

Biophysical parameters of skin: map of human face, regional, and age-related differences

SLAHEDDINE MARRAKCHI* AND HOWARD I. MAIBACH

Department of Dermatology, School of Medicine, University of California, San Francisco, CA 94143-0989, USA

The face showed anatomical variation on reaction to chemicals, which could be related to differences in biophysical specificities of the skin. The aim of this study was to establish a map of the face for 6 biophysical parameters. 10 young human volunteers (24–34 years) and 10 old volunteers (66–83 years) were studied to prepare a map of the human face based on regional variations and age-related differences by measuring various biophysical parameters. 7 locations on the face, neck, and forearm were investigated. Skin blood flow, transepidermal water loss (TEWL), stratum corneum hydration (capacitance), temperature, pH, and sebum content of the skin surface were measured. In both groups, skin blood flow in the nose showed the highest value. Perioral and nasolabial areas showed the highest TEWL values. The neck showed the highest capacitance value. The highest skin temperature was detected in the neck in the young group and in the nasolabial area in the old group. The chin showed the most alkaline pH in both groups. Nasolabial area showed the highest sebum content in the young group, as did the chin in the old group. These baseline values provide a framework to build on for ascertaining disease and intervention-related effects.

Key words: capacitance; LDF; non-invasive measuring; pH; sebum; skin physiology; temperature; TEWL. © Blackwell Munksgaard, 2007.

Accepted for publication 14 February 2007

The face showed anatomical variation on reaction to chemicals, which could be related to differences in biophysical specificities of the skin. Few studies tried to draw a map of the human face based on biophysical measurements. Even when available, these studies explored either limited areas of the face or restricted biophysical parameters (1–6).

The aim of this study was to establish a map of the facial skin for 6 biophysical parameters used to explore various components of the skin: transepidermal water loss (TEWL), skin hydration (capacitance), upper dermis vascularization by laser Doppler flowmeter (LDF), skin surface temperature, skin surface pH (pH), and lipid content of the skin surface (sebum).

Materials and Methods

Subjects

2 age groups were examined: 10 healthy volunteers in the young group, aged 29.8 ± 3.9 years (range

24–34 years), and 10 in the old group, aged 73.6 ± 17.4 (range 66–83 years). All the volunteers gave written consent, and the study was approved by the local ethical committee.

Methods

9 regions (forehead, upper eyelid, nose, cheek, nasolabial and perioral areas, chin, neck, and volar forearm) were studied. TEWL was measured using an evaporimeter (Servo Med EP1; Servo Med, Stockholm, Sweden), according to the European Society of Contact Dermatitis recommendations (7). The results were expressed as $\text{g/m}^2/\text{h}$. Electrical capacitance of the stratum corneum (8) was measured with a capacitance meter (Corneometer CM 420; Schwartzhaupt Medizintechnik, Cologne, Germany). The capacitance was expressed in arbitrary units.

Infrared pyrometer (Omega OS 611; Omega Engineering Inc., Stamford, CT, USA) was used to measure skin temperature. Skin pH was recorded by using a skin surface pH meter (skin pH-meter PH 900 PC; Courage & Khazaka, Cologne, Germany). A small area of each site investigated was wiped with ethanol and 1 hr later

*Current address: Department of Dermatology, H. Chaker Hospital, Sfax 3029, Tunisia.

the lipid content of the skin surface (sebum) was determined by using a sebumeter (Sebumeter SM 810; Courage & Khazaka) (9). The sebumeter determines sebum output in $\mu\text{g}/\text{cm}^2$. Measurements of the cutaneous blood flow were taken using an LDF (10) (laser blood flow monitor MBF3D; Moor Instruments, Axminster, UK). Blood flow measurements were not taken on the upper eyelid because of the potential effect of the laser beam on the retina. Blood flow was monitored at 1 measurement per second for 30 seconds and the values were averaged. LDF measurements were expressed in arbitrary units.

Room temperature and relative humidity were recorded each time a subject was studied. Room temperature during the young group study ($20.3 \pm 2.3^\circ$ celsius) was significantly ($P = 0.042$) lower than in the old group study ($22.1 \pm 2.3^\circ$ celsius). Relative humidity during the young group study (52.6 ± 3.8) was significantly higher ($P = 0.009$) than in the old group study (46.5 ± 5.5).

Statistical analysis

To compare the measurements of the various skin sites within each group, the ANOVA test was used. The two-tailed Student's *t*-test for unpaired data was used to compare the differences between the 2 age groups. Linear regression and correlation analysis of measured parameters for each skin location and global correlation involving all the sites were performed using the Pearson's product-moment correlation coefficient.

Results

LDF measurements

Comparison between regions. The nose showed the highest value in both groups. Blood flow in the nose was significantly higher when compared with the forearm ($P < 0.001$) and almost significantly higher than the neck ($P = 0.066$) in the young group (Fig. 1). The perioral and nasolabial areas, the forehead, the chin, the cheek, and the neck took an intermediate position and showed higher baseline blood flow than the forearm ($P < 0.05$). Statistical significance was more obvious in the old group: nose blood flow was significantly higher than all the areas studied except the chin. It was followed by the chin, perioral and nasolabial areas, and cheek that showed higher blood flow values than the neck and forearm. The forehead and neck showed higher blood flow values than forearm only.

In the 2 groups, the forearm showed the lowest baseline blood flow value.

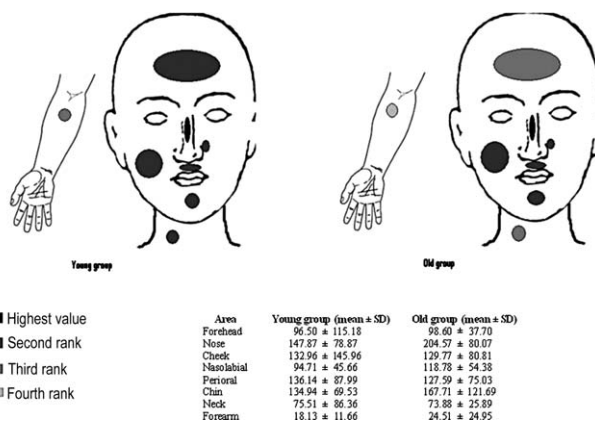


Fig. 1. Classification of regional variation in laser Doppler flowmeter (LDF) values. The nose shows the highest value in both age groups. LDF is the lowest in the forearm. In the young group, LDF values were similar in the remaining areas. In the old group, LDF values in the chin, perioral, nasolabial areas, and the cheek are similar and follow the LDF nose values. The forehead and neck show higher LDF values than forearm. The table shows LDF values (mean ± SD) in young and old groups expressed in arbitrary units.

Comparison between the 2 age groups.

Although no statistical significance was found, mean LDF values of the nose, nasolabial area, chin, and forearm were higher in the old group.

Transepidermal water loss

Comparison between regions. The perioral and nasolabial areas showed the highest TEWL values in both groups (Fig. 2). In the young group, TEWL in the nasolabial area was significantly ($P < 0.05$) higher than TEWL in 5 areas: forehead, upper eyelid, nose, cheek, and forearm. The perioral TEWL was higher than TEWL in 3 areas: forehead, cheek, and forearm. In the upper eyelid, TEWL was higher than TEWL in the cheek and forearm. In the forehead, the nose, the cheek, the chin, and the neck, TEWL was higher than only TEWL in the forearm.

In the old group, the nasolabial area TEWL was significantly ($P < 0.05$) higher than all the areas studied except the perioral area. In the perioral area, the chin, and upper eyelid, TEWL was higher than the 4 areas: forehead, cheek, forearm, and neck. In the nose, the neck, the forehead, and the cheek, TEWL was higher than in the forearm. In both age groups, the forearm showed significantly lower TEWL values than the other investigated areas.

Comparison between the two groups. Although no statistical significance was found between the 2 age groups, the young group showed a higher TEWL mean values in the perioral area, the neck, and the forearm. In the nasolabial area, the upper eyelid, forehead, chin, and nose, TEWL was higher in the old group.

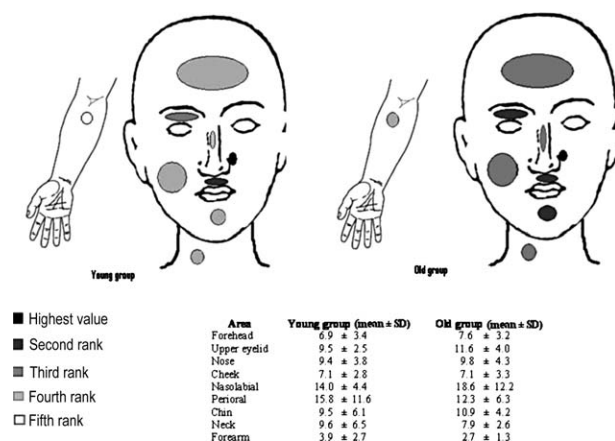


Fig. 2. Classification of regional variation in TEWL values are shown. In the young group, the nasolabial area shows the highest value, followed by the oral area, and then by the eyelid. The forehead, nose, cheek, chin, and neck show similar TEWL values. In the old group, the nasolabial area shows the highest TEWL value, followed by perioral area, the chin, and the upper eyelid. The nose, neck end, forehead, and cheek follow with similar TEWL values. The forearm shows the lowest TEWL values in both groups. The table shows TEWL values (mean ± SD) in young and old groups expressed as $\text{g/m}^2/\text{h}$.

Stratum corneum hydration (capacitance)

Comparison between regions. The neck showed the highest capacitance value in both age groups and was significantly more hydrated than in all the other areas studied (Fig. 3). The nose was the least hydrated area.

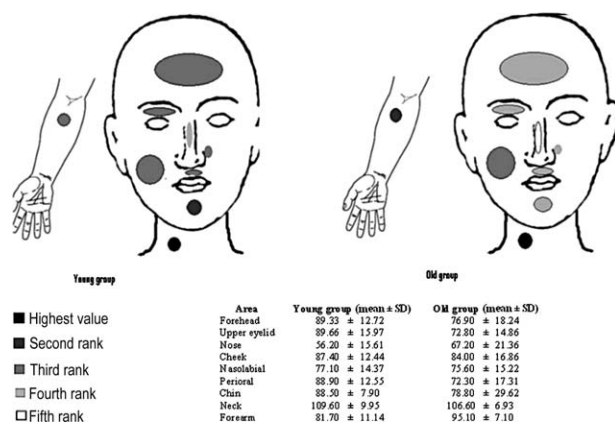


Fig. 3. Classification of regional variation in capacitance values are shown. The neck is the most hydrated area in both groups, and the nose is the least one. In the young group, the neck is followed by the chin, then by forehead, upper eyelid, cheek, perioral and nasolabial areas, and forearm, which show similar capacitance values. In the old group, the neck is followed by forearm, and then by the cheek. The forehead, upper eyelid, nasolabial and perioral areas, and the chin follow in the fourth position. The table shows capacitance values (mean ± SD) in young and old groups expressed in arbitrary units.

In the young group, the chin was significantly more hydrated than the nose and the nasolabial area, while the upper eyelid, the forehead, perioral and nasolabial areas, the cheek, and the forearm showed higher capacitance values than the nose.

In the old group, the forearm was significantly more hydrated than the nose and the cheek, and almost significantly more hydrated than the nose ($P = 0.067$). Although capacitance mean values of the chin, the upper eyelid, the forehead, and perioral and nasolabial areas were higher than the nose, significance was not reached.

Comparison between the 2 age groups. Stratum corneum hydration in the young group was significantly higher in the upper eyelid ($P = 0.029$) and perioral area ($P = 0.025$). The forearm capacitance was significantly higher ($P = 0.005$) in the old group.

Skin temperature

Comparison between regions. The skin temperature of the neck showed the highest value in the young group followed by the nasolabial and perioral areas (Fig. 4). In the old group, the nasolabial followed by the perioral area showed the highest temperature value.

The neck in the young group showed a significantly higher skin temperature than the 3 areas: forehead, cheek, and forearm. The nasolabial skin temperature was higher than temperature in the forearm and almost significantly higher than cheek and nose skin temperatures ($P = 0.055$ and

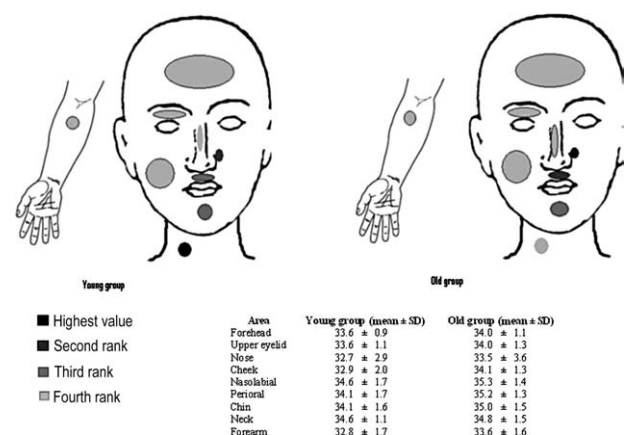


Fig. 4. Classification of regional variation in skin temperature values are shown. In the young group, the neck shows the highest temperature, followed by nasolabial area, perioral area, and the chin. Forehead, upper eyelid, cheek, nose, and forearm show the lowest skin temperature. In the old group, nasolabial area shows the highest skin temperature, followed by perioral area, then by the chin. The lowest skin temperature is shown in the remaining areas. The table shows skin temperature values (mean ± SD) in young and old groups expressed in degrees celsius.

$P = 0.092$, respectively). The chin and perioral area showed almost significantly higher skin temperature ($P = 0.093$ and $P = 0.090$, respectively) than the forearm. Forehead, upper eyelid, cheek, nose, and forearm showed the lowest skin temperatures.

In the old group, nasolabial area showed higher temperature than the 3 areas: forehead, upper eyelid, and forearm. The perioral area showed higher skin temperature than the 2 areas: forehead and forearm. Skin temperature in the chin was almost significantly higher than temperature in forehead and forearm. Temperature was similar in the 6 remaining areas: neck, cheek, forehead, upper eyelid, forearm, and nose.

The lowest skin temperature values were detected in the nose followed by the forearm in both age groups.

Comparison between the 2 groups. Although no statistical difference was detected between the 2 age groups, skin temperature mean values were higher in the old group in all the areas studied.

Skin pH

Comparison between regions. The chin showed the most alkaline skin pH in both groups (Fig. 5).

In the young group, the chin showed higher skin pH than the 4 areas: forehead, upper eyelid, cheek, and perioral area. The forearm, nose, nasolabial and perioral areas, the cheek, and the neck showed significantly higher pH than the 2 areas: forehead and upper eyelid.

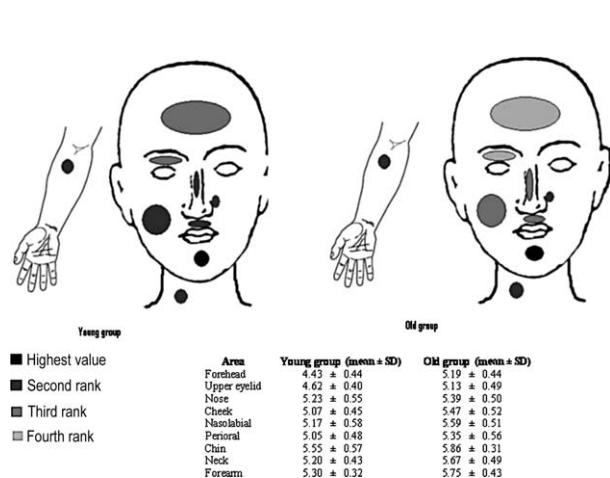


Fig. 5. Classification of regional variation in skin pH values are shown. In both groups, the chin shows the most alkaline skin pH, while forehead and upper eyelid show the most acidic pH. In the young group, forearm, nose, nasolabial and perioral areas, cheek, and neck show similar skin pH values. In the old group, the forearm, the neck and nasolabial area show lower skin pH than the chin, followed by the cheek, perioral area, and the nose. The table shows skin pH values (mean ± SD) in young and old groups.

In the old group, chin skin pH was higher than the pH in 4 areas: forehead, upper eyelid, nose, and perioral area. In the forearm, the neck, and the nasolabial area, pH was higher or almost significantly higher than the pH in 2 areas: forehead and upper eyelid. The cheek, perioral area, and nose did not show higher pH than forehead and upper eyelid, which showed the most acidic skin pH in both age groups.

Comparison between the 2 groups. In all the areas studied, the skin pH means were higher in the old group. Statistical significance was found in the following areas: forehead ($P = 0.001$), upper eyelid ($P = 0.021$), neck ($P = 0.036$), and forearm ($P = 0.017$).

Sebum

Sebumeter measures total lipids, which, on the face, is largely sebum (Fig. 6).

Comparison between regions. Nasolabial area, followed by the chin and the perioral area, showed the highest skin surface lipids contents in the young group. Sebum in the nasolabial area was significantly ($P < 0.05$) higher than in all the other studied areas except the chin. In the chin and perioral area, sebum content was higher than the 3 regions: upper eyelid, neck, and forearm. The forehead, the cheek, and the nose showed higher sebum values than the 2 areas: neck and forearm. Sebum content in the upper eyelid and the neck was higher than the forearm.

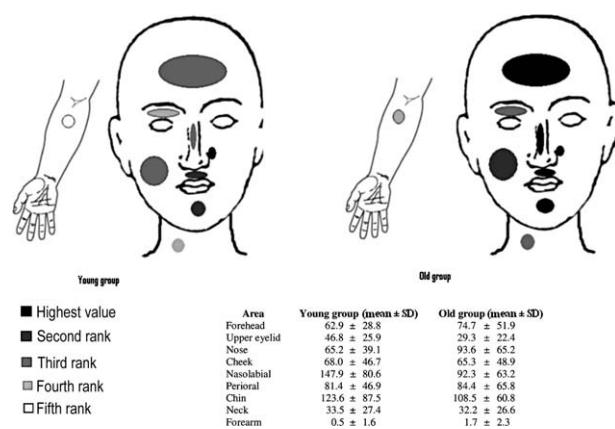


Fig. 6. Classification of regional variation in sebum content are shown. In the young group, nasolabial areas show the highest sebum content followed by perioral area and the chin, then by forehead, cheek, and nose. The neck and upper eyelid follow. The forearm shows the lowest sebum content. In contrast to the young group, the old group shows the classical T-shaped distribution of sebum production. The highest values are found in the forehead, nasolabial and perioral areas, and the chin. The cheek follows, then the neck, and upper eyelid. The table shows sebum content (mean ± SD) in young and old groups expressed in $\mu\text{g}/\text{cm}^2$.

In the old group, the chin, followed by the nose and nasolabial area showed the highest value. The chin, nasolabial and perioral areas, forehead, and nose showed significantly higher sebum content than the 3 areas: upper eyelid, neck, and forearm. The cheek showed higher sebum values than 2 areas: upper eyelid and forearm. The neck and upper eyelid showed higher sebum content than the forearm.

Only the forearm did not show measurable sebum content in both groups.

Comparison between the 2 age groups. No statistically significant differences were found. However, the old group showed higher mean values than the young group in the forehead, nose, and perioral area. The young group showed higher sebum mean values in the upper eyelid, nasolabial area, and chin.

The differences were slight in the cheek, perioral area, and neck.

Correlations studies

All parameters were correlated with each other in each age group but without considering the regions separately.

Correlations between TEWL and skin temperature ($r = 0.51$, $P < 0.01$ in the young group; $r = 0.44$, $P < 0.01$ in the old group) and between sebum and LDF ($r = 0.40$, $P < 0.01$ in the young group; $r = 0.65$, $P < 0.01$ in the old group) were the strongest detected.

Discussion

Baseline LDF

In both age groups and in concordance with the Shriner classification (11), the nose showed the highest blood flow levels in the face. Differences in blood flow between various areas of the face exist (3) probably because of variability in skin vascular architecture (12). However, some discrepancies exist between various studies probably under the influence of some parameters (age, gender, and race) (13). Besides these potential influencing parameters, a great spatial and temporal intra-individual heterogeneity of LDF measurements has been demonstrated by Braverman (14). This heterogeneity would be explained by the microanatomical organization of the microcirculation units of the upper dermis. The vascular unit was compared with an umbrella, with the handle is represented by ascending arterioles, and the umbrella proper is formed by the arteriolar and veinular branches forming the upper vascular plexus. The ascending arterioles are spaced at intervals of 1.5–7 mm and give high erythro-

cytes flux and high concentration of moving red blood cells. Areas of relative avascularity give low erythrocytes flux and low concentration of moving red blood cells (14). Thus, LDF values depend upon the position of the LDF probe on the skin.

Moderate correlation was found between LDF and sebum content in both age groups, which is not surprising because the sebaceous glands should require more oxygen, and thus more blood supply as their metabolism and sebum production increase. As reported by Moretti et al. (15), the face is richly vascular, and all arterioles and capillaries are organized in vascular units around the appendages of the face, so an increase in sebaceous glands number requires more vascularization.

Transepidermal water loss

Nasolabial and perioral areas showed the highest TEWL levels in the 2 age groups. The forearm showed the lowest values. In concordance with other studies, significant regional variations were found (4, 5, 11, 16, 17). TEWL is dependent on various factors including skin temperature (18), skin blood flow (19), local haemodynamics (20), the degree of corneocyte formation (6), and stratum corneum lipids contents (21).

In this study, nasolabial and perioral areas showed the highest skin temperature values in the old group. This could partly explain the high TEWL values in these areas. In the young group, nasolabial and perioral areas showed the highest skin temperature values after the neck. As described earlier (18, 22), skin temperature and TEWL are correlated when sweat glands are inactivated. This is confirmed by our results even though eccrine glands were only inactivated by rest in our study.

Conflicting results have been published concerning the effect of ageing on TEWL (6). Some studies reported a significant decrease in TEWL mainly after the sixth decade (16, 21, 23, 24). Some others reported a trend towards decreased TEWL with age without reaching the statistical significance (11, 25). Our results are difficult to compare with the literature because only few studies involving various areas of the face have been published (11, 16). Also, standard experimental conditions should be defined to make the different studies comparable (ambient temperature, age, race, and sex).

Capacitance

As reported by Shriner and Maibach (11), the neck showed the highest level of hydration in both age groups. The nose showed the lowest capacitance in the 2 age groups. Based on our data

(Figs 2 and 3) and the links reported in the literature between capacitance, TEWL (17), and haemodynamic factors (20), we may subdivide the face into the 3 areas: (i) areas with a lack of influx of water in the epidermis: low capacitance and TEWL (nose and forehead); (ii) areas with excess of water evaporation: high TEWL and low capacitance (nasolabial and perioral areas), and (iii) areas with high water-holding capacity: high capacitance and low TEWL (the neck).

In concordance with some investigations (16, 26), most of the areas studied did not show any age-related variation in skin hydration. However, in 7 of the 9 areas studied, the skin hydration was higher in the young group although statistical significance was reached only in 2 areas (upper eyelid and perioral area). So, as reported by Berardesca and Maibach (24), a trend to lower skin hydration of the face is found in the elderly.

Skin temperature

In concordance with the data previously published (11), the old group showed higher skin temperature on the face than the young group, although the statistical significance was not reached. However, the need for standardized experimental conditions is obvious taking into account the circadian rhythm shown for skin temperature (27).

We have discussed the correlations between skin temperature and TEWL. Skin temperature was weakly but significantly correlated with the sebum content of the skin in both age groups. These 2 parameters are probably related to a third parameter, the baseline blood flow. But only in the old group, a correlation ($r = 0.39$, $P < 0.01$) was found between skin temperature and baseline LDF. It is well known that increase in skin temperature increases sebum excretion in the range of 10% per 1° celsius (28).

Sebum

Few studies have been published comparing the sebum production in various areas of the face. Sebum level distribution occurs in a T-shaped fashion with high values on the forehead, nose, and chin, with the cheek having the lowest values (5, 6, 29); however, the nasolabial and perioral areas, the eyelid, and the neck were not previously studied. In our study, the T-shaped distribution was found only in the old group. In the young group, the highest values were found in the central area of the face: nasolabial and perioral areas and chin, with the forehead ranking third. The minor discrepancies found could be explained by the heterogeneity of the studied populations and by the variation in the experimental conditions. Cunliff

et al. reported that sebum excretion increases by 10% as local temperature increases by 1° celsius (28). However, we did not find a similar distribution pattern between skin temperature and sebum excretion (Figs 4 and 6). Also, Le Fur et al. (27), who showed chronological variation of skin temperature in the forearm and not in the face, found time-dependent sebum excretion in the face and not in the forearm. Thus, one could assume that sebaceous glands react to variation in skin temperature differently depending of the glands size or appendages local density, which is variable depending of the face areas. Other factors (hormonal, age, sex, and race) could influence sebum secretion rendering the need for standardized protocols and experimental conditions mandatory.

Skin pH

In our study, the chin pH was the most alkaline area in both age groups. The forehead and upper eyelid showed the lowest pH values in both groups.

The forehead, upper eyelid, neck, and forearm showed significantly higher pH values in the old group. In the remaining areas studied, the pH was also higher in the old group, although not statistically significant.

In concordance with our study, Wilhelm et al. (16), comparing the skin pH of the forearm and forehead with 9 other areas, found that the pH in the forehead was one of the most acidic and the pH of the volar forearm was one of the most alkaline. In the same study, the skin pH of the forehead was significantly higher in the elderly than in the young group. No significant difference between the two age groups was found in the skin pH of the forearm.

Zlotogorski (30), who studied the skin pH distribution in the forehead and cheek, found that the skin pH of the forehead was lower than the pH of the cheek in 89% of the subjects, and that the pH in these 2 areas was significantly higher in the group over 80 years.

In a chronobiologic study of biophysical skin parameters, Le Fur et al. (27) found a more alkaline pH in the forearm than in the forehead. A circadian rhythm of pH in the skin face was also found but not in the forearm, suggesting that structural specificities of the epidermis might account for the area-related variability of skin pH measurements.

Although few studies focused on the skin pH in terms of regional variations and age-related differences (16, 30), our study confirms that the pH is more alkaline in the old subjects, and that regional differences exist among the various areas of the face.

A negative correlation was detected in the chin and neck between sebum content and skin pH ($r = -0.49$, $P = 0.03$ for the chin; $r = -0.53$, $P = 0.02$ for the neck). More acute studies on the surface lipid composition and skin pH might probably give more information on the influence of the surface skin lipids on the pH.

Conclusion

We prepared a preliminary map of the human face, based on the measurement of various biophysical skin parameters, commonly used in skin research. Regional variations and less commonly age-related differences were found. However, the needs for standardized experimental conditions (climate and chronobiologic variations) and the use of homogeneous studied populations (age, sex, and race) are mandatory to allow comparison of the various studies and should facilitate investigation into disease and intervention effects.

References

- Schnetz E, Kuss O, Schmitt J, Diepgen T L, Kuhn M, Fartasch M. Intra- and inter-individual variations in transepidermal water loss on the face: facial locations for bioengineering studies. *Contact Dermatitis* 1999; 40: 243–247.
- Lopez S, Le Fur I, Morizot F, Heuvin G, Guinot C, Tschachler E. Transepidermal water loss, temperature and sebum levels on women's facial skin follow characteristic patterns. *Skin Res Technol* 2000; 6: 31–36.
- Stücker M, Steinberg J, Memmel U, Avermaete A, Hoffmann K, Altmeyer P. Differences in the two-dimensionally measured laser Doppler flow at different skin localisations. *Skin Pharmacol Appl Skin Physiol* 2001; 14: 44–51.
- Youn S W, Kim S J, Hwang I A, Park K C. Evaluation of facial skin type by sebum secretion: discrepancies between subjective descriptions and sebum secretion. *Skin Res Technol* 2002; 8: 168–172.
- Choi S J, Song M G, Sung W T, Lee D Y, Lee J H, Lee E S, Yang J M. Comparison of transepidermal water loss, capacitance and pH values in the skin between intrinsic and extrinsic atopic dermatitis patients. *J Korean Med Sci* 2003; 18: 93–96.
- Kobayaschi H, Tagami H. Functional properties of the surface of the vermilion border of the lips are distinct from those of the facial skin. *Br J Dermatol* 2004; 150: 563–567.
- Pinnagoda J, Tupker R A, Agner T, Serup J. Guidelines for transepidermal water loss (TEWL) measurement. A report from the standardization group of the European Society of Contact Dermatitis. *Contact Dermatitis* 1990; 22: 164–178.
- Blichmann C W, Serup J. Assessment of skin moisture: measurement of electrical conductance, capacitance and transepidermal water loss. *Acta Derm Venereol* 1988; 68: 284–290.
- Dikstein S, Zlotogorski A, Avriel E, Katz M, Harms M. Comparison of sebumeter and the lipometre. *Bioengineering and the Skin* 1987; 3: 197–207.
- Bircher A, de Boer E M, Agner T, Wahlberg J E, Serup J. Guidelines for measurement of cutaneous blood flow by laser Doppler flowmetry. A report from the standardization Group of the European Society of Contact Dermatitis. *Contact Dermatitis* 1994; 30: 65–72.
- Shriner D L, Maibach H I. Regional variation of nonimmunologic contact urticaria: functional map of the human face. *Skin Pharmacol* 1996; 9: 312–321.
- Chang H. Arterial anatomy of subdermal plexus of the face. *Keio J Med* 2001; 50: 31–34.
- Rodrigues L M, Pinto P C, Leal A. Transcutaneous flow related variables measured in vivo: the effects of gender. *BMC Dermatol* 2001; 1: 4.
- Braverman I M. The cutaneous microcirculation. *J Invest Dermatol Symp Proc* 2000; 5: 3–9.
- Moretti G, Elis R A, Mescon H. Vascular patterns in the skin of the face. *J Invest Dermatol* 1959; 33: 103–112.
- Wilhelm K-P, Cua A B, Maibach H I. Skin aging: effect on transepidermal water loss, stratum corneum hydration, skin surface pH, and casual sebum content. *Arch Dermatol* 1991; 127: 1806–1809.
- Rodrigues L M, Pinto P C, Pereira L M. Quantitative description of human skin water dynamics by a disposition-decomposition analysis (DDA) of trans-epidermal water loss and epidermal capacitance. *Skin Res Technol* 2003; 9: 24–30.
- Grice K, Sattar H, Sharratt M, Baker H. Skin temperature and transepidermal water loss. *J Invest Dermatol* 1971; 57: 108–110.
- Hattingh J. The influence of blood flow on transepidermal water loss. *Acta Derm Venereol* 1972; 52: 365–370.
- Rodrigues L M, Pinto P C, Magro J M, Fernandes M, Alves J. Exploring the influence of skin perfusion on transepidermal water loss. *Skin Res Technol* 2004; 10: 257–262.
- Schürer N Y, Plewig G, Elias P M. Stratum corneum lipid function. *Dermatologica* 1991; 183: 77–94.
- Mathias C G T, Wilson D M, Maibach H I. Transepidermal water loss as a function of skin surface temperature. *J Invest Dermatol* 1981; 77: 219–220.
- Leveque J L, Corcuff P, De Riga J, Agache P. In vivo studies of the evolution of physical properties of the human skin with age. *Int J Dermatol* 1984; 23: 322–329.
- Berardesca E, Maibach H I. Transepidermal water loss and skin surface hydration in the noninvasive assessment of stratum corneum function. *Derm Beruf Umwelt* 1990; 38: 50–53.
- Roskos K V, Guy R H. Assessment of skin barrier function using transepidermal water loss: effect of age. *Pharmacol Res* 1989; 6: 949–953.
- Cua A B, Wilhelm K-P, Maibach H I. Frictional properties of human skin: relation to age, sex and anatomical region, stratum corneum hydration and transepidermal water loss. *Br J Dermatol* 1990; 123: 473–479.
- Le Fur I, Reinberg A, Lopez S, Morizot F, Mechakouri M, Tschachler E. Analysis of circadian and ultradian rhythms of skin surface properties of face and forearm of healthy women. *J Invest Dermatol* 2001; 117: 718–724.
- Cunliff W J, Burton J L, Shuster S. The effect of local temperature variations on the sebum excretion rate. *Br J Dermatol* 1970; 83: 650–654.
- Youn S W, Na J I, Choi S Y, Huh C H, Park K C. Regional and seasonal variations in facial sebum secretions: a proposal for the definition of combination skin type. *Skin Res Technol* 2005; 11: 189–195.
- Zlotogorski A. Distribution of skin surface pH on the forehead and cheek of adults. *Arch Dermatol Res* 1987; 279: 398–401.

Address:
 Slaheddine Marrakchi
 Department of Dermatology
 H. Chaker Hospital
 Sfax 3029
 Tunisia
 Tel: +216 74 242627
 Fax: +216 74 273039
 e-mail: slaheddine.marrakchi@tunet.tn