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The Effect of Prolonged Drying on Transepidermal Water Loss, Capacitance and pH of Human Vulvar and Forearm Skin

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The effect of prolonged drying on transepidermal water loss (TEWL), capacitance and pH of vulvar and forearm skin was studied in 15 healthy female volunteers. A desiccation chamber that absorbed water evaporating from the skin surface was applied to the forearm and labia majora skin daily for 4 days. Skin TEWL, capacitance and pH were measured daily and 4 days after removal of the desiccation chamber at the site of drying and at a symmetrical control site. Under desiccation, TEWL both of forearm and of vulvar skin showed an increase during the first days of drying, followed by a gradual decrease. After 4 days of drying, forearm TEWL was reduced to 91% of the control value, without reaching significance. Vulvar TEWL was significantly reduced to 80% of the control value. Although relative reduction of vulvar TEWL was higher than that of forearm TEWL, the absolute value of vulvar TEWL after drying remained significantly higher than that of forearm TEWL. Skin capacitance significantly decreased under drying both in forearm and vulvar skin. Skin pH was significantly reduced by drying at the vulva, but not at the forearm. It is concluded that although changes in physiological parameters during drying seem to be more pronounced in vulvar than in forearm skin, differences suggest that the specific properties of vulvar skin are not explained by anatomically related occlusion alone. *Key words: Desiccation.*

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Vulvar skin has a less complete barrier than the skin of the forearm since transepidermal water loss (TEWL) is significantly higher in vulvar than in forearm skin (1). However, barrier function may be modulated by occlusion, which is a typical feature of the vulva. The vulva may be occluded in two ways, by clothing and by anatomically adjacent skin. Recent findings indicate, that even allowing for occlusion, vulvar TEWL exceeds forearm TEWL (Oriba & Maibach, unpublished data). To further ascertain if reduced barrier function is a genuine property of vulvar skin or mainly a result of continuous occlusion, the effect of prolonged drying on physiological skin parameters was studied. To test the hypothesis that prolonged drying would reduce vulvar TEWL by removing the occlusion factor and thereby reveal the 'intrinsic TEWL', but that it would have little effect on forearm TEWL, a desiccation chamber was placed on the vulvar and forearm skin for 4 days. TEWL, capacitance as an indicator of stratum corneum hydration and skin surface pH were measured each day during the drying period and 4 days after drying was discontinued.

MATERIAL AND METHODS

Study population

Fifteen healthy female subjects entered into the study after informed consent. To exclude variation due to the menstrual cycle, only postmenopausal women were chosen, between 50 and 87 years of age (mean 64.9, median 63.0, standard deviation 9.8 years). Information was obtained regarding body weight, height and physical exercise.

Desiccation chamber

In order to dry a defined area for a prolonged period, a special chamber was devised containing a desiccating agent that absorbed the water permeating through the skin surface.

Choice of desiccant. Although agents like metal aluminosilicates are more efficient for drying purposes, silica gel was chosen for its low toxicity (2). Silica gel is an amorphous granular form of synthetic silica which is chemically inert and non-corrosive. It consists of a complex network of interconnected, microscopic pores that attract and entrain water by means of physical adsorption and capillary condensation. It typically absorbs 40% of its own weight of water.

Construction of the chamber. The desiccation chamber was constructed as follows (Fig. 1 *a*): The waxed paper backing and the cotton pad were removed from a small polypropylene (Hilltop®, Hilltop Laboratory, Cincinnati, Ohio) chamber (area exposed to skin 1 cm^2, diameter 1.1 cm). A 9-mm hole

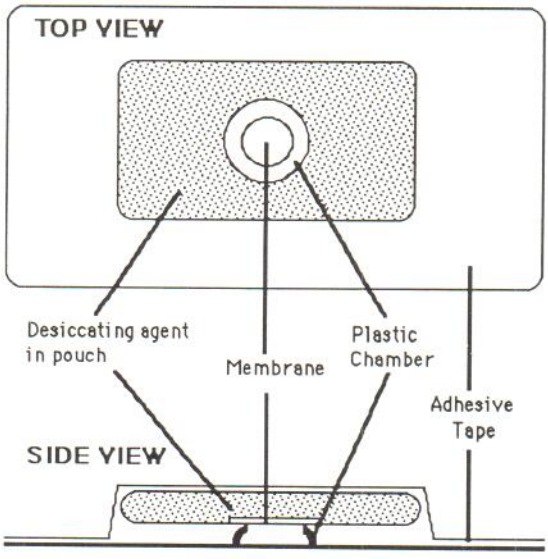

Fig. 1 a. Schematic diagram of desiccation chamber.

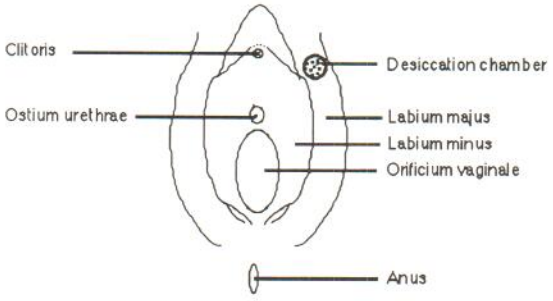

Fig. 1 b. Position of the desiccation chamber on labium majus.

was punched into the roof of the chamber using a No. 4 corkborer. A 9-mm hole was also punched into a sheet of boilable cooking foil (Seal-A-Meal, Dazey). This hole was covered gluing a circle of water-permeable polytetrafluoroethylene (0.2 µm pore size) membrane (Gore-tex®, W. L. Gore & Associates, Elkton, Md.) to the edges using cyanoacrylate glue (Duro® Super Glue, Loctite, Cleveland, Ohio). With a thermal sealing machine, another sheet of cooking foil was attached to the first one forming a pouch. Then the back of the polypropylene chamber was glued onto the pouch, noting that the hole in the chamber and the membrane-covered hole matched. The pouch was filled with 2 g of dried silica gel with humidity indicator (Sigma No. S-7625) and sealed immediately. The total area covered by the device when placed on the skin was 10 cm^2.

To protect the chamber from absorbing environmental water, it was sealed into a larger, hermetically closed pouch until use.

Application of the desiccation chamber

The test site was marked with a waterproof marker (VWR lab marker, VWR Scientific, San Francisco, Calif.) to align the desiccation chamber to the same site daily. The chamber was applied to the skin on a sheet of cotton with a hole punched in at the appropriate location for the polypropylene chamber and fixed with adhesive transparent dressing (1625/Tegaderm, 3M, St. Paul, Minn.).

Application sites were the anterior third of the labia majora (Fig. 1 *b*) and the middle third of the volar forearm. Localization bias was minimized using symmetrical control sites and assigning application and control sites according to a randomization list.

The chambers were applied for 24 h, then removed and replaced with chambers for 4 days.

As a quality control, the chambers were checked for drying capacity before and after application by measuring the water diffusion gradient over the opening of the chamber with the evaporimeter probe. A negative diffusion gradient was found in all chambers after 24-h application periods indicating persistent desiccant water uptake.

Measurements

All measurements were performed after subjects had been physically inactive for at least 15 min and 5 min after chambers had been removed. Before measurements were made on vulvar skin for the first time, hairs were clipped off the anterior third of both labia majora.

TEWL and capacitance of treatment and control sites were measured before application of desiccation chambers, each day during and 4 days after the drying period. pH was measured before drying, after 4 days of drying and 4 days after the drying period.

TEWL was measured with an evaporimeter (Servo Med Ep 1, Servo Med, Stockholm, Sweden) under neutral environmental circumstances (room temperature 19–23°C, relative humidity 48–57%) (3). The hand-held probe was fitted with a 1-cm tail cimmey extension to reduce air turbulence around the hydrosensors and the metallic shield (supplied by Servo Med) minimized the possibility of sensor contamination. Measurements ($g*m^2*h^{-1}$) stabilized within 30–45 s on the forearm and 1–3 min on the vulva. Skin temperature was monitored by placing a thermistor (Tele-Thermometer, Yellow Springs Instruments, Yellow Springs, Ohio) on the skin surface. TEWL values were converted to values at a standard reference temperature as previously described (4).

Electrical capacitance of the skin surface as an indicator of stratum corneum moisture was measured with a capacitometer (Corneometer CM 820 PC, Courage + Khazaka, Cologne, West Germany) according to the manufacturer's guidelines as quoted in (5). The capacitance is expressed digitally in arbitrary units (a.u.). Skin surface pH was measured using the pH meter (pH meter 125, Corning, Medfield, Mass.) with a flat surface pH electrode (Orion, Boston, Mass.). The meter was calibrated before use on each volunteer using standards at pH 4 and 7. To perform a measurement, 0.2 ml of distilled water (pH 7.0) was applied to the measuring site and the electrode was dipped into the fluid and pressed on the skin. Excess water was removed instantly. The measurement was taken after the pH reading stabilized.

Table I. *Physiologic skin parameters at forearm and vulvar control sites before application of the drying chambers (day 0). (N=15)*

Parameter	Site	Mean	SEM	Significance
TEWL (g/m^2*h)	Forearm	13.4	0.4	+
	Vulva	19.5	1.3	
Capacitance (a.u.)	Forearm	112.8	6.9	+
	Vulva	126.8	5.3	
pH	Forearm	5.02	0.12	+
	Vulva	6.05	0.10	

TEWL = transepidermal water loss, n = number of measurements in 15 volunteers, a.u. = arbitrary units. A difference between means was regarded as significant (+) if the probability of error in Wilcoxon's matched-pairs signed-ranks test was <0.05.

Table IIb. *Relative transepidermal water loss, capacitance and pH-difference of vulvar skin under prolonged drying (see Materials and Methods)*

Parameter	Study day	Mean	SEM	Significance
Relative TEWL	1	121.7	14.9	NS
	2	97.8	18.8	NS
	3	110.5	21.6	NS
	4	79.9	9.1	+
	8	89.5	4.9	NS
Rel. capacitance	1	98.8	3.0	NS
	2	94.8	2.4	NS
	3	90.9	3.4	+
	4	95.9	3.8	NS
	8	106.5	4.7	NS
pH difference	4	−0.63	0.15	+
	8	−0.10	0.08	NS

Statistical methods

Statistical computations were performed with a statistical package (SPSS-PC+®, SPSS, Chicago, Ill.) on an IBM XT-compatible computer. For TEWL and capacitance, values for each treatment were expressed in percent of control sites. Thus changes in TEWL and capacitance can be compared better between forearm and vulvar skin. Since pH is a logarithmic parameter, for pH measurements the arithmetic differences between the pH values at the dried and at the untreated sites were calculated.

Differences between means were checked for significance (+) using Wilcoxon's matched-pairs signed-ranks test. A probability of error of less than 0.05 was regarded as significant.

Table IIa. *Relative transepidermal water loss, capacitance and pH-difference of forearm skin under prolonged drying (see Materials and Methods)*

Parameter	Study day	Mean	SEM	Significance
Relative TEWL	1	138.5	14.1	+
	2	168.6	36.3	NS
	3	104.0	9.5	NS
	4	90.9	7.5	NS
	8	78.8	4.9	+
Rel. capacitance	1	99.0	1.9	NS
	2	97.8	2.2	NS
	3	91.5	3.2	+
	4	91.8	2.4	+
	8	99.5	3.4	NS
pH difference	4	−0.19	0.12	NS
	8	0.01	0.05	NS

Linear association between single variables was assessed using the procedure CORRELATION. The influence of several independent variables on a dependent variable was studied using the procedure REGRESSION; model selection was achieved using the BACKWARD elimination method. The backward elimination starts with all independent variables in the equation and removes them sequentially, if they don't meet the minimum *F*-value to remain in the equation. The method is used when all independent variables might be expected to be correlated with the dependent variable.

RESULTS

The absolute values of the parameters measured at control sites are given in Table I. TEWL values of vulvar control sites were more than twice as high as those at the forearm control sites, whereas the difference in skin capacitance was less pronounced, but still significant. Vulvar pH was more than one pH unit higher than forearm pH.

No correlation was found between the values of TEWL and pH at forearm and vulvar sites in individual volunteers. However, a significant correlation between the capacitance values at these sites was noted ($r=0.59$). The relative TEWL of treatment sites showed an increase first and then a gradual decrease, reaching 91% of control values after 4 days of drying on forearm skin and 80% on vulvar skin (Table IIa, b). A decrease in TEWL was still noticeable 4 days after treatment termination, although it was significant only for forearm skin.

No transient increase in skin capacitance was observed, but a gradual decrease was noted, to about

Table III. *Multiple regression analysis of relative vulvar TEWL after 4 days of drying*

Variables in the regression equation			
Variable	B	SE B	Beta
VCTEWL	−2.04	0.65	−0.61
BW	−1.09	0.48	−0.45
(Constant)	186.96	35.83	

VCTEWL = absolute value of vulvar control TEWL after 4 days of drying, BW = body weight, B = slope, SE B = standard error of B, Beta = standardized regression coefficient.

91% both on the forearm and at the vulva. After treatment was stopped, capacitance returned to control values on the forearm but exceeded control values significantly at the vulva ($p<0.05$, Table II a, b). After 4 days of drying, skin pH showed a moderate decrease at the forearm which did not reach significance. There was a considerable and highly significant ($p<0.01$) decrease of more than 0.6 pH units at the vulva, however. Four days after treatment, pH values nearly equalled control values (Table II a, b). Although there was a significant decrease in mean vulvar TEWL after 4 days of drying, the variation between subjects was considerable with 3 subjects showing an increase of TEWL. In order to account for these marked differences, a regression analysis was performed, choosing relative decrease in vulvar skin TEWL as the dependent variable and age, body weight, height, exercise, absolute value of vulvar control TEWL and decrease in forearm TEWL as independent variables. The backward elimination model only left the absolute vulvar control TEWL and body weight as significantly related to the dependent variable in the equation (Table III). There was no correlation between body weight and vulvar control TEWL in the correlation matrix ruling out an interaction between these variables.

DISCUSSION

TEWL is regarded as an in-vivo index of the efficiency and integrity of stratum corneum. The previously reported observation that vulvar TEWL is significantly higher than forearm TEWL (1), which was confirmed in this study, suggests that the epidermal barrier is weaker at the vulva than on the forearm. However, water loss measured at the skin surface does not only reflect transcorneal water flux, but also occlusion-related water loss. Occlusion is not of usual concern on the forearm, but it is of concern on vulvar skin (skin/skin occlusion and skin/garment occlusion). We therefore hypothesized that we would be able to 'deocclude' vulvar skin with our desiccating chamber. The resulting TEWL should be lower than the TEWL at a control site and reflect the 'true' or 'intrinsic' TEWL of vulvar skin, thus allowing a better assessment vulvar skin barrier function. No (or only minor) TEWL changes were anticipated for using the desiccating chamber on forearm skin.

In interpreting the results, the possibility that the observed changes are not related to drying, but that they are side effects of the desiccation chamber has to be taken into account. The hypothesis that the chamber was ineffective, i.e. that it occluded the skin instead of 'deoccluding' it, can be rejected, since the efficacy of the desiccant water uptake was tested after each application (see Methods) and since capacitance and pH would be expected to increase under occlusion, not to decrease as it was actually observed. Irritation of the skin by the desiccating chamber can also be excluded: No clinical signs of irritation like erythema or scaling were noted and the pattern of changes in the biophysical parameters differed from that expected in irritant dermatitis. Although no blanching was observed clinically, compression of dermal circulation by the chamber is a possible cause of systematic error which cannot be ruled out with certainty. It seems difficult, however, to interpret the observed changes as effects of an altered blood flow.

The finding of a biphasic TEWL reaction under drying, i.e. a transient TEWL increase first, followed by a definite TEWL decrease, was unexpected and is difficult to explain. A TEWL increase linked to a decrease in stratum corneum hydration has been associated with the clinical phenomenon of dry winter skin and the clean room syndrome (6, 7). Since we have no information on the exact relative humidity in the desiccation chamber, it may well be conceivable that relative humidity was very low and that the TEWL increase during the first days of drying was induced by the described mechanism. This concept cannot explain, however, why after 4 days of drying, a TEWL decrease was observed, which was more pronounced in vulvar than in forearm skin as was expected by our hypothesis. Thus the changes in epidermal barrier function under drying seem more complex than anticipated and await further clarification.

TEWL changes under desiccation were more pronounced in women with a high TEWL baseline value

and in the heavier women. Both of these conditions may be linked with more sweating and a higher degree of occlusion in the vulvar area. These factors then may damage barrier function more, leading to a more pronounced restoration under desiccation.

Changes in capacitance as an indicator of skin moisture were far less dramatic than TEWL changes and showed a monophasic reaction with a gradual decrease during the drying period. In vulvar skin, a backlash in skin capacitance was noted after discontinuing the treatment.

The relationship between epidermal barrier function and skin surface pH is not well understood. Externally induced pH changes do not seem to induce irritation nor do they cause a TEWL increase (8). However, an increase in skin pH parallels a rise in TEWL under prolonged occlusion (9, 10). Occlusion seems to enhance stratum corneum ion permeability, thus neutralizing the normally acid skin surface. In all intertriginous areas, pH values are significantly higher than on non-occluded skin (11), a finding termed "gap in the acid mantle" by Marchionini & Hausknecht (12). The present study shows that by prolonged drying, a partial restitution of the acid mantle in an intertriginous area may be achieved. Since disposition to bacterial and fungal infection has been linked to increased skin pH and common clinical experience indicates that clearing of infections in intertriginous areas is enhanced by drying the skin, our findings may be of practical value in the prophylaxis of genital skin infections.

In conclusion, our study confirms that differences in barrier function exist between vulvar and forearm skin. Since the differences in TEWL, capacitance and pH are diminished but not eliminated by prolonged drying, they cannot be explained by the different degree of occlusion alone. Rather, biochemical differences in stratum corneum composition may exist between vulvar and forearm skin.

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