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THE EFFECT OF AMBIENT HUMIDITY ON TRANSEPIDERMAL WATER LOSS*

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ABSTRACT

Sweating was abolished and the transepidermal water loss (TEWL) measured at constant skin temperature. TEWL was not greatly affected by rising ambient humidity (RH) in 18 subjects. There was a 2–3 fold increase in the rate of TEWL when RH was raised from the initial 2–3% to 30–50%. By 73–77% RH the TEWL had fallen to or near the initial rate.

It is suggested that rising ambient humidity increases the permeability of the stratum corneum by increasing its water content; hence TEWL rises. *Pari passu* there is a decreasing vapor pressure difference between the stratum corneum surface and ambient air, and the TEWL tends to fall. As suggested from previous *in vitro* findings, the diffusion coefficient of the stratum corneum alters with changing ambient humidity.

Transepidermal water loss at 2–3% and 70% RH is similar. Therefore an approximate calculation of daily total body surface TEWL can be made from measurements of TEWL in small skin areas at low humidity (2–3% RH).

It is generally accepted that the transepidermal water loss (TEWL) is a passive diffusion process (1). It might be expected therefore that the rate of diffusion through the stratum corneum would be dependent on ambient relative humidity (RH) and could be predicted from simple diffusion equations (2, 3).

$$\text{TEWL} = K\,(VP_s - VP_a)$$

where K is a permeability constant, VP_s is the vapor pressure of water at skin surface temperature and VP_a is the aqueous vapor pressure of the air.

In a few experiments it has been shown that decreasing the rate of air flow over the skin surface decreases the TEWL (4, 5, 6). The explanation suggested was that the decreased rate of TEWL in these cases was due to an increased relative humidity over the skin. (Decreasing air speed was also discussed as a possible explanation for the decrease in TEWL).

However in other experiments, where sweating was not inhibited, the expected relationship between skin water loss and vapor pressure was not that predicted (3, 7). The explanation of these findings could be the presence of invisible sweating. The alternative explanation offered is that with increasing air humidity there is an increase in the water content of the stratum corneum thereby altering the diffusion coefficient (2, 5, 3, 7).

To resolve this question, in the present series of investigations the presence of sweating was eliminated. The TEWL was measured at varying ambient humidities at constant air speed and constant skin and flow temperatures.

METHODS AND MATERIALS

The system used for measuring the transepidermal water loss (TEWL) was similar to that described previously (8, 9).

Dry nitrogen was passed via the MEECO electrolytic water analyzer and the Sage hygrometer unit to the skin capsule fixed to the outer surface of the forearm. The moisture content of the gas leaving the capsule was measured by the Sage hygrometer unit. There were 8 efferent and 1 afferent narrow range sensors which measured relative humidity from 0% to 95%. A flowmeter attached to the exit of the system checked that the system remained sealed. The temperature of the skin, flow system and skin galvanic resistance were measured throughout.

Polytetrafluoroethylene (PTFE) was used for tubing and the skin capsule. Sweating was inhibited by painting 4% poldine methosulphate and leaving the painted site occluded for 12 hours. The galvanic skin resistance (GSR) was measured to ensure sweating had been completely inhibited. The GSR was >1000MΩ in the absence of sweating. Room temperatures were 20–22° C and room RH 58–65%.

Saturated salt solutions were used for maintaining a constant humidity. The following salts with their resulting RH as described (10, 11) were used:

Sodium chloride (NaCl)	72–74% RH	at 20–22° C.
Calcium nitrate ($Ca(No_3)_2 4H_2O$)	43.5–46% RH	at 20–22° C.
Potassium acetate ($CH_3COOK\ 1\frac{1}{2}H_2O$)	19.3–20.5% RH	at 20–22° C.

Saturated solutions of the salts were allowed to equilibrate for 3–4 days in 1L Erlenmeyer flasks.

The TEWL measurements were made at constant air flows of 100 ml/min and constant skin and gas temperatures were maintained in each experiment:

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Exp. 1. In 12 normal subjects sweating was abolished in 25 cm^2 of the anterior surface of the forearm. In each subject the transepidermal water loss was measured (by the Sage hygrometer) in a dry ambient humidity after equilibrium had been reached. (The water content of the dry nitrogen reaching the skin, measured by the MEECO hygrometer, was 8–15 ppm.)

The TEWL was then remeasured in the same subjects, in raised ambient humidities of 22–27%, 43–52% and 73–77%.

Nitrogen, at a constant flow rate, was brought to a constant humidity by passing it first through the potassium acetate solution for 20–30 minutes. The skin capsule was in the meantime opened to room humidity and temperature. The TEWL was then remeasured in the 22–27% RH after equilibrium had been reached as judged by a steady reading being obtained: this took from 30–60 minutes. The difference between the humidity of the air reaching and leaving the capsule was a measure of TEWL.

The procedure was then repeated using in turn calcium nitrate and sodium chloride solutions.

The time that elapsed between separate TEWL readings varied between 1 to 3 hours. For each determination, at each relative humidity, steady state was reached in 30–60 minutes. To show that no further change occurred after this time, two experiments in ambient RH of 43% and 44% were prolonged for 3 hours.

In seven cases, TEWL readings were made in successive ascending ambient humidities. In the other five cases either descending or a random order of humidity was used.

Exp. 2. To verify the accuracy of the method, 6 experiments were performed using a closed capsule sealed with polythene. The experimental procedures and salt solutions were the same as those used for the *in vivo* tests.

Exp. 3. In 5 normal subjects the TEWL was measured at ambient RH 75–79% (NaCl solution) and remeasured after equilibrium had been reached in a dry ambient humdity.

TABLE I

In vitro *experiments with closed capsule at steady air-flow and temperature (to show % error of method)*

No. experiment	% RH of chamber inlet	% RH of chamber outlet
1.	19.0	19.0
	46.5	46.5
	71.5	71.0
2.	18.8	18.5
	45.5	45.5
	70.5	70.5
3.	19.0	19.0
	47.5	47.5
	72.0	72.5
4.	19.4	19.2
	47.3	47.2
	71.0	70.5
5.	18.6	19.2
	46.0	46.0
	72.5	72.5
6.	18.8	19.0
	47.5	47.0
	71.5	71.5

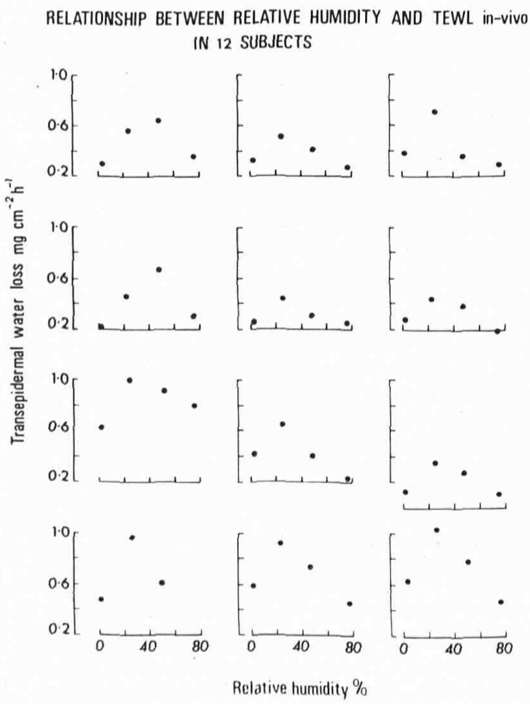

FIGURE.

RESULTS

The Figure shows the effect of increasing humidity on the rate of TEWL. Although there was individual variation, in all cases the rate of TEWL was increased by raising the RH up to about 50%. The maximum TEWL occurred at about 30% RH in 9 cases and at 50% in 2 cases. By 73–77% RH the TEWL had fallen to about the initial TEWL rate.

The results of the *in vitro* experiments (Table I) show the accuracy of the method. The errors are independent of relative humidity and thus aggregating the data of the 18 readings the SD of the error distribution was estimated as being 0.3%.

Table II shows the effect on TEWL of decreasing RH from 75–79% to 2–4%. The findings are similar to those shown in the Figure, i.e. in most cases the TEWL at 75–79% RH was little different from that at 2–4% RH. In two cases (case 2 and 5) the TEWL at 75 and 79% RH was somewhat lower than that at 2 and 4% RH.

In the two experiments in which the skin was left in contact with raised ambient RH for 3 hours, no further change took place after reaching the steady state at 30–60 minutes. The change in TEWL which occurred between the 30-minute point and 3-hour-point was in one instance 0.04

TABLE II

Effect of decreasing ambient humidity on transepidermal water loss in the absence of sweating (GSR > 1000MΩ)

Case no.	Capsule ambient humidity %	Transepidermal water loss mg/cm²/hr.
1.	76.7	0.3
	2.2	0.3
2.	79.1	0.4
	3.9	0.7
3.	78.6	0.3
	2.4	0.3
4.	77.6	0.5
	2.9	0.6
5.	74.8	0.1
	2.4	0.3

TABLE III

Summary of transepidermal water loss resulting from changes in relative humidity

Relative humidity % (mean, range)	TEWL Mg/cm²/hr. (mean, SD, number of cases)
2.6 (1.7–3.6)	0.36 ± 0.4 (n 17)
25.0 (22.2–27.0)	0.58 ± 0.24 (n 12)
49.0 (43.5–52.3)	0.47 ± 0.21 (n 12)
76.0 (73.0–77.0)	0.30 ± 0.2 (n 16)

mg/cm²/hr (lower) and in the second experiment 0.03 mg/cm²/hr (higher). These changes are within experimental error.

Table III provides a summary of the data.

DISCUSSION

Mellanby (12) found that the air under a shirt of a resting man varied between 23–70% RH (at air temperatures 23–37° C). The daily water loss from diffusion (TEWL) from the total body surface with normal skin is said to be approximately 150 ml (SD 44.2 ml) (13) or 120 ml (9). This was calculated from the total body surface area (SA) and TEWL measurements in small skin areas under dry ambient conditions (2–3% RH).

$$\text{TEWL (mg/cm}^2\text{/hr)} \times \text{SA} \times 24 = \text{Total TEWL per day}$$

In view of the present findings this estimation seems justified in the clothed "basal man" when the ambient RH under clothes is 70% (as we have shown the TEWL is similar at 70% and at 2–3% RH). At lower air temperature, where there is less sweating and hence a lower RH under the shirt, the total daily TEWL loss may be double the calculated figure. The calculated total loss is only an approximation as regional TEWL differences occur.

The apparent paradox that rising ambient humidity initially increased the rate of TEWL can be explained. Stratum corneum has a great capacity for taking up water (14). With increasing ambient humidity the dry stratum corneum took up more water, (at constant temperature and air speed) and hence increased its water permeability and therefore the TEWL.

The rate of net diffusion outwards through a membrane depends not only on the permeability (P) of the membrane but also is proportional to the concentration of the penetrant on the inside (C_1) minus its concentration on the outside (C_2) (15). Thus, Net diffusion α $P(C_1 - C_2)$. As the ambient vapor pressure rose there was a decreasing difference between it and the skin vapor pressure: the driving force causing diffusion was less and the TEWL tended to fall. This factor would explain the fall of TEWL when RH was increased from 20% or 50%.

The findings in these experiments are compatible with the suggestion that the diffusion coefficient of stratum corneum *in vitro* (like that of horn keratin) (16) alters with changing ambient humidity.

TEWL varies with skin temperature as well as with humidity and a formula has been arrived at to correct TEWL readings for skin temperature (8). In the present investigation, in which varying ambient humidity and TEWL measurements have been correlated, there were not sufficient experimental points in each to allow a correction formula for humidity to be proposed.

CONCLUSION

The relationship of transepidermal water loss to rising ambient humidity is not linear. With increasing humidity the TEWL rises until at about 30–50% RH it starts falling. The TEWL is not greatly affected by ambient humidity: there is only a 2–3 fold increase when the RH is raised from 2–3 to 30–50%. Measurement of TEWL and the calculated loss from the total skin surface may be of clinical value in assessing the metabolic state of patients with erythroderma.

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