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Sweat Gland Awakening on Physical Training: A Skin Capacitance Mapping Observation

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Received: 06 January, 2015; Accepted: 10 May, 2015; Published: 25 June, 2015

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Abstract

Skin capacitance mapping (SCM) is an established real-time non-invasive method useful in the assessment of sweat production. We presently review and explore the sweat gland production following a mild 10-min physical training on a cycloergometer. Sprouts of sweat vapor are progressively increased by recruiting increasing numbers of active sweat pores. An overall moisturization of the stratum corneum ensues, and liquid sweat appears in a further step. These aspects are conveniently assessed using SCM while blind assessments of the skin surface water loss cannot distinguish these functional features.

Keywords: Eccrine sweat gland; Skin capacitance mapping; Cycloergometer

Introduction

In normal conditions, the epidermis over a large part of the body produces a tidy Stratum Corneum (SC) composed of 15-20 layers or so of corneocytes with a total thickness of about 6-20 µm. This part of the epidermis is continuously renewed from the granular layer, and the outermost corneocytes gradually desquamate from the surface [1]. Corneocytes are embedded in a hydrophobic domain formed by lipid bilayers. Such combined SC structure guarantees its water holding capacity, and it impedes the trans-SC water flux, thus preventing dessication of the body. Both the SC structure and the Transepidermal Water Loss (TEWL) result from dynamic processes that are possibly altered in physiological conditions and diseases. Based on the likely relationship between the SC moisturization and the macroscopic aspect of the skin, a series of methods assessing the SC hydration and the sweat gland production were developed over time [2,3].

At rest and cool conditions, water evaporation from sweat pores at the skin surface is added to the regular Transepidermal Water Loss (TEWL) to create the so-called insensible perspiration corresponding to the global Skin Surface Water Loss (SSWL). This latter parameter is not perceptible at the clinical inspection alone. The literature remains occasionally quite confusing regarding the clear-cut distinction between TEWL and SSWL.

Electrometric Properties of Skin

Electrical properties of skin are influenced by its surface texture and microrelief, as well as by the water and electrolyte content in the SC. In addition, sweat production is primordial. Measuring skin electrical capacitance is convenient although indirect way for appreciating any changes in these physiological parameters. The capacitance method is rooted on the higher permittivity of water than for most other molecules. Thus, the dielectric characteristics of the SC mainly depend on its water content. According to the site of measurements, potential sources of variation in the data and sources of errors include sweat production, occlusion of the sweat ducts, density in vellus hairs, as well as the electrolyte content of the SC, and some artefacts from applied xenobiotics. Regular devices devoted to skin capacitance measurements provide average electrometric values over the global skin area covered by the sensor probe. Hence, there is no information about the possible heterogeneity in the measured physical parameter over the test area.

Over the past decade, an innovative progress afforded the Skin Capacitance Mapping (SCM) method representing a specific type of nonoptical skin surface imaging [4-7]. This method relied on fine-tuned electrometric measurements of the skin surface properties. Such electrometric assessments of the upper layers of the epidermis represented a convenient noninvasive way for assessing the SC hydration. Such properties are closely related to a series of specific SC structures and functions [6-9].

The virtue of the SCM method relies on the specific information avoiding some misleading concepts about the reality of SC hydration. The method has probably greater impact for assessing a wide range of physiological and pathological changes altering functional skin characteristics than for providing diagnostic clues in dermatology. Anyway, some SCM aspects are seemingly typical for some disorders [7,10,11].

SCM method

The SCM sensor is dedicated for computer recordings of both the skin surface hydration and microrelief [6-9]. The Moisture Map HM100 device (CK Technology, Visé, Belgium) is built with a close network of microcapacitors orderly dispersed on a 18 × 12.8 mm plate protected by a thin silicon oxide layer [11]. The probe is closely applied to the skin surface for about 5s in order to collect the relevant information without interfering with both the water flux through and water storage inside the SC.

In practice, the real-time SCM nonoptical images are acquired and displayed on a computer screen. They provide simultaneously SC capacitance measurements every 50 µm over the explored area. Capacitance values of the superficial SC appear as pixels in a range of 256 grey levels. The darker pixels correspond to high capacitance (hydrated) spots, while the clear ones represent the lower capacitance (dry) values.

The SCM method is noninvasive, ethical and applicable without any restriction in humans. It provides objective and quantitative information that is not provided by any other method. The SCM procedure has been validated by several research groups. SCM combines accuracy, precision, sensitivity and reproducibility. With regard to SC moisturization and detection of sweat gland activity, SCM has a low limit of detection allowing detecting minute changes in capacitance. In addition, the range of detectable values is large at any of the measuring points.

Sweat Gland Activity and Stratum Corneum Permeability

In regular unstimulated physiological conditions, water is lost by evaporation through the combination of a transepidermal way and a discrete activity of eccrine sweat glands [8]. Basically, three distinct conditions were described regarding SCM aspects of the sweat gland activity. One condition represents a quiescent stage of activity without any peculiar SCM manifestation. A distinct condition is recognized by pin-point darker spots present at some acrosyringia. There is no liquid sweat poured out and vapor is apparently inconspicuous without any significant TEWL increase. It was suggested that this aspect was due to a moisturized cap of SC occluding acrosyringia openings. By contrast, the third boosted condition referred to watery liquids poured out through active sweat glands [8].

TEWL measurements are commonly used for testing the SC barrier function in absence of sweating activity, but this condition is probably not fulfilled in all circumstances. A number of variables affect TEWL, including person-linked factors as well as environmental and instrumental variables. In particular, any physical, thermal and emotional stress ainfluence TEWL measurements. Therefore, a premeasurement 15 to 30 min rest time out of physical activity in a temperature-controlled room at 20°C - 22°C is respected in most studies. The same considerations apply to electrometric measurements including SCM. In these different technical approaches, it is often hardly possible to distinguish the genuine TEWL from the so-called “imperceptible perspiration” by sweat glands [8]. The contribution of this latter physiological parameter in the instrumentally-measured TEWL values has never been thoroughly assessed and is commonly neglected in the interpretation of TEWL data.

Sweat glands excrete sweat only intermittently, in cyclic alternations of periodic discharges and pauses. The pulsatility reaches about 0.3 to 12 sprouts per minute [3]. Such cyclic activity depends on individuals, circumstances, and body areas. It results from spasmodic contractions of periluminal myoepithelial cells once distended by the flow of sweat. Apparently, the different glandular groups are active alternately [3]. Even in case of profuse sweating, about 50% of the pores do not give out liquid at a given time.

Sweating and thermoregulation

Eccrine sweat glands are located in the dermis over the vast part of the body. Men sweat more than women do in similar situations (approximately 800 mL/h for men vs. 450 mL/h for women during exercise). When corrected for body surface area, the sweat rate in men is still 30% to 40% higher [10].

Sweating and thermoregulation are impaired with age. The number of eccrine glands diminishes and the output of eccrine sweat is reduced. Men over 60-70 years old display lower sweat rates and higher core temperatures in response to exercise than younger men and boys [12], and the temperature threshold to induce sweating is 0.5°C higher in aged men. The elevated temperature threshold for sweating and reduced sweat response was more pronounced in aged women. However, a small study comparing 8 women aged 50-62 with 8 young women aged 20-30 found that in a hot-dry environment, the older women’s whole body and local sweat rates were significantly lower than those of younger women, but in a warm-humid environment, there was no age-related difference [13].

Sweating patterns during physical training

A preliminary study in a group of 20 healthy volunteers used SCM for exploring sweating under physical exercise [8]. The study was approved by the Ethic Committee of the University Hospital (B70720084875), and it was performed in accordance with the Declaration of Helsinki. It appeared that sweat glands were discretely active even in absence of visible sweating, in which case they emitted only water vapor. Such imperceptible perspiration through sweat glands was conveniently observed using SCM. Tiny black dots marked the joining up of each discretely active sweat gland apparatus at the skin surface. Each tiny black dot corresponded to an open sweat duct or to a soft cornified and moisturized plug covering such openings. This structure probably exhibited a sweat-holding capacity trapping sweat vapor. There was no running sweat at that stage of gland activity. This condition frequently occurred in association with an overall increase in interadnexal SC moisture. In such instance, the TEWL was commonly increased. When sweating was more active, SCM black dots enlarged, and some merged to form irregular black “puddles”.

At the onset of sweating remaining clinically imperceptible, only black dots appeared, marking the active sweat gland openings [8]. This finding questions the interpretation to be given to blind TEWL determinations which are indeed influenced by imperceptible sweating. Progressively, the SCM black dots become larger and larger till merging to form continuous black puddles.

This study was extended by the inclusion of the 36 additional healthy Caucasian volunteers of both genders. Their ages ranged 21-56 years. At inclusion, two sites were delimited by self-adhesive rings placed on the volar aspect of each forearm, either in distal or proximal locations. In the test procedure, they remained at rest for at least 20 minutes before the first SCM assessment was performed. Then, they started a mild training program using an exercise cycloergometer for 10 min in a room at controlled temperature (21 ± 1°C) and relative humidity (RH: 52 ± 3 %). Other SCM captures were performed at the completion of exercise as well as 1 min and 5 min later. Skin temperature was measured using a Skin Thermometer® ST500 (C + K electronic, Cologne, Germany), and TEWL/SSWL was measured using a Tewameter® TM300 (C + K electronic).

Data of the present study were combined to those of the previous one [8]. They were expressed as means and standard deviations or as medians and ranges according to the type of data distribution. Statistical comparisons were performed using the two-sided paired t-test, the Mann-Whitney test or the Kruskal-Wallis test, as appropriate. The linear regression analysis model was applied to evaluate the relationships between paired variables. A p value < 0.05 was considered significant.

None of the volunteers developed visible sweat running at the skin surface during the test procedure. At rest, TEWL, skin temperature, and the mean SCM showed no significant differences between both forearms, and between genders.

Compared with the resting condition (Figure 1), significant changes were found after mild physical exercise (Table 1). The SSWL values were markedly increased for at least 5 min following exercise (Table 1). Of note, a large range of SSWL assessments (6.0 – 78.9 g/h/m^2) were found 1 min after exercise. Compared to the rest condition, skin temperature was initially significantly decreased at completion of exercise, but increased significantly 5 min later (Table 1). The SCM values were significantly increased at completion of exercise and 1 min later, but returned to normal after 5 min.

SCM after exercise showed a combination of two major changes affecting the sweat gland activity and the SC hydration.

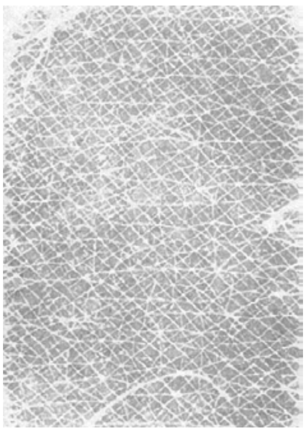


Figure 1: Subject at rest.

Table 1: Healthy subjects (n = 56). Values of skin parameters at rest and at the end of a mild physical exercise.

10-min physical exercise	TEWL/SSWL (g/h/m^2)	Skin temperature (°C)	Mean SCM
A rest	6.6 ± 1.1	30.1 ± 0.2	27.4 ± 7.3
At completion	60.3 ± 9.8***	29.1 ± 0.5***	41.6 ± 8.4**
1 min later	27.4 ± 15.6***	29.8 ± 1.3	36.4 ± 6.3**
5 min later	9.8 ± 1.7**	30.4 ± 0.1**	29.8 ± 6.6

* p < 0.05, ** p < 0.01, *** p > 0.001 compared to rest
TEWL, Transepidermal Water Loss
SSWL, Skin Surface Water Loss
SCM, Skin Capacitance Mapping

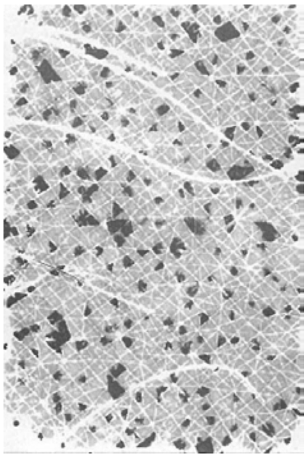


Figure 2: At completion of a 10 min-exercise revealing an irregular pattern of dark dots corresponding to openings of sweat gland ducts. The majority of the small dots share the same size. A few dots are larger and they probably correspond to the fusion of tiny dots.

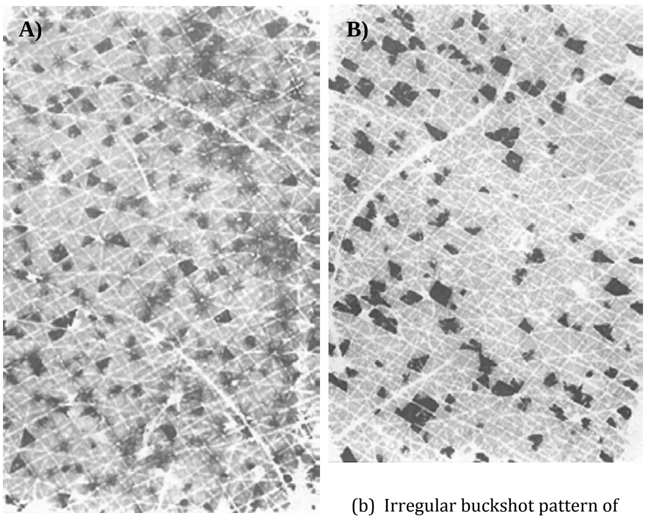
On the one hand, a large number of tiny black dots revealed the presence of discretely active sweat glands. Their size and distribution over the skin surface were quite uniform. Some larger dark spots resulted from the enlargement and merging of the tiny black dots (Figure 2). On the other hand, the SCM background of the SC appeared darker than before exercise, suggesting increased SC moisture. These features were particularly obvious at completion of, as well as 1 min after exercise, but they faded after 5 min. These findings highlight the diversity in functional activity of sweat pores at the skin surface (Figure 3 a,b). This aspect could be added to a previous characterization of skin pores [14]. The patterns of sweat pore activity and SC moisture were not similar (Figure 4 a, b, c).

Significant linear correlations (p < 0.05) were found between TEWL and the mean SCM 1 min after exercise (r = 0.73) and 5 min after exercise (r = 0.59). A negative correlation (p < 0.05) was found between skin temperature and the mean SCM 1 min after exercise (r = -0.37).

In our panel of volunteers, we did not encountered intraindividual variations of SCM patterns of the SC as reported on the chest of aged individuals in a previous study [15].

Conclusion

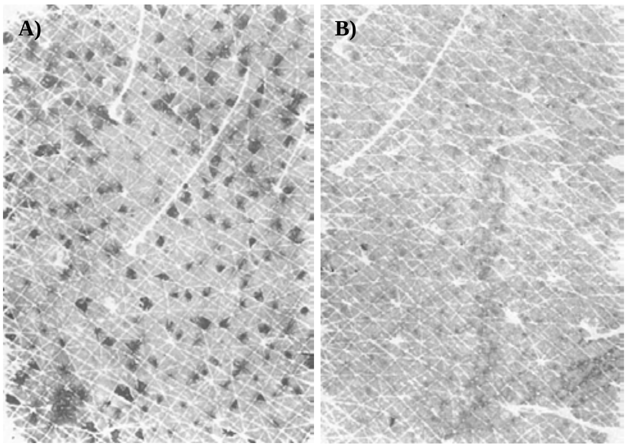
A given mild physical exercise globally activates sweat gland



(a) Dense pattern.

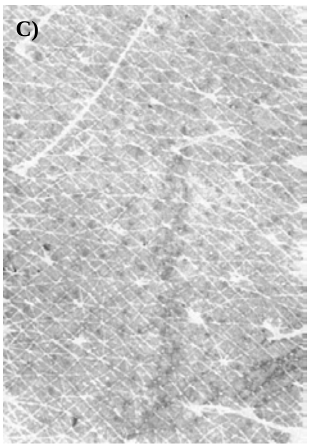
(b) Irregular buckshot pattern of sweat gland activity.

Figure 3: Patterns of sweat gland activity at completion of a 10-min exercise. The black dots correspond to active sweat pores.



(a) Diffuse sweat gland activity with widespread SC hydration.

(b) Discrete sweat gland activity with diffuse SC hydration.



(c) Diffuse homogeneous SC hydration pattern corresponding to an increased transepidermal water loss unassociated but probably following previous sweat gland activation during exercise.

Figure 4: Post exercise patterns of capacitance.

activity. The effect is associated with an initial drop in skin temperature and activation of SSWL and SC moisturization. The effect on SC persists for a couple of minutes at completion of the activation of sweat pores. Initially, a variable amount of sweat pores, releases sweat vapor without any evidence for liquid sweat production. In a further step, liquid sweat is produced by a progressive recruitment of active sweat pores. The combination of sweat vapor production, liquid sweat pouring out and SC moisturization is variable among individuals and blind evaluations of SSWL and TEWL reflect a set of distinct sweat gland activations and SC moisturization.

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