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# Transepidermal water loss and stratum corneum hydration in forearm versus hand palm

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## Abstract

**Background:** Skin measurements of transepidermal water loss (TEWL) and stratum corneum hydration (SCH) reflect different aspects of skin physiology. Since epidermal water loss depends on epidermal-to-air water vapor gradients, a possible quantitative relationship between TEWL and SCH may exist. This investigation's purpose was to test the possible TEWL-SCH relationship.

**Materials and Methods:** SCH and TEWL were measured noninvasively on forearm and palmer thenar eminence (hand) in 40 young adults (20 males) along with total body fat percentage (FAT) via bioimpedance.

**Results:** A significant positive nonlinear correlation ($p < 0.001$) was detected between SCH and TEWL in hands of the male cohort that occurred when SCH exceeded a threshold level. This threshold level was not exceeded in male or female forearms and forearms did not display a SCH-TEWL correlation. There was a weak inverse dependence of TEWL on FAT on both forearm and hand ($p < 0.05$), but no SCH-FAT relationship was observed. TEWL values on the forearm and hand were moderately correlated with each other ($p = 0.002$) but SCH values were not.

**Conclusion:** The findings clarify the relationship between forearm and palmer hydration and TEWL values, and their relationship to total body fat percentages in young healthy adults. The significant correlation between palmer stratum corneum hydration and palmer TEWL that was discovered in the male but not the female cohort suggests a threshold hydration level for which TEWL depends both on skin barrier function and stratum corneum hydration. This implies that conditions with increased SCH may in part account for elevated TEWL values.

KEYWORDS
measuring edema, measuring lymphedema, skin moisture, skin water, skin water loss, thenar eminence, total body fat, total body water, volar forearm

## 1 | BACKGROUND AND INTRODUCTION

Skin measurements of transepidermal water loss (TEWL) and stratum corneum hydration (SCH) reflect different aspects of skin physiology with an unresolved possible quantitative relationship between these two parameters. SCH is typically used as a measure of skin dryness based on parameters related to the stratum corneum electrical capacitance or conductance,[1,2] whereas TEWL is often used as a measure of skin barrier function as reflected by the amount of insensible skin water loss.[3–5] Current TEWL measurements use devices that are

placed in contact with skin and collect water vapor flux into a chamber for a fixed amount of time or until a certain volume has been achieved,[6,7] using either open or closed chamber methods.[4,5,8,9] The resulting measurement yields total water loss (TWL) that has two components. One component is attributable to water diffusion through the intact epidermis that depends on the epidermal-to-air gradient in water vapor pressure. This is the TEWL component that is most directly related to skin barrier function herein termed epidermal water loss (EWL). However, because many skin sites have eccrine glands present, the contribution of sweat-related activity is variable and, in most cases, unknown. The separation between contributions of EWL versus those contributed via eccrine activation to TEWL is difficult although some procedures have been used for this purpose.[10,11] From a mechanistic viewpoint a possible relationship between SCH and TEWL may exist since EWL depends on the epidermal-to-air water pressure gradient.[3,12,13] If true, a corollary is that TEWL would increase with increasing SCH. However, systematic experimental evidence of such a positive correlation between SCH and TEWL is not evident from the literature. The main purpose of the present investigation is to obtain experimental data to test this possible TEWL-SCH relationship.

## 2 | METHODS

### 2.1 | Subjects

Data from 40 young adult medical students who were participants in a skin research practicum were evaluated as part of this study that was approved by university's Institutional Review Board. Entry requirements for subjects were that they reported having no current or prior skin condition affecting forearm and hand target measurement sites. The group consisted of 20 females and 20 males with a group age (mean ± SD) of 25.0 ± 1.8 years. Subjects were advised not to use any lotions or creams on their arms on the day of their evaluation. They were also advised to wear short-sleeved scrub shirts, not to do any vigorous exercise, or wash hands within 4 h of their scheduled evaluation. Each subject attested to these requirements prior to being evaluated.

### 2.2 | Measurements and procedures

TEWL (g/m$^2$/h) was measured using the closed chamber VapoMeter (Delfin Technologies, Kuopio, Finland)[9] and SCH was assessed by a parameter related to stratum corneum capacitance as measured using the MoistureMeterSC (Delfin Technologies) at a frequency of 1.25 MHz.[1] SCH is expressed in arbitrary units (a.u.). TEWL and SCH measurements were done in triplicate at two sites on the nondominant upper limb. One site was the volar forearm 5 cm distal to the antecubital fossa. The other was on the palmar surface of the hand in the middle of the thenar eminence (Figure 1). SCH was measured first at both sites (forearm then hand); rapidly followed by TEWL measurements (forearm then hand). In addition, skin temperature (TSK) was measured once at both sites using a precision infrared thermometer (Model DX501, Exergen, Watertown, MA, USA). Measurements were done while subjects were seated with their arm comfortably resting palm up on a flat surface, approximately at heart level. Measurements did not start until an acclimation interval of at least 20 min had elapsed (range 20–30 min). At the conclusion of skin measurements, subject weight, total body fat percent (FAT) and total body water (TBW) percentage were measured via bioimpedance using the InnerScan Body Composition Monitor (Tanita model BC558, The Competitive Edge, Vancouver, WA, USA). All measurements were done in the afternoon between 1400 and 1600 hours. Room temperature and relative humidity over the full set of measurements was 20.4°C ± 0.8°C and 58.7% ± 7.5%, respectively. Methodologic and validation studies for skin property measurement devices used in the present study have been previously reported.[1,5]

### 2.3 | Analyses

Tests for differences between genders and sites was done using the nonparametric Mann-Whitney U-test with a p-value $< 0.05$ accepted as statistically significant. Tests for relationships between TEWL and SCH at each anatomical site were based on regression analysis with all statistics done using SPSS version 16 and a p-value $< 0.05$ accepted as statistically significant. The dependence of TEWL or SCH on either FAT or TBW was assessed with correlation analysis with a statistically significant correlation accepted with a p-value $< 0.05$.

## 3 | RESULTS

### 3.1 | Comparisons between sexes

Table 1 compares all parameters by subject gender. Males and females had similar ages with a combined group age of 25.0 ± 1.8 years. Body mass index (BMI) and TBW of males was greater than that of females ($p < 0.001$), and male FAT was less ($p < 0.001$). With respect to measured skin parameters, males had greater skin temperatures at arm ($p = 0.003$) and hand ($p = 0.013$). Males also had greater TEWL values at arm ($p = 0.002$) and hand ($p = 0.020$). Contrastingly, there was no significant male–female difference in SCH at arm or hand sites.

### 3.2 | Site comparisons

As shown in Table 1, SCH and TEWL on hands were greater than those measured on forearms ($p < 0.001$). The hand-to-arm SCH ratio ($SCH_R$) was calculated (mean ± SD) to be 2.90 ± 1.93 for males and 2.06 ± 1.05 for females with differences in this ratio between genders not statistically significant ($p = 0.165$). The combined $SCH_R$ ($N = 40$) was 2.48 ± 1.59. The hand-to-arm TEWL ratio ($TEWL_R$) for males was 8.71 ± 5.41 versus 6.15 ± 3.43 for females ($p = 0.201$) with a combined $TEWL_R$ of 7.43 ± 4.65.

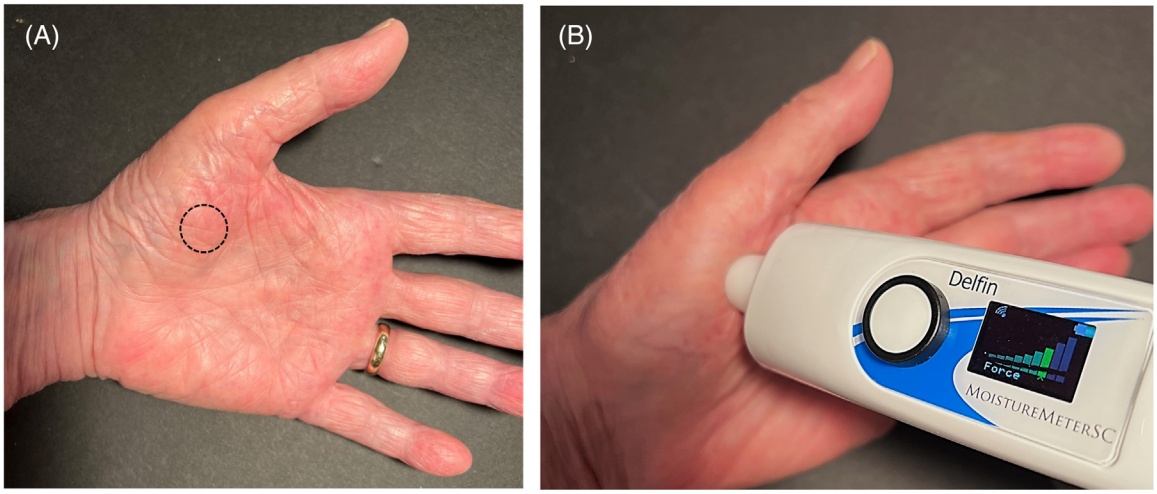


**FIGURE 1** Hand measurement site. Part (A) shows the palmer hand thenar eminence site and part (B) shows a measurement of the stratum corneum hydration (SCH) measured at a standardized force. Transepidermal water loss (TEWL) (not illustrated) is measured at the same site.

**TABLE 1** Parameter values by gender and measurement site

| | Females | Males | p-value | Combined |
|---|---|---|---|---|
| N | 20 | 20 | | 40 |
| Age (years) | 25.0 ± 2.1 | 25.0 ± 1.5 | 0.640 | 25.0 ± 1.8 |
| BMI (kg/m$^2$) | 23.0 ± 4.8 | 26.7 ± 5.2 | <0.001** | 24.8 ± 5.2 |
| FAT (%) | 30.8 ± 7.6 | 21.2 ± 11.5 | <0.001** | 26.0 ± 10.8 |
| TBW (%) | 52.0 ± 5.5 | 57.2 ± 5.2 | <0.001** | 54.6 ± 5.9 |
| Forearm SCH (a.u.) | 26.5 ± 9.2 | 26.4 ± 10.2 | 0.678 | 26.4 ± 9.6 |
| Hand SCH (a.u.) | 51.3 ± 29.6 | 66.9 ± 40.1 | 0.201 | 59.1 ± 35.7 |
| Hand/forearm SCH ratio | 2.06 ± 1.05 | 2.90 ± 1.93 | 0.165 | 2.48 ± 1.59 |
| Forearm TEWL (g/m$^2$/h) | 7.9 ± 1.4 | 10.0 ± 2.6 | 0.002** | 9.0 ± 2.3 |
| Hand TEWL (g/m$^2$/h) | 47.9 ± 26.8 | 88.7 ± 64.7 | 0.020* | 68.4 ± 53.1 |
| Hand/forearm TEWL ratio | 6.15 ± 3.43 | 8.71 ± 5.41 | 0.201 | 7.43 ± 4.65 |
| Forearm TSK (°C) | 30.7 ± 1.1 | 31.7 ± 0.8 | 0.003** | 31.2 ± 1.0 |
| Hand TSK (°C) | 30.3 ± 1.8 | 31.7 ± 1.7 | 0.013* | 31.0 ± 1.8 |
| Hand/forearm TSK ratio | 0.986 ± 0.052 | 1.00 ± 0.048 | 0.253 | 0.994 ± 0.050 |

*Note*: Table entries are mean ± SD. SCH is stratum corneum hydration in arbitrary units (a.u.) and TEWL is transepidermal water loss expressed in g/m$^2$/h. (**) and (*) denote statistical difference between sexes with $p < 0.01$, and $p < 0.05$, respectively. Males had a lower body mass index (BMI), lower total body fat percentage (FAT), and greater total body water (TBW) percentage. Males also had a greater TEWL, SCH, and skin temperature (TSK) at hand and forearm. SCH and TEWL values were greater on the hand than on forearm for both sexes ($p < 0.001$).

### 3.3 | SCH and TEWL dependence on body fat and water percentages

As shown in Figure 2, forearm and hand TEWL were weakly ($R^2 = 0.130$ to 0.138) and inversely correlated with FAT with only 13%–13.8% of TEWL variation attributable to FAT variation. Hand TEWL was also weakly ($R^2 = 0.129$, $p = 0.018$) but positively correlated with TBW, whereas forearm TEWL was not correlated with TBW ($p = 0.172$). Forearm and hand SCH showed no significant correlation with FAT or TBW.

### 3.4 | Forearm-hand relationships

As shown in Figure 3, there was a moderate positive correlation between forearm and hand TEWL values ($R^2 = 0.223$, $p = 0.002$).

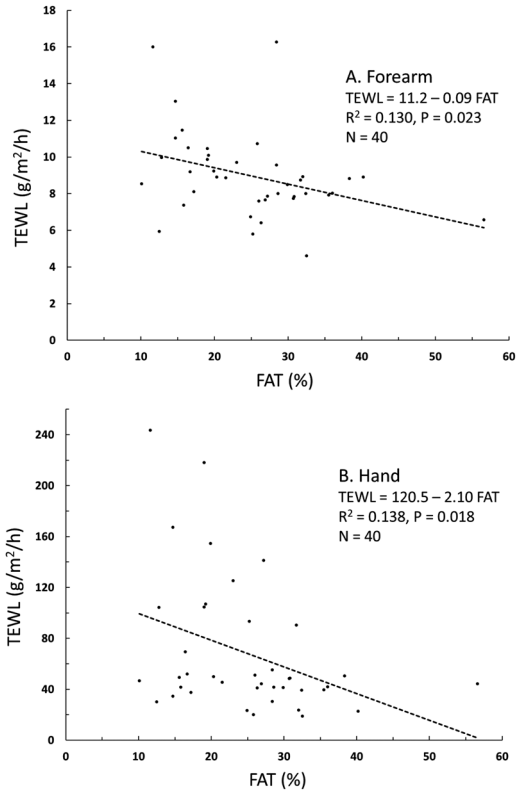


**FIGURE 2** Transepidermal water loss (TEWL) versus total body fat percentage (FAT). TEWL measured on the forearm (A) and thenar eminence of the hand (B). FAT is the total body fat percentage measured via bioimpedance. $R^2$ is the coefficient of determination for the regression shown as the dashed line for all 40 subjects. P is the p-value for the regression. A weak negative correlation is demonstrated for both sites.

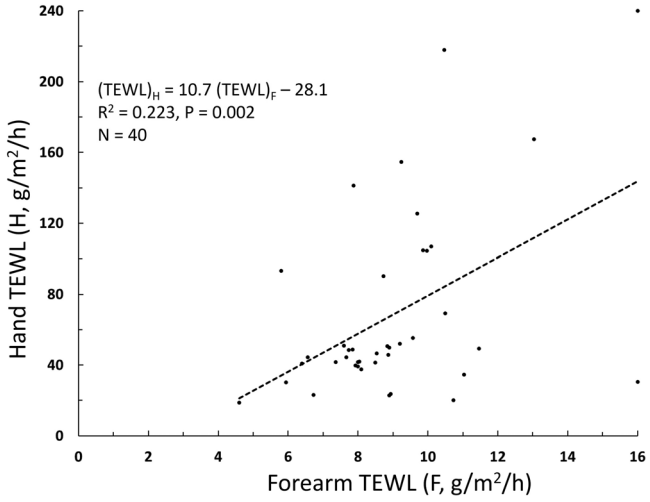


**FIGURE 3** Relationship between hand and forearm transepidermal water loss (TEWL). Hand $(TEWL)_H$ and forearm $(TEWL)_F$ values demonstrate a moderate positive correlation between each other. $R^2$ is the coefficient of determination for the regression shown as the dashed line for all 40 subjects.

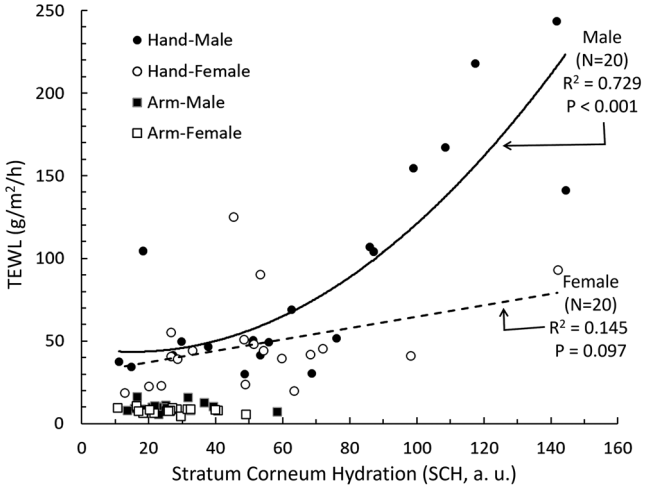


**FIGURE 4** Transepidermal water loss (TEWL) relationship to stratum corneum hydration (SCH). Filled data points are for males and open data points are for females. Regression lines are shown for males (solid line) and females (dashed line) along with coefficient of determinations ($R^2$) and significance of the regression (P). The only significant relationship detected was for male hands for which $TEWL = 46.0 + 0.329\,(SCH) + 0.011\,(SCH)^2$, $P < 0.001$.

Contrastingly there was no correlation between SCH values measured on the forearm versus those measured on the hand ($R^2 = 0.007$, $p = 0.588$).

### 3.5 | SCH-TEWL relationships

For males, but not for females, there was a significant positive relationship between SCH and TEWL when measured on the hand thenar eminence. Figure 4 depicts this best fit nonlinear regression determined as $TEWL = 46.0 + 0.329\,(SCH) + 0.011\,(SCH)^2$, $p < 0.001$, $R^2 = 0.729$. The corresponding linear regression equation for females is $TEWL = 0.34\,(SCH) + 30.3$, but is not statistically significant ($p = 0.097$). There was no significant correlation between TEWL and SCH on forearm for either males ($R = -0.056$) or females ($R = -0.286$).

## 4 | DISCUSSION

The primary aim of the present study was to investigate the extent to which skin TEWL was quantitatively related to SCH. This was evaluated by determining paired TEWL and SCH values in arm and hand skin comprising skin areas with differing skin properties. The arm site measured was the widely studied volar forearm and the hand site measured was the palmar hand at the mid-thenar eminence. Notable differences in the skin properties of these two anatomical sites include eccrine sweat gland density and TEWL as extensively reviewed by Taylor and colleagues.[14]

### 4.1 | TEWL values

Reference data on measurements of TEWL on the palm of healthy persons have been reported in an extensive meta-analysis to range from a mean value of 37.03 g/m$^2$/h on the right hand to 42.19 g/m$^2$/h on the left hand with 95% intervals ranging from 30.39 to 43.6 g/m$^2$/h on the right and 40.32-44.06 g/m$^2$/h on the left.[7] Another review of four earlier studies reported TEWL values to range from about 45 to 108 g/m$^2$/h on palmar hand,[14] whereas a smaller TEWL value of 38.3 g/m$^2$/h was reported for the palmer hypothenar region in 20 control subjects.[15] This control value was significantly less than measured in 40 patients with palmer hyperhidrosis (117–120 g/m$^2$/h).[15] The presently measured average TEWL at the palmer thenar eminence for combined males and females of 68.4 ± 51.3 g/m$^2$/h is somewhat greater than these previously reported hand palmer surface values, but similar to average values reported on palms of young adult female nursing students of 58.6 to 63.5 g/m$^2$/h.[16] However, most prior studies did not separately report on male versus female subjects, whereas the present findings include a significantly larger TEWL value for males. With respect to forearm measurements, based on 22 studies that included 544 subjects, a left mid-volar forearm TEWL value of 9.1 g/m$^2$/h with a 95% confidence interval (CI) of 7.3 to 11.0 g/m$^2$/h was reported.[7] TEWL measurements on 30 male and 30 female subjects with ages similar to the present studied group (20–29 years) yielded forearm TEWL values of 10.13 ± 3.20 and 8.82 ± 2.83 g/m$^2$/h, respectively.[17] Other forearm TEWL values measured on 252 mostly female subjects ranged from 7.7 to 11.3 g/m$^2$/h with a median value of 9.2 g/m$^2$/h.[18] Thus the present combined male–female TEWL value of 9.0 ± 2.3 g/m$^2$/h is consistent with these prior reported forearm average values. The average palmer/forearm TEWL ratio based on the present measurements was 7.43 ± 4.65.

### 4.2 | SCH values

SCH values have been widely reported on forearm, less reported for the palmer hand surface, and few specifically delineating whether on the hypothenar or thenar eminence as herein measured. Reference data on SCH values at various anatomical sites including the hand palm and volar forearm have been provided via a meta-analysis.[19] However, direct comparisons of absolute SCH values therein reported to the present SCH values are not possible since a single measuring device, different from what was herein used, was considered in that study. However, values obtained from different measuring devices correlate even though their absolute values differ.[1] Based on measurements from two studies with a combined sample size of 261, a palmer SCH value of 40.37 a.u. with a 95% CI of 39.19 to 41.56 has been reported.[19] Values reported for the volar forearm, based on nine studies with a combined sample size of 1558, were 36.62 with a 95% CI of 34.14 to 39.14 with no statistical difference in values between males and females. Combined male and female average SCH values herein measured on the palm were greater (59.1 a.u.), whereas those measured on the forearm were less (26.4 a.u.) with no statistical difference between males and females. Consequently, based on the present measurements, the palmer/forearm SCH ratio was 2.48 ± 1.59.

### 4.3 | Hand-to-forearm ratio comparisons

Prior paired TEWL and SCH measurements on forearms and hands of 10 healthy subjects yielded estimated TEWL values on hand of approximately 30 and approximately 5 on forearm.[20] Using these values, a hand-to-arm ratio of 6.0 is calculated, which is not very dissimilar to the average value of 7.43 determined for the present group of 40 healthy subjects. This hand-to-forearm TEWL ratio is also consistent with reported differences in sweat gland distributions between the two sites. Estimated active gland densities (glands/cm$^2$) in palmer hand and volar forearm, based on multiple studies averaged 518 versus 104.[14] These average densities yield an approximate 5:1 hand/forearm ratio. Contrastingly, the approximate SCH hand-arm ratio, based on a composite of literature data previously cited (40.37/36.62)[19] yields a ratio = 1.1 and combined data from 25 males and 25 females SCH hand/arm ratio (40.47/51.00) = 0.80.[21] Both estimates are considerably less than the hand-forearm SCH ratio determined in the present study (2.48). Although measurement devices used in prior studies differed from that presently used, possibly giving rise to different SCH absolute values at forearm and palmer sites, it might be expected that site SCH ratios would be similar. Since this is not the case, the larger SCH hand-to-arm ratio herein determined is unexplained. Possible explanations may relate to differences in ages of studied or the specific hand or forearm sites previously measured. This latter possibility is suggested by the fact that significant differences in forearm SCH have been reported depending on the specific forearm location using the same measuring device with arbitrary values on mid-forearm ranging from 65[22] to 60[23] to 50[17] to 43[24] to about 30.[25]

### 4.4 | TEWL-SCH relationship

A main new outcome of the present study is the finding of a substantial positive correlation between TEWL and SCH on the hand palmer surface at the thenar eminence only and only in the male cohort evaluated. As shown in Figure 2, this relationship was best described via a nonlinear regression between TEWL and SCH in which a threshold-like dependence of TEWL on SCH is observed for SCH values approximately ≥ 60 a.u. This threshold-like behavior may account for the absence of a TEWL–SCH correlation on forearm since forearm SCH values did not exceed this 60 a.u. threshold value. However, the presence of a threshold does not explain the difference in TEWL dependence on SCH between males and females. Prior research has examined the correlation between TEWL and SCH and age in females[26] and males,[27] and have compared these groups by age range,[17] but none of these studies evaluated or reported on correlations between TEWL and SCH. However, early pioneering in vitro studies using diffusion chambers have demonstrated an apparent relationship between SCH and TEWL.[28] In this study, plantar skin was soaked for 2.5 h and the

evaporative TEWL measured immediately and tracked for over an hour sequentially. The initial post-saturation TEWL value was 140 g/m$^2$/h that decreased nonlinearly to a steady-state value of about 32 g/m$^2$/h. The view held was that the stratum corneum receives water from the underlying tissue by diffusion and loses water to the environment by evaporation in relation to the extent of SCH with the main barrier located near the stratum corneum base.[29] This view was later modified to include the lower two-thirds of the stratum corneum[30] and then to include the barrier properties of the entire stratum corneum.[31]

Of specific relevance to the present findings was the previous demonstration that the diffusion coefficient for stratum corneum water increases with stratum corneum water content.[12] This feature would be consistent with the herein observed nonlinear increase in TEWL with increasing SCH that as far as known, is among the first reports of this relationship occurring in vivo in healthy skin. The fact that the observation was most evident in males who had generally higher measured SCH levels, may relate to arousal differences between sexes that impacted palmer eccrine gland activation. It is known that in response to assessment procedures of various types there may be increased electrodermal activity reflective of increased hand eccrine gland activation.[32] There is also some limited evidence of reduced sweating rates in females that might be linked to lower sweat gland sensitivity or reduced sweat production per gland.[33] However, it is unclear if there is a gender differential in either palmer sweat gland density or response that could explain the present male-female difference since no reports of direct gender comparisons have been located.

### 4.5 | Potential clinical implications

It is commonly accepted that abnormal increases in TEWL reflect a deficit in the skin barrier function[34] although some findings suggest there are limitations to this interpretation.[35] The present findings suggest that the contribution of increased SCH cannot always be overlooked. Although the present study showed this effect only on the palm, its absence on forearm may simply be because SCH levels did not exceed the threshold level. This possibility needs further study. However, in the single locatable study in which TEWL has been measured in lymphedematous limbs, TEWL values were 40.8% greater in lymphedematous arms and 29.5% greater in lymphedematous legs as compared to contralateral unaffected limbs.[36] Based on the current knowledge at the time, the authors concluded that this reflected significant skin barrier breakdown due to the lymphedema. However, a possible alternative interpretation is that the elevated TEWL was at least in part related to elevated SCH. Although SCH was not specifically measured by these authors, their measurements of skin water, based on tissue dielectric measurements, showed percentage increases of 36.2% and 30.7% for arm and legs, respectively. Values remarkably close to their reported increases in in TEWL.

## 5 | CONCLUSION

The findings clarify the relationship between forearm and palmer hydration and TEWL values and their relationship to total body fat and water percentages in young healthy adults. The significant correlation between palmer SCH and palmer TEWL that was discovered in the male but not the female cohort suggests the presence of a threshold hydration level for which TEWL depends both on skin barrier function and SCH. This implies that conditions accompanied by increased SCH may in part account for elevated TEWL values. Perhaps concomitant measurements of SCH should be considered in clinical or research situations in which TEWL is used to assess barrier function.

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### CONFLICT OF INTEREST

The author has no conflict of interest to disclose.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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