

# Impact of Age and Body Site on Adult Female Skin Surface pH

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## Key Words

Skin care · Aging · Anti-aging · Cosmetics · Epidermal barrier

## Abstract

**Background:** pH is known as an important parameter in epidermal barrier function and homeostasis. **Aim:** The impact of age and body site on skin surface pH (pH<sub>SS</sub>) of women was evaluated in vivo. **Methods:** Time domain dual lifetime referencing with luminescent sensor foils was used for pH<sub>SS</sub> measurements. pH<sub>SS</sub> was measured on the forehead, the temple, and the volar forearm of adult females (n = 97, 52.87 ± 18.58 years, 20–97 years). Every single measurement contained 2,500 pH values due to the luminescence imaging technique used. **Results:** pH<sub>SS</sub> slightly increases with age on all three investigated body sites. There are no significant differences in pH<sub>SS</sub> between the three investigated body sites. **Conclusion:** Adult pH<sub>SS</sub> on the forehead, the temple and the volar forearm increases slightly with age. This knowledge is crucial for adapting medical skin care products.

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## Introduction

Skin pH is known as an important parameter in skin integrity, epidermal barrier function, and wound healing [1, 2]. Regarding skin surface pH (pH<sub>SS</sub>) there are obviously diverging data available in the literature. To our knowledge, the lowest reported pH<sub>SS</sub> range is given with 4.0–5.5 [3]. The full pH<sub>SS</sub> spectrum reported in the literature ranges from as low as 4.0 up to 6.3 as reviewed by Lambers et al. [4]. In contrast, according to the prevailing medical doctrine the pH<sub>SS</sub> spectrum ranges from 5.4 to 5.9 [5]. In terms of site-specific differences in pH<sub>SS</sub> there is no clear evidence in the literature either. Some studies have reported differences [6, 7], whereas others have failed to confirm this assumption [8]. Besides, there is still controversy as regards the impact of age and different body sites on pH<sub>SS</sub>.

Skin acidification is crucial for epidermal barrier function and antimicrobial capacity [1, 2]. Elevated stratum corneum (SC) pH (pH<sub>SC</sub>) leads to an alteration of epidermal barrier homeostasis by degradation of corneodesmosomes, resulting in impaired SC integrity and decreased activity of lipid-processing enzymes, which require extracellular acidity for activation [9–13]. Behne et al. found the sodium-proton exchanger NHE1 to be an

**Table 1.** Changes in epidermal barrier function during aging

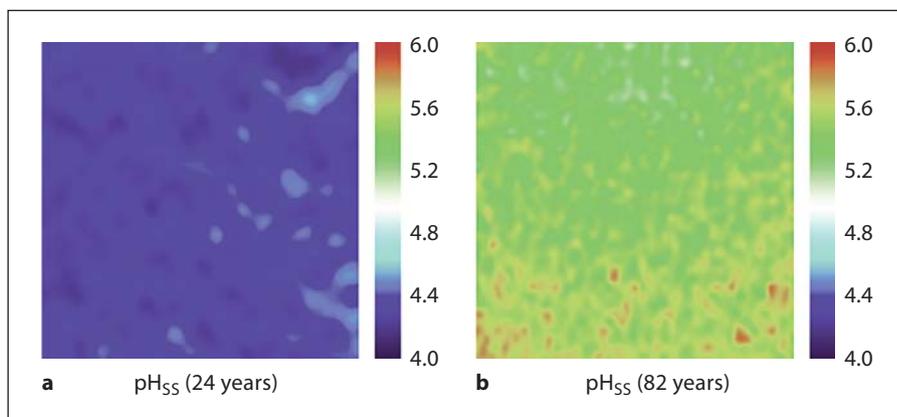
| Reference                      | Study population (age)  | Findings   |
|--------------------------------|---|--|
| Behne et al. (2003) [17]       | neonatal rats (days 1–7, n = 11–15)   | <ol style="list-style-type: none"> <li>1 less acidic skin surface pH in newborns</li> <li>2 skin surface pH drops on day 4 and reaches adult levels on day 7</li> <li>3 initial acidification in the lower stratum corneum with outward progression</li> </ol>   |
| Choi et al. (2007) [16]        | young humans (13–21 years, n = 65) versus aged humans (51–80 years, n = 55)<br>young mice (8–12 weeks, n = 6) versus aged mice (12–15 months, n = 6)  | <ol style="list-style-type: none"> <li>1 decrease of stratum corneum acidity with age</li> <li>2 impaired epidermal barrier recovery in aged epidermis</li> <li>3 normal epidermal lipid synthesis in aged murine epidermis</li> <li>4 abnormal lipid processing and stratum corneum integrity in aged murine epidermis</li> <li>5 decreased NHE1 expression in aged murine epidermis</li> </ol> |
| Fluhr et al. (2000) [18]       | parents (21–44 years, n = 44) versus their children (1–6 years, n = 44)   | average skin pH value of 4.91 in children vs. 5.07 in parents  |
| Ghadially et al. (1995) [9]    | young humans (20–30 years, total n = 15, for barrier recovery n = 5) versus aged humans (>80 years, total n = 6, for barrier recovery n = 5)<br>young mice (6–10 weeks, n = 5 for lipid analysis, n = 10 for barrier recovery) versus aged mice (18–24 months, n = 5 for lipid analysis, n = 10 for barrier recovery) | <ol style="list-style-type: none"> <li>1 delayed epidermal barrier recovery in aged human epidermis</li> <li>2 decreased transepidermal water loss in aged epidermis</li> <li>3 decrease in lipid content in aged vs. young murine epidermis</li> </ol>  |
| Ghadially et al. (1996) [19]   | aged mice ( $\geq 18$ months, n = 3–7)  | decrease of stratum corneum lipid content and extracellular bilayers in aged murine epidermis  |
| Giusti et al. (2001) [20]      | infants (8–24 months, n = 70) versus young women (25–35 years, n = 30)  | <ol style="list-style-type: none"> <li>1 no difference in skin surface pH according to sex and age in infants</li> <li>2 significantly lower skin surface pH in infants versus adults, no significant difference in transepidermal water loss between infants and adults</li> </ol>  |
| Hoeger and Enzmann (2002) [21] | neonates (3 days, 4 and 12 weeks, total n = 202)  | <ol style="list-style-type: none"> <li>1 skin surface pH decrease from day 3 to 12 weeks</li> <li>2 no significant difference in skin surface pH between male and female infants</li> </ol>  |
| Wilhelm et al. (1991) [22]     | young humans (20–30 years, n = 14) versus aged humans (55–85 years, n = 15)   | <ol style="list-style-type: none"> <li>1 no significant differences between the two groups for skin surface pH on most anatomic locations</li> <li>2 significantly lower transepidermal water loss in the older group</li> </ol>   |
| Ye et al. (2002) [23]          | young mice (8–12 weeks, n = 5) versus aged mice (23–27 months, n = 5)   | deficiency in IL-1 signaling in aged epidermis contributing to epidermal barrier abnormalities   |
| Yosipovitch et al. (2000) [24] | neonates (1 and 2 days, n = 44)   | significantly lower skin surface pH on day 2 versus day 1  |

essential regulator of  $\text{pH}_{\text{SC}}$  [14]. Due to altered skin barrier function in aged skin, skin diseases such as xerosis cutis and pruritus are affected by the supposedly age-dependent changes in  $\text{pH}_{\text{SS}}$  [15]. Choi et al. showed that the increased vulnerability of aged skin is due to abnormal SC acidity, resulting in defective lipid processing and loss

of SC integrity [16]. Table 1 summarizes known changes in epidermal barrier function during aging [9, 16–24], which may affect  $\text{pH}_{\text{SC}}$  and  $\text{pH}_{\text{SS}}$ .

To examine the effects of age, body site and UV exposure on  $\text{pH}_{\text{SS}}$ , we used a luminescence-based method for pH detection as previously described by our group [25].

**Fig. 1.** Representative pseudocolor images of  $\text{pH}_{\text{SS}}$  on the volar forearm of a 24-year-old (a) and an 82-year-old woman (b). Relatively uniform distribution of  $\text{pH}_{\text{SS}}$  is seen in the investigated areas. The mean  $\text{pH}_{\text{SS}}$  values (central  $50 \times 50$  pixels squares) were 4.39 (a) and 5.49 (b).



$\text{pH}_{\text{SS}}$  was recorded on three body sites: forehead, temple (both chronically UV-exposed) and volar forearm (virtually UV-unexposed). Data obtained from female volunteers (20–97 years) were analyzed.

## Subjects and Methods

### Preparation of Microparticles and Sensor Foils

In short, fluorescein isothiocyanate (FITC, Sigma-Aldrich Chemie GmbH, Talkirchen, Germany) was covalently conjugated to aminocellulose (AC) particles (Presens, Regensburg, Germany) to form FITC-AC pH indicator particles [25, 26]. Reference particles were synthesized by incorporating ruthenium(II) tris-(4,7-diphenyl-1,10-phenanthroline) ( $\text{Ru}(\text{dpp})_3$ , Sigma-Aldrich) in polyacrylonitrile (PAN) (Sigma-Aldrich) to form  $\text{Ru}(\text{dpp})_3$ -PAN particles [25, 27]. FITC-AC and  $\text{Ru}(\text{dpp})_3$ -PAN (3:1) were mixed with 20 ml of a solution consisting of polyurethane hydrogel (Cardiotech International Inc., Wilmington, Mass., USA) in ethanol/water (90/10 v/v) [25, 28]. This mixture was then spread on a transparent poly(vinylidene-chloride) (PVdC) foil (Saran plastic wrap, Dow Chemicals, Midland, Mich., USA). In previous works [25], we showed (i) that dyes do not leak out of the sensor particles, (ii) that sensor particles do not leak out of the polyurethane hydrogel matrix in which they are immobilized on inert PVdC foils, and (iii) that sensor particles are neither directly cytotoxic nor quickly taken up by human epidermal keratinocytes and L929 fibroblasts. Thus, biocompatible sensor foils were used for all measurements. For a detailed description of microparticle and sensor foil preparation, we refer to our methodology paper [25].

### pH Measurement

pH was recorded with luminescent sensor foils. For luminescence imaging (distance from camera to skin 8 cm, focus-controlled) we used data from standard-sized squares (triplicate samples of  $50 \times 50$  pixels).

In short, luminescence intensity ratios  $R$  were calculated for each pixel according to the time domain dual lifetime referencing method we described previously [25, 29]. Means of  $R$  were then computed for the respective area. Foils were calibrated and a five-

parametric sigmoidal fit was performed. The resulting equation was then solved for pH, thus enabling us to calculate pH and the respective  $\text{H}^+$  concentration based on  $R$  [25].

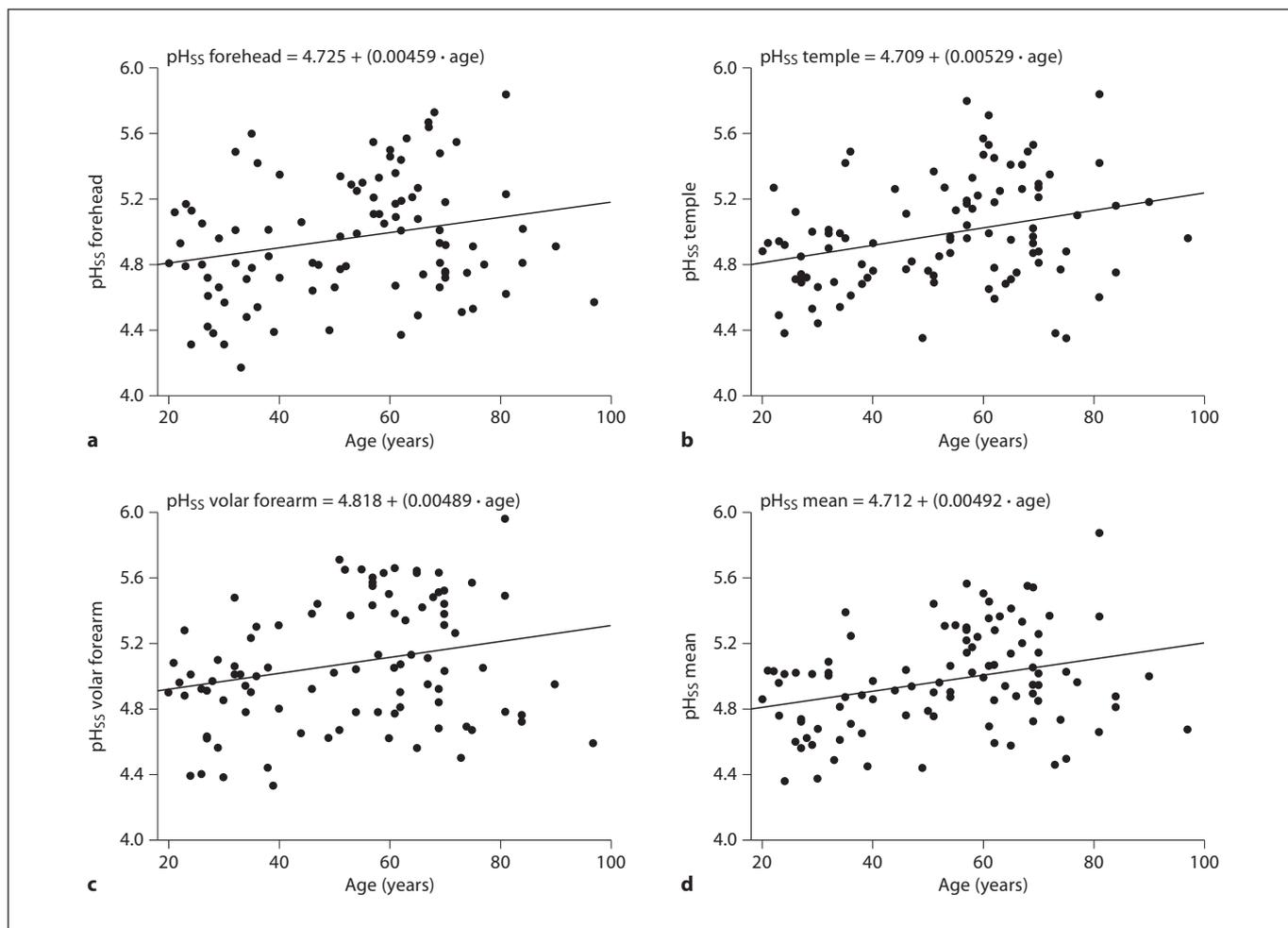
The camera was combined with a quickly pulsating, light-emitting 460 nm LED array (Luxeon V Star LXHL-LB5C, Lumileds Lighting Company, San Jose, Calif., USA). To image 2D pH, time domain dual lifetime referencing detection [29] was performed using an ImageX Time Gated Imaging system (TGI, Photonic Research Systems, Salford, UK) with an integrated 12 bit CCD chip ( $640 \times 480$  pixels). For details we refer to our methodology paper [25]. Calculations were performed with ImageX software (Microsoft Corporation, Redmond, Wash., USA). Representative pseudocolor images of  $\text{pH}_{\text{SS}}$  on the volar forearm of two women (fig. 1) were created with ImageJ (<http://rsbweb.nih.gov/ij/>).

### Study Subjects

Female volunteers ( $n = 97$ ,  $52.87 \pm 18.58$  years, 20–97 years) were included. Volunteers did not exercise, wash or apply topical formulations on the investigated body sites for 24 h prior to measurements. Such standardized conditions are of major importance for studies on  $\text{pH}_{\text{SS}}$  as routine procedures like showering with plain tap water (pH about 8 in many European countries) increase the  $\text{pH}_{\text{SS}}$  over at least 4 h [4]. Apart from that,  $\text{pH}_{\text{SS}}$  is influenced by detergents and other skin cleansing agents [30, 31]. All participants were provided with verbal as well as written information on the study and signed informed consent was obtained from each participant. All experiments were conducted in full accordance with the current revision (Seoul, Korea, 2008) of the Declaration of Helsinki (1964).

### Statistics

We used Sigma Plot 11.0 (Systat Software Inc., Chicago, Ill., USA) for all analyses. Data are given as mean  $\pm$  standard deviation (SD) except otherwise denoted. Means were calculated from the respective  $\text{H}^+$  concentrations, which were obtained for each pixel square. Subsequently, mean pH values were calculated from mean  $\text{H}^+$  concentrations. We did linear regression analyses for age dependency of  $\text{pH}_{\text{SS}}$ . Kruskal-Wallis ANOVA on ranks was performed to analyze differences between  $\text{H}^+$  concentrations for the different body sites.



**Fig. 2.** pH<sub>SS</sub> versus age. A slight increase in pH<sub>SS</sub> with age was seen on the forehead (a), on the temple (b), on the volar forearm (c) and for the combined means of all three body sites (d). pH<sub>SS</sub> values show a high variability for all ages. n = 97, all female.

## Results

pH<sub>SS</sub> slightly increased with age on the three investigated body sites (fig. 2a–c). Mean pH<sub>SS</sub> amounted to  $4.8 \pm 0.4$  on the forehead, and pH<sub>SS</sub> on the forehead ranged from 4.2 (33-year-old woman) to 5.8 (81-year-old woman) (fig. 2a). Mean pH<sub>SS</sub> amounted to  $4.9 \pm 0.3$  on the temple, and pH<sub>SS</sub> on the temple ranged from 4.2 (49-year-old woman) to 5.8 (81-year-old woman) (fig. 2b). Mean pH<sub>SS</sub> amounted to  $4.9 \pm 0.4$  on the volar forearm, and pH<sub>SS</sub> on the forearm ranged from 4.3 (39-year-old woman) to 6.0 (81-year-old woman) (fig. 2c). Mean pH of the three body sites also increased slightly with age (fig. 2d). Mean pH<sub>SS</sub> of all three body sites amounted to  $4.9 \pm 0.3$ , and mean pH<sub>SS</sub> ranged from 4.4 (24-year-old woman) to 5.9 (81-year-

old woman) (fig. 2d). There were no significant differences between pH<sub>SS</sub> on the three investigated body sites ( $p = 0.113$ ).

## Conclusions

In this work we show that pH<sub>SS</sub> slightly increases with age. Furthermore, there were no significant differences between pH<sub>SS</sub> on the forehead, the temple and the volar forearm. As there was no significant difference between the pH<sub>SS</sub> in sun-exposed skin (forehead, temple) as compared to sun-shielded skin (volar forearm), it seems to be unlikely that chronic exposure to UV light induces pH<sub>SS</sub> changes in human skin. Here, a moderate difference of

pH<sub>SS</sub> in aged versus young females was detected at the three investigated body sites.

In a previous study, Ghadially et al. observed an abnormal barrier recovery in aged compared to younger human epidermis [9]. Moreover, aged epidermis exhibits a decreased rate of transepidermal water loss, abnormal cytokine/growth factor signaling and a reduction in epidermal lipid synthesis [18, 32]. Interestingly, the omega-3 polyunsaturated fatty acid 11,14,17-eicosatrienoic acid was found to be increased in photoaged human epidermis and also after UV irradiation, whereas a decrease was found in intrinsically aged human epidermis [33]. A deficiency of IL-1 signaling in murine aged epidermis, which may contribute to epidermal barrier abnormality, has been reported by Ye et al. [23]. An improvement in barrier recovery has been achieved with the administration of imiquimod to aged murine skin, as imiquimod induces an alteration in multiple cytokine pathways, in-

cluding an increase in IL-1 $\alpha$  levels, and this seems to improve barrier recovery in aged epidermis [23, 34].

The future will show whether an adaptation of pH in topical therapeutics and skin care products is of benefit for patients and customers of these products.

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### Disclosure Statement

The authors have no competing financial interests to disclose.

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