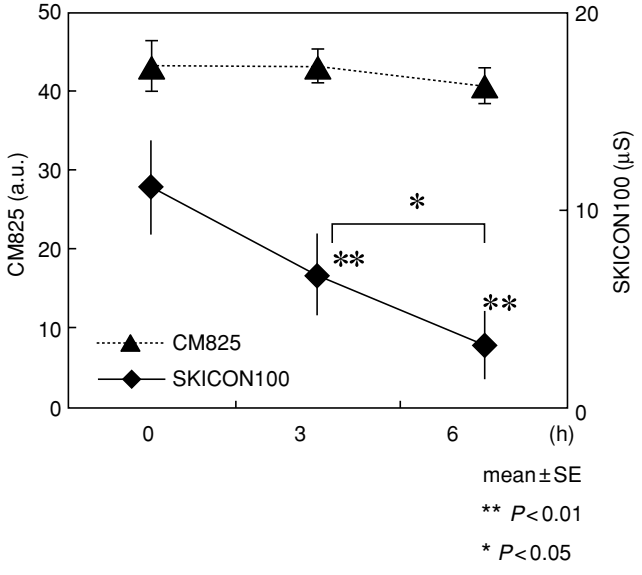

Fig. 3. Change in the moisture content in the stratum corneum on cheek. The moisture content was obtained by SKICON100 and CM825 at 0, 3 and 6 h after start of low humidity treatment.

Changes in the physiological parameters on TEWL

Figure 4 shows the change of transepidermal water loss of both the forearm and the cheek measured by using Tewameter TM210. The values obtained on the forearms showed a decrease at 3 h and the value from the cheeks showed a much lower level at 6 h. The *P*-values on the time points 3 h and 6 h compared with 0 h for the forearms were both under 0.01. In the cheek, the TEWL values showed a tendency to decrease from the time point 0 h to 3 h ($P = 0.084$) and a significant decrease ($P < 0.05$) was observed at 6 h.

Changes in the physiological parameters on skin surface pattern

Figure 5 shows the VC1 value for both the forearm and the cheek before and after the change to a low humidity. Figure 6 shows the changes in the roughness parameters—Ra, Rz and Sm—of the

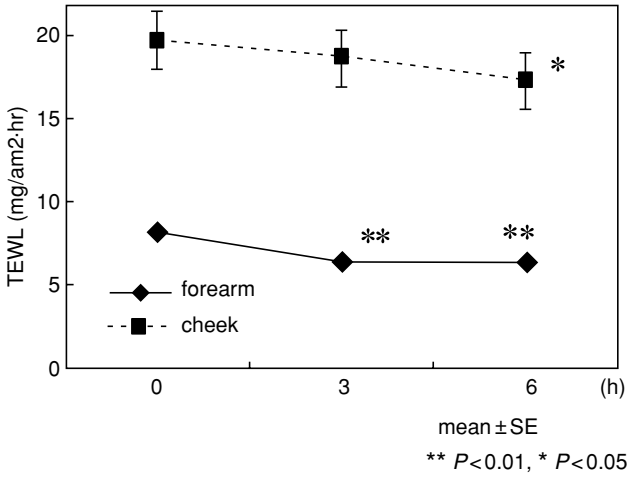

Fig. 4. Change in transepidermal water loss.

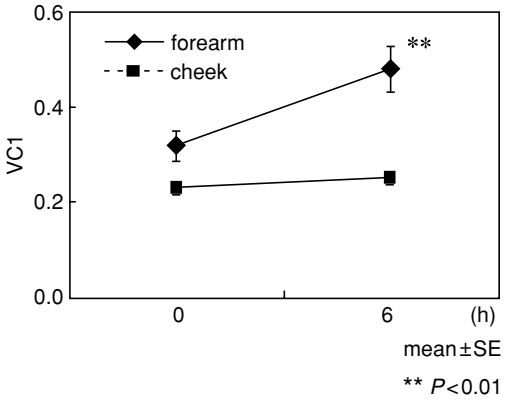

Fig. 5. Change in anisotropy of skin furrows (VCI) after 6 h of low humidity treatment.

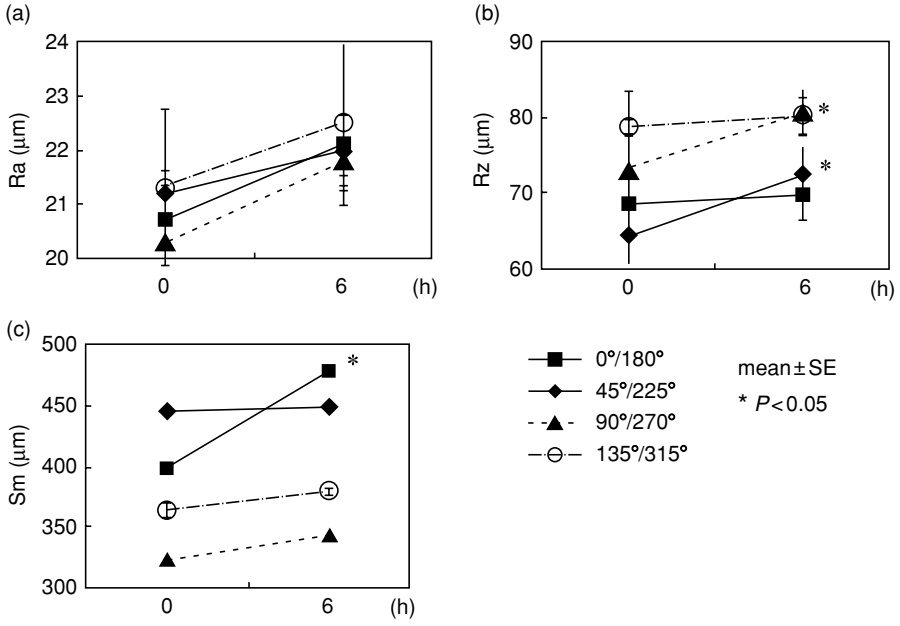

Fig. 6. Changes in skin surface roughness on forearm after 6 h of low humidity treatement. (a) Ra, (b) Rz and (c) Sm.

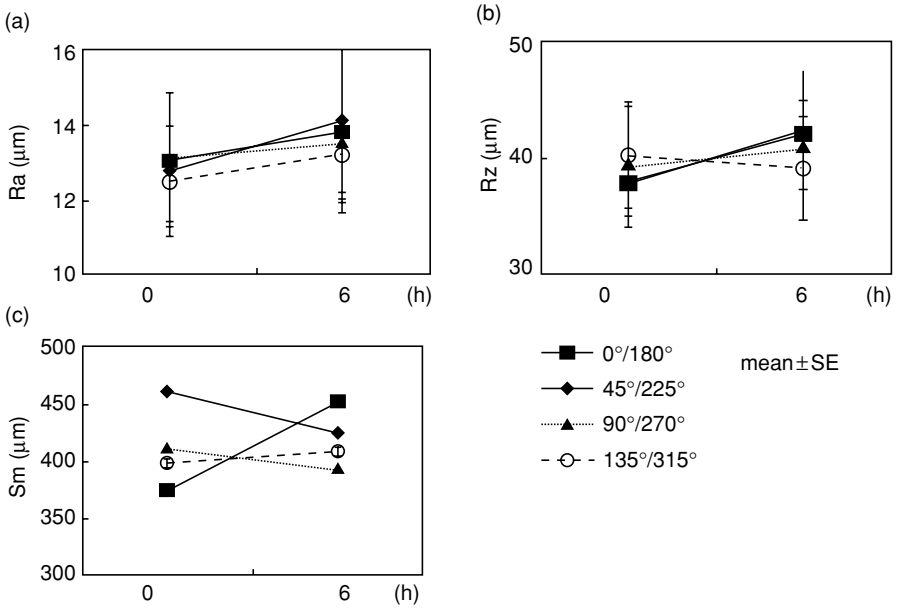

Fig. 7. Changes in skin surface roughness on cheek after 6 h of low himidity treatment. (a) Ra, (b) Rz and (c) Sm.

forearm in the four directions and Fig. 7 shows those of the cheeks.

The VC1 value increased in almost all the subjects at the cheek and showed a significant increase ($P < 0.05$) from the time point 0 h to 6 h. Concerning the skin surface roughness, Rz in the directions of $45^\circ/135^\circ$ and $90^\circ/270^\circ$ and Sm in the directions of $0^\circ/180^\circ$ showed a significant increase ($P < 0.05$) in the ventral forearm after 6 h in a dry condition. Regarding the cheek, Rz in the directions of $45^\circ/135^\circ$ showed a tendency to increase ($P = 0.059$).

Discussion

Changes in the skin condition after exposure to low humidity have been generally experienced and are widely known. For example, the skin is dehydrated in an air-controlled room during the hot season or during a long flight by an airplane. Recently developed measurement devices have enabled us to evaluate such sensuous experiences and present various parameters with noninvasive examinations. However, there

have been few reports on a bioengineering approach to human skin.

Our results suggest that even a short exposure to a low-humidity environment such as for 3 or 6 h can induce changes in the moisture content in the stratum corneum and in the skin surface pattern. In our experiments by using human subjects, we obtained significant differences in water content in the stratum corneum, transepidermal water loss and skin surface pattern before and after the exposure to a low humidity.

Regarding the evaluations of water content in the stratum corneum in such a low humidity, the changes obtained with SKICON100 and CM825 were different. It is generally known that SKICON estimates electric conductance of the upper layers of the stratum corneum and CORNEOMETER evaluates electrostatic capacitance of the stratum corneum layers to a lower depth (6, 7). Therefore, the various results obtained with SKICON and CORNEOMETER could be caused by the fact that a 6-h exposure to a low humidity could decrease the water content in the upper part of the stratum corneum, but perhaps with no influence on the lower region.

Barel and Clarys (8) reported that the TEWL value was affected by the temperature of the probe and external relative humidity. The fall of the surrounding humidity encouraged release of water. However, our results showed that the TEWL value decreased by exposure to a low-humidity environment. We often experience a lowering of the effective air temperature when the humidity is low. In the present experiment, all panelists complained of cold when exposed to a low humidity for a long time. Transepidermal water loss was significantly lowered by an unknown mechanism. It may have been related to an effect of the lowering of effective air temperature on the circulatory system.

Cook and Craft (14) and Linde et al. (15) have reported interesting findings on the changes of the skin surface pattern. Cook and Craft compared the skin surface pattern of the dry skin and that of the nondry skin on the lower leg by using skin profilometry. Dry skin showed a significantly smaller number of peaks. Linde et al. reported that the skin on the back of atopic patients showed an increase in Ra and Rmax (the maximum peak to valley height) and decrease in Rn (the number of peaks per cm) compared to healthy individuals; that is, the number of peaks was smaller and the peak height was greater in atopic patients. In the present study, the exposure to a low-humidity condition increased Sm, which is the distance between peaks at the ventral forearm sites; that is, the number of peaks is decreased. Furthermore, Rz, which reflects the peak height was increased both at the ventral forearm and the cheek, and VC1 was increased in the cheek. These changes are consistent with those reported by Cook and Craft and Linde et al. and indicate that exposure to a low-humidity condition for only a few hours could induce a skin surface morphology state similar to that observed in dry skin.

Furthermore, analysis of the roughness parameters in four directions revealed a specific pattern of the changes in the surface morphology (Fig. 8). In the forearm, the height of the ridges and the depth of the furrows were increased along with the forearm axis (see Sm in the directions of 0°/180°). In a perpendicular and cross direction, the width of the skin ridges was increased (see Rz in the directions of 45°/225°, 90°/270°). Considering that the Langer's lines (16) are running in the direction of the elbow to the wrist (slightly sideways from the center line of the ventral forearm to inside and outside of the forearm) in the ventral forearm, it can be speculated that the depth of the furrows and the width of the skin ridges in the

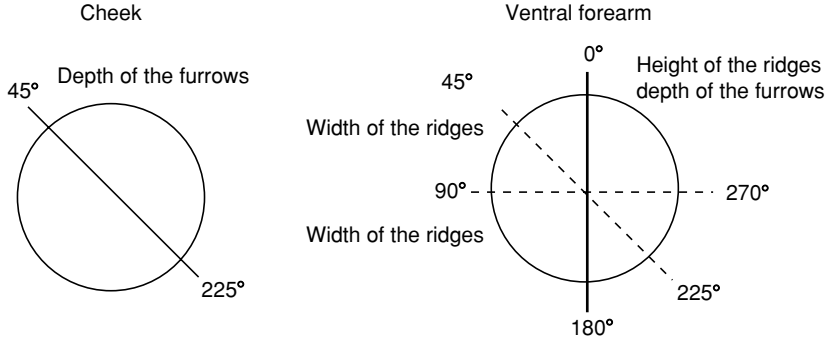

Fig. 8. Direction dependency in change of skin roughness parameters lines on the circle show the increasing direction.

parallel direction of the Langer's lines would be increased.

In the cheek, the Langer's lines are running in the direction of 45°/225° (Fig. 1). Because the direction of the Langer's lines at the site of replica sampling was slightly sideways according to the size of face and the site of sampling area of replica, this could not be determined clearly. Only the depth of the furrows had a tendency to increase in the direction of the Langer's lines (see Rz in the directions of 45°/225°). Considering that the formation of fine wrinkles is mostly in the same direction as the Langer's lines, the changes in the skin surface pattern caused by exposure to low humidity in our experiment lead us to consider that dryness of skin even in such a short period would be related to the formation of fine wrinkles. One of the reasons for the greater change of skin surface pattern (VC1) in the cheek than in the forearm would be that the startum corneum is thinner in the cheek than in the forearm.

Conclusion

Changes on human skin during a dry condition were measured by using noninvasive measurement devices. A short exposure to a low-humidity environment induced changes in the moisture contents in the stratum corneum and skin surface pattern, which lead us to assume that a dry environment in our daily life would make fine wrinkles related to lack of water in the stratum corneum.

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