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A novel continuous colour mapping approach for visualization of facial skin hydration and transepidermal water loss for four ethnic groups

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Synopsis

OBJECTIVES: The aim of this exploratory study was to develop a novel colour mapping approach to visualize and interpret the complexity of facial skin hydration and barrier properties of four ethnic groups (Caucasians, Indians, Chinese and Black Africans) living in Pretoria, South Africa.

METHODS: We measured transepidermal water loss (TEWL) and skin capacitance on 30 pre-defined sites on the forehead, cheek, jaw and eye areas of sixteen women (four per ethnic group) and took digital images of their faces. Continuous colour maps were generated by interpolating between each measured value and superimposing the values on the digital images.

RESULTS: The complexity of facial skin hydration and skin barrier properties is revealed by these measurements and visualized by the continuous colour maps of the digital images. Overall, the Caucasian subjects had the better barrier properties followed by the Black African subjects, Chinese subjects and Indian subjects. Nevertheless, the two more darkly pigmented ethnic groups had superior skin hydration properties. Subtle differences were seen when examining the different facial sites.

CONCLUSIONS: There exists remarkable skin capacitance and TEWL gradients within short distances on selected areas of the face. These gradients are distinctive in the different ethnic groups. In contrast to other reports, we found that darkly pigmented skin does not always have a superior barrier function and differences in skin hydration values are complex on the different parts of the face among the different ethnic groups.

Résumé

OBJECTIF: Le but de cette étude exploratoire était de développer une nouvelle approche de cartographie couleur pour visualiser et interpréter la complexité de l'hydratation de la peau du visage et de ses propriétés barrières à travers quatre ethnies (caucasienne, indienne, chinoise et noire africaine) vivant à Pretoria, Afrique du Sud.

MÉTHODES: Nous avons mesurés la perte insensible en eau (TEWL: transepidermal water loss) et la capacitance de la peau sur 30 régions prédéfinies du front, de la joue, de la mâchoire et de l'œil de seize femmes (quatre par ethnie) et avons réalisé des images numériques de leur visage. Une cartographie couleur exhaustive du visage a été générée en interpolant les valeurs entre chaque région mesurée et en la superposant à l'image numérique.

RÉSULTATS: La complexité de l'hydratation de la peau du visage et de ses propriétés barrières sont révélées grâce à ces mesures et visualisées via la cartographie couleur sur les images digitales. Globalement, les sujets caucasiens ont de meilleures propriétés barrières suivi par les sujets noirs africains, chinois et indiens. En revanche, les deux ethnies ayant la peau la plus pigmentée possède des propriétés d'hydratation cutanées supérieure. De subtiles différences ont été observées lors de l'examen des différents sites du visage.

CONCLUSIONS: Il existe de remarquables gradients de capacitance et TEWL sur de petites distances parmi les zones sélectionnées du visage. Ces gradients sont différents pour chaque ethnie. Contrairement à de précédents rapports, nous avons trouvé que les peaux fortement pigmentées n'avaient pas toujours une fonction barrière supérieure et que les différences dans les valeurs d'hydratation de la peau sont complexe en fonction des différentes parties du visage des différentes ethnies.

Introduction

A survey conducted by Kitamura *et al.* [1] revealed that consumers living in the metropolitan cities of Japan, America and France still have major unmet needs in key skin care targets despite decades of skin care research and product development. Moreover, as much as 40% of these populations perceived themselves as having a facial dry skin problem. Another study by Baek *et al.* [2] has also confirmed that as much as 72% of Korean women also had a dry skin problem on their faces. Kligman *et al.* [3] have reported that dryness of the face afflicts a majority of women past the age of 40 and is almost universal after the menopause. Prall *et al.* also reported that 60% of the female population suffers from low-level skin dryness [4]. Equally, Cooper *et al.* [5] followed the occurrence of dry skin on the forehead and cheeks over a 14-month period. The forehead always had a greater average dry skin score than the cheek, even in the summer months of the year. When separating con-

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sumers into dry, normal and greasy skin phenotypes greater skin dryness occurred on the cheeks of the dry and normal subjects in winter whereas for the forehead sometimes the highest score could be observed. Le Fur *et al.* [6] also reported that skin roughness was greater on the forehead compared with the cheeks. Thus, the expression of dry skin on the face is complex. Moreover, Rawlings *et al.* [7] have shown that visual and tactile roughness on the face is more difficult to treat compared with the lower extremities.

Several groups have used skin bioengineering methods to better understand the complexity of facial skin hydration and skin barrier properties (Table I). Rougier [8] has demonstrated for instance that the forehead has a higher transepidermal water loss (TEWL) value than post-auricular sites. Numerically but not statistically higher values for the cheek vs. post-auricular testing sites have recently been reported on three ethnic groups by Voegeli *et al.* [9]. Tagami has studied the location-related differences in the stratum corneum (SC) properties on five areas of the face showing that TEWL values increase from the cheek < forehead < nose < chin < nasolabial fold whereas skin hydration measured by skin conductance was nose > chin > nasolabial fold > forehead > cheek [10]. Schnetz *et al.* [11] compared 10 symmetrical facial locations (five per half face) and found that the highest TEWL values were cheek > chin > cheekbone = medial border of musculus masseter crossing the cavity of the mouth = forehead > superior to right nervis (right forehead). They also found that there was good correlation between the left- and right-hand sides of the face. Interestingly, they also found that the TEWL values over a period of 3 days correlated on both sides of the face but did not correlate with the forearm. Bazin and Fanchon also examined five areas of the face by corneometry and found decreasing values from the temple > forehead > chin > cheek > maxilla [12]. Marrakchi and Maibach examined six areas of the face (forehead, upper eyelid, nose, cheek, nasolabial and perioral regions), and the highest TEWL values were obtained in the perioral and nasolabial areas of both young and old subjects [13]. Concerning skin hydration, the capacitance values were least for the nose. The chin was more significantly hydrated than the nose and the nasolabial area and all other areas were more hydrated than the nose. Thus, one can see that it is difficult to interpret all these values in different areas of the face and a new approach is needed.

Lopez *et al.* [14] examined 90 sites on the full faces of five Caucasian women comparing TEWL, temperature and sebum levels. They observed that forehead TEWL values were lower than the chin and cheek values. They also reported that a median zone with elevated TEWL values corresponding to the paranasal and chin area could be discerned. Equally, they showed that all measures were symmetrical around the mid-line of the face and values were superimposable on both cheeks. This was a good step forward and we have modified their approach while also assessing skin hydration together with TEWL in different ethnic groups.

Here we report for the first time, a comprehensive, continuous facial mapping of skin capacitance and TEWL measurements on thirty pre-defined sites on the left side of the face of subjects from four ethic groups with normal facial skin. Equally, we report the use of a unique facial visualization procedure to allow the better interpretation of the regional differences of these properties on the face and between the different ethnic groups. This approach to imaging the data, essentially using continuous colour maps, allows a better description and visual comparison of the empirical data. We believe that this preliminary exploratory work may aid our understanding of the unique but complex properties of apparently normal facial skin and help in understanding how to best moisturize the face and meet this unmet global consumer need through targeted and personalized treatments.

Materials and methods

Study population and study set-up

The study was a cross-sectional study and was approved from the School of Health Care Sciences Research and Ethics committee (SREC) together with the Medunsa Campus Research and Ethics committee (MREC) and was conducted in accordance with the Declaration of Helsinki Principles. Written, informed consent was obtained from all participants before enrolment.

Table I Compilation of literature data comparing facial transepidermal water loss (TEWL) and skin hydration

Type of measure	Facial sites	Subject/ethnicity	Reference
TEWL	Forehead > post-auricular	Unspecified ethnicity	[8]
TEWL	Cheek > post-auricular	Blacks, Caucasians	[9]
TEWL	Nasolabial fold > chin > nose > forehead > cheek	Japanese	[10]
TEWL	Cheek > chin > cheekbone = m masseter	Unspecified ethnicity	[11]
TEWL	Perioral > nasolabial > chin = nose > cheek = forehead	Young subjects, unspecified ethnicity	[13]
TEWL	Nasolabial > perioral > chin > nose > forehead > cheek	Old subjects, unspecified ethnicity	[13]
Conductance	Nose > chin > nasolabial fold > forehead > cheek	Japanese	[10]
Capacitance	Temple > forehead > chin > cheek > maxilla	Unspecified ethnicity	[12]
Capacitance	Forehead = perioral = chin > cheek > nasolabial > nose	Young subjects, unspecified ethnicity	[13]
Capacitance	Cheek > chin > forehead > nasolabial > perioral > nose	Old subjects, unspecified ethnicity	[13]

To limit the biological variability of the subject groups, twelve healthy young female volunteers without visual signs of photoaging, living in Pretoria, South Africa participated in this observation, which took place from end of May to mid of June 2014. The average outdoor temperature was 11°C, the minimum temperature reached 4°C and the maximum was 19°C. There were four age-matched groups of Black African, Indian, Chinese and Caucasian subjects (all 21.8 ± 1.1 years old). All subjects are South African Citizens who were either students or office workers. For the one-day conditioning phase, the subjects did not apply any dermatological or cosmetic products to their faces and cleansed the face with tepid water in the morning as well as in the evening. Before conducting the bio-instrumental measurements, the skin was cleaned by gentle swabbing with a cotton pad soaked with distilled water of ambient temperature and allowed to dry for 20 min. Subjects were acclimatized for 30 min before any measurements, and measurements were performed in a climate-controlled room at a temperature of 21 ± 1°C and 35 ± 10% relative humidity. The study was conducted over a three week-day period when the weather was stable so climate-induced changes in barrier function could be excluded. All subjects participated in all stages of the study. There were not any dropouts.

Skin hydration and barrier function assessments

SC capacitance was measured using a Corneometer CM825 (Courage & Khazaka, Colonge electronic, Germany) and basal TEWL using an Aquaflux AF200 (Biox Systems, London, U.K.) on 30 predefined sites on the left-hand side of the face. All procedures were conducted following the published guidelines [15–17]. Skin capacitance was expressed as the mean value of three recordings, TEWL was measured once.

Three digital images were taken with the Visia-CR imaging system (Canfield, Fairfield, NJ, U.S.A.): one each from anterior, oblique and lateral view.

To reduce an interindividual variation of the measurements, a template was used to ensure the same facial site was measured on each occasion (Table II and Fig. 1).

Table II Description of facial sites measured

Site #	Description of site	Localization of site
01	Forehead, central, upper	Central brow top
02	Forehead, central, middle	Central brow mid
03	Forehead, central, lower	Central brow lower, between eyebrows
04	Forehead, middle left, upper	Mid brow top, 2 cm away from site 01
05	Forehead, middle left, middle	Mid brow mid, 2 cm away from site 02
06	Forehead, middle left, lower	Mid brow lower, 2 cm away from site 03
07	Forehead, left, middle	Outer brow mid; 2 cm from site 05
08	Forehead, left, lower	Temple brow
09	Eyelid	Eyelid
10	Forehead, outer, level with eyebrow	Temple, outer edge of brow
11	Nose, bridge	Nose, bridge
12	Under eye, inner corner	Under inner edge of lower eyelid
13	Under eye, middle	Under middle of lower eyelid 2 cm from 12
14	Outer eye canthus	Outer eye canthus, below site 08
15	Cheek, lateral	Outer cheekbone ±4 cm below site 10
16	Nose, apex	End of nose
17	Nasolabial sulcus, top	Nostril, top left, below site 12
18	Cheek, middle, oblique	Cheek-level with outer edge of nostril below site 13
19	Cheek, middle, oblique/lateral	Cheek-level with site 18 and below site 14
20	Cheek, middle, lateral	Cheek-level with site 18 and below site 15
21	Philtrum	Middle of upper up in cleft
22	Nasolabial sulcus, midpoint	In line with site 21 and site 17, nasolabial fold
23	Cheek, lower, oblique	In line with site 21 and site 18
24	Cheek, lower, oblique/lateral	In line with site 21 and site 19
25	Cheek, lower, lateral	In line with site 21 and site 20
26	Chin, central	Middle of chin
27	Jaw, anterior/oblique	2 cm from site 22
28	Jaw, oblique	2 cm from site 23
29	Jaw, oblique/lateral	2 cm from site 24
30	Jaw, lateral	2 cm from site 25

Colour mapping of the bio-instrumental readings

Each of the pre-defined sites was positioned on the Visia-CR images, and X and Y coordinates were recorded. A 2D model was computed to link TEWL and capacitance data to the corresponding facial positions. Between each measuring sites, physiological values are interpolated using a thin plate spline transform (1). It allows to obtain a value for all pixels (X, Y) of the facial image.

Two colour maps were created to represent TEWL and capacitance. They generate colour for each physiological value. The choice was made to represent good skin condition in deep blue and impaired skin condition in deep red. Limit skin condition was set to white colour: 16 g m^{-2} h^{-1} for TEWL values and 40 AU for capacitance. Between these landmarks, colours were linearly interpolated in the CIELAB space.

Finally, skin pixels on the Visia-CR images were segmented and, depending on their position, biophysical data were attached to them. The corresponding colour was superimposed to the original value with a transparency level [18]. The colour mapping images were generated from the mean values of each ethnic group. Individual heat maps were not generated as this method is extremely labour intensive.

Statistics

All data were collected in Microsoft Excel 2010. One-way ANOVA with subject groups and subgrouped facial sites (intra- and inter-ethnic) as fixed effect yielded P-values of < 0.05, except for the intra-ethnic analysis of TEWL values of subgrouped facial sites of the Chinese subjects. All the data were checked for normality using the D'Agostino and Pearson omnibus normality test. As all data were normally distributed unpaired Student's t-tests were used to compare each testing site.

Results

The complexity of facial hydration and barrier properties in the ethnic groups is clearly visible in the unique images shown in Fig. 2. On some areas of the face, subtle differences were found but in others, there were steep particular gradients within short distances. The gradients are distinctive in the different ethnic groups. When considering the overall ethnicity and overall SC barrier properties, TEWL values (g m^{-2} h^{-1}) were greatest for Indians (20.4 ± 2.6) > Chinese (18.6 ± 3.5) > Black Africans (16.7 ± 1.6) > Caucasians (12.4 ± 2.4), with the Chinese group showing

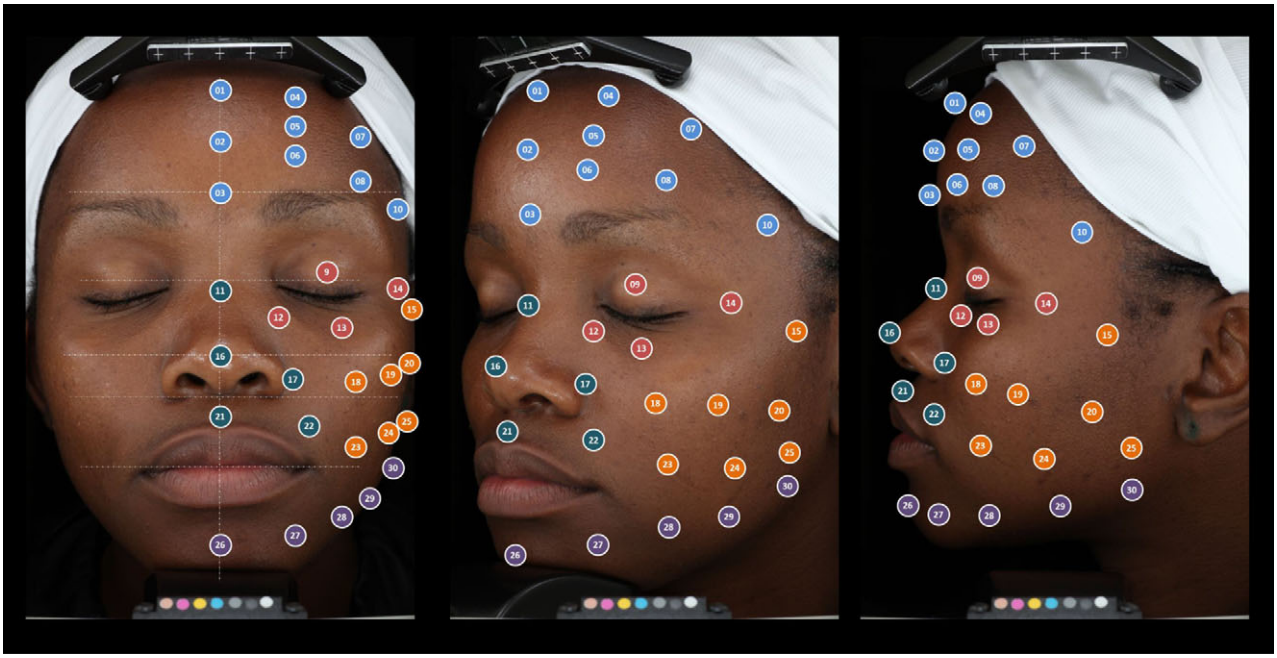

Figure 1 Anterior, oblique and lateral Visia-CR images of 30 pre-defined facial sites measured, demonstrated on one selected subject. The colour of the circles show the subgrouping of the facial sites, blue, forehead region; red, eye region; orange, cheek region; purple, jaw region. The green circles were not compiled.

the most complexity (Table III and Fig. 3a). However, overall skin hydration values, shown as Corneometer readings (AU), were greatest for Black Africans (55.0 ± 1.3) > Indians (51.0 ± 2.7) > Caucasians (46.8 ± 1.2) > Chinese (41.5 ± 3.1) (Table III and Fig. 3b).

On statistical comparison the Corneometer data of the Black African subjects were statistically significantly different to the Caucasian subjects ($P < 0.01$) and Chinese subjects ($P < 0.001$), whereas the Indian subjects were more hydrated than the Chinese ($P < 0.01$). The Caucasian subjects had the lowest TEWL values, the order was Caucasians < Black Africans < Chinese < Indians ($P < 0.01$ for each).

On closer inspection, grouping the skin sites into areas of the forehead, eye region, cheek and jaw TEWL was generally in the order Caucasians < Black Africans < Chinese < Indians with statistically significant differences between the jaw regions for Caucasians vs. Indians ($P < 0.01$) and Caucasians vs. Chinese ($P < 0.05$). Also the cheek TEWL values were lower for the Caucasians vs. the other subject groups (Table III, Fig. 4a).

Conversely, the Black African subjects had the highest capacitance values on these four regions and higher values were generally in the order Black Africans > Indians > Caucasians > Chinese except in the eye region where the mean values for Caucasians were lower than those of the Black African subjects but greater than the other two ethnic groups. Black African subjects were always statistically greater than Caucasian and Chinese subjects at all regions except the eye region for the Caucasians (Table III, Fig. 4b).

The eye region had a significantly higher TEWL compared with the cheek in all ethnic groups except for the Chinese subjects and was significantly higher than the jaw region in the Caucasian subjects (Table IV). TEWL was also higher in the eye region compared with the forehead in the Black Africans and the Indians.

Capacitance was also highest in the eye region (Table IV) in all ethnicities compared with the cheek, jaw and forehead regions. This was the case as well for the forehead compared to the cheek region, whereas the jaw region had a higher capacitance compared with the cheek region in Caucasian and Black African subjects.

When examining the 30 individual sites, the findings were more complex (Table III). The testing sites that were significantly different between the different ethnic groups are shown in Fig. 4a,b but are more clearly delineated in the continuous mapping results (Fig. 2). As can be seen for TEWL, Caucasians had significantly lower values under the eyes, the middle oblique cheeks and the oblique jaw regions than Indians. Similarly, Caucasians had a lower TEWL than the Black African subjects on the cheek, chin, anterior, oblique jaw and the lateral oblique jaw. Caucasians also had superior barrier properties to the Chinese subjects in the oblique jaw region.

However, the results are more clearly integrated by the continuous mapping images. Overall, the lowest TEWL values were observed on the lateral middle cheek followed closely by the oblique/lateral – lateral lower cheek and jaw regions. The highest TEWL values were observed in the eye regions, the nasolabial fold, the philtrum and the nose tip (Table III). Gradients of increasing TEWL (Fig. 2a–d) were observed from the:

Middle cheek to the top of the nasolabial fold.
Outer forehead to the outer eye canthus and under eye region.
Upper forehead to the lower forehead.
Oblique/lateral jaw to the chin.

Much more numerous statistical differences in skin hydration were observed between the different ethnic groups (Fig. 4b).

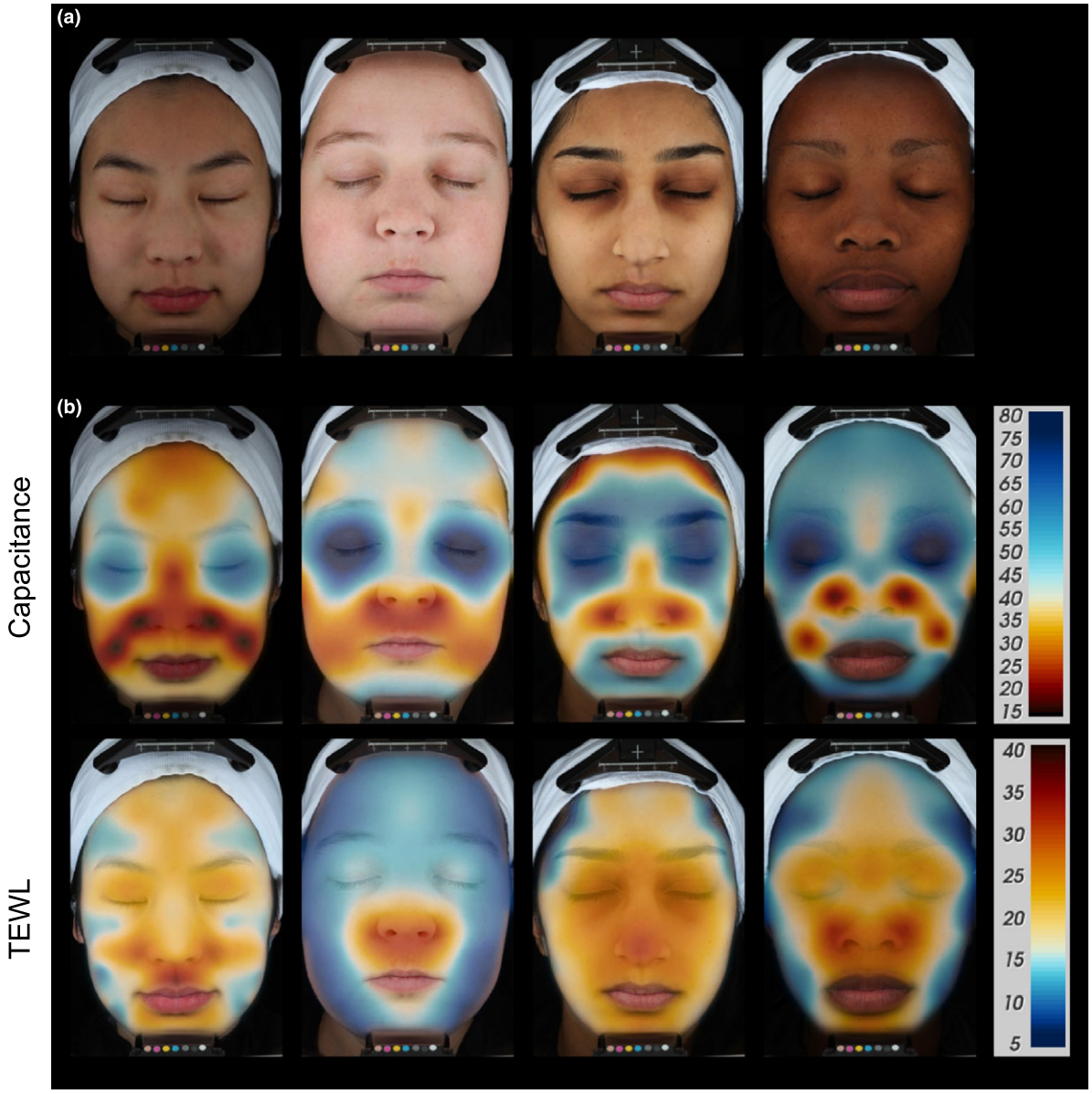

Figure 2 Continuous transepidermal water loss (TEWL) and capacitance colour maps of one selected subject per skin ethnicity, mean values of each group, from left: Chinese, Caucasians, Indians, Black Africans. Colour code for Corneometer values (15–80 AU) and TEWL values (5–40 g m^{-2} h^{-1}) shown on the colour scales on the right. Blue colour represents good skin condition and red colour impaired skin condition. Limit skin condition (40 AU for capacitance values and 16 g m^{-2} h^{-1} for TEWL) is set to white. a: unmapped subjects, b: anterior view, c: oblique view, d: lateral view; top row: Corneometer data, bottom row: TEWL data.

As can be seen Black African subjects had higher capacitance values than Caucasians in the apex of the nose, the middle lateral cheek, the lower oblique cheek and the oblique lateral jaw regions. Similar superior values were observed on the apex of the nose vs. the Indians and Chinese subjects. Compared with the Chinese the Black African subjects also had superior skin hydration in the central upper forehead, the middle left upper forehead and the middle left lower forehead together with the central chin area, and lateral oblique jaw area. Caucasian skin hydration was inferior to Indian skin hydration in the central middle forehead and the Philtrum areas but was superior to the hydration characteristics of Chinese subjects in the central upper forehead and middle left upper forehead together with the apex of the nose and the lower oblique jaw. Similarly, Indian skin hydration was superior to that of Chinese skin in the central middle forehead, central lower forehead middle left lower forehead and the lower oblique jaw regions.

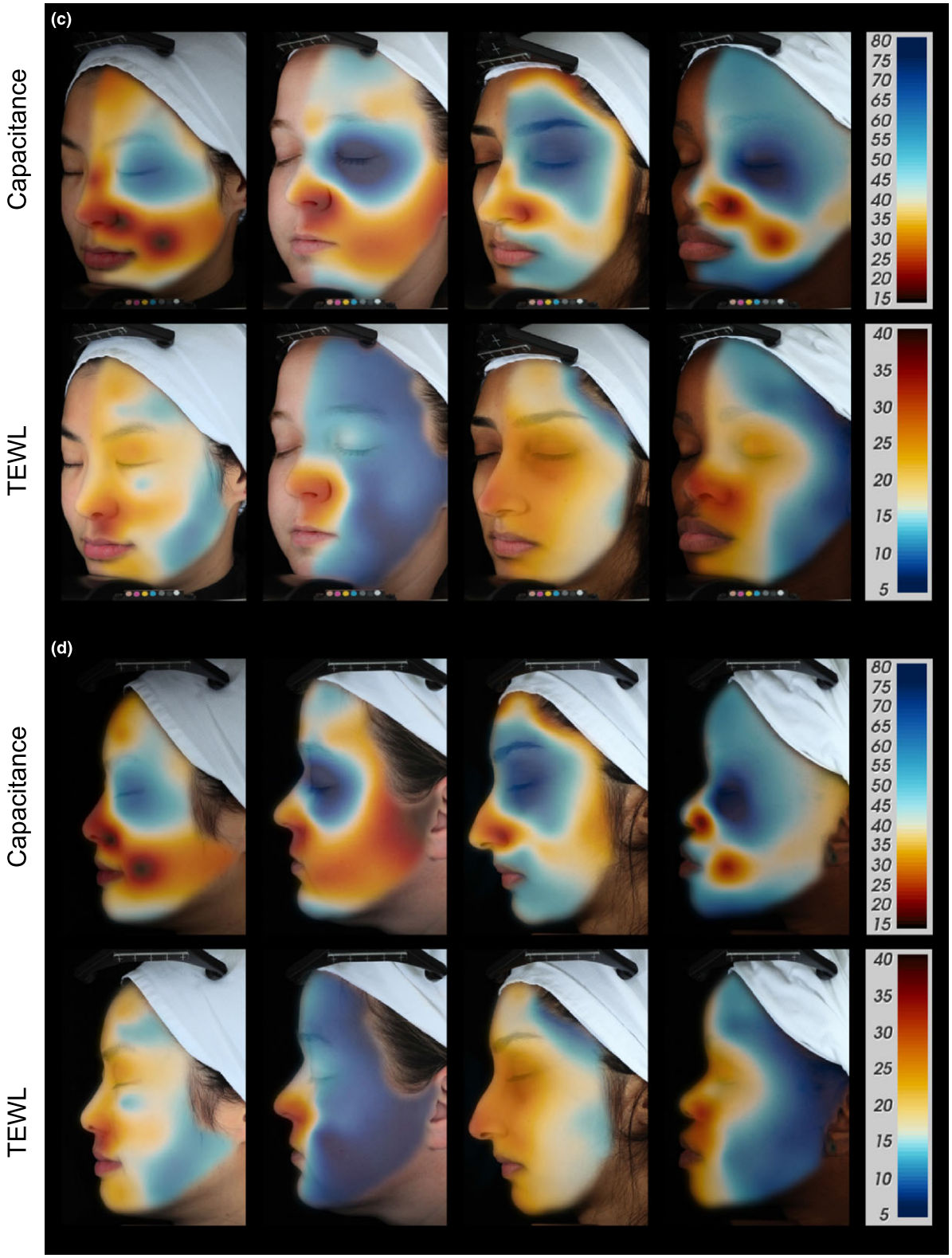

Figure 2 (continued)

Table III Comparison of the 30 testing sites for the four ethnic groups. Results represent mean ± SEM, $n = 4$ per group, n.a. measurement not possible due to too close adjacent testing sites, dash $P > 0.05$. (a) transepidermal water loss (TEWL) data, (b) capacitance data. Ch, Chinese; Ca, Caucasians; In, Indians; Bl, Black Africans

						***P* value of comparison**					
Site #	**Description of site**	**Chinese**	**Caucasians**	**Indians**	**Black Africans**	**Ch vs. Ca**	**Ch vs. In**	**Ch vs. Bl**	**Ca vs. In**	**Ca vs. Bl**	**In vs. Bl**
(a) TEWL											
	All sites	**18.6 ± 3.5**	**12.4 ± 2.4**	**20.4 ± 2.6**	**16.7 ± 1.6**	**<0.001**	–	–	**<0.001**	**<0.01**	–
	Forehead region	**17.4 ± 3.1**	**10.6 ± 2.5**	**17.5 ± 1.8**	**14.5 ± 1.2**	**<0.001**	–	–	**<0.01**	**<0.05**	–
01	Forehead, central, upper	18.5 ± 3.5	12.4 ± 2.9	16.3 ± 4.4	15.9 ± 1.5	–	–	–	–	–	–
02	Forehead, central, middle	21.8 ± 4.4	13.9 ± 4.4	19.3 ± 1.3	19.0 ± 3.6	–	–	–	–	–	–
03	Forehead, central, lower	22.0 ± 6.1	12.7 ± 2.6	25.2 ± 4.5	19.7 ± 1.5	–	–	–	<0.05	–	–
04	Forehead, middle left, upper	20.7 ± 5.9	10.0 ± 2.3	19.5 ± 1.9	13.3 ± 1.5	–	–	–	<0.05	–	<0.05
05	Forehead, middle left, middle	15.6 ± 3.8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
06	Forehead, middle left, lower	16.3 ± 5.0	10.5 ± 3.4	17.0 ± 3.2	15.4 ± 2.1	–	–	–	–	–	–
07	Forehead, left, middle	13.8 ± 1.5	8.5 ± 1.7	n.a.	12.7 ± 0.8	–	n.a.	–	n.a.	–	n.a.
08	Forehead, left, lower	13.7 ± 1.0	8.8 ± 2.2	15.2 ± 3.0	10.7 ± 1.3	–	–	–	–	–	–
10	Forehead, outer, level with eyebrow	17.2 ± 2.6	7.9 ± 1.8	11.6 ± 2.3	9.2 ± 1.5	<0.05	–	<0.05	–	–	–
	Eye region	**21.2 ± 5.6**	**13.7 ± 1.7**	**24.2 ± 4.5**	**20.3 ± 2.3**	**–**	**–**	**–**	**<0.01**	**<0.05**	**–**
09	Eyelid	24.7 ± 6.1	14.6 ± 1.8	24.2 ± 5.2	23.8 ± 3.3	–	–	–	–	<0.05	–
12	Under eye, inner corner	22.5 ± 4.6	17.1 ± 3.0	26.6 ± 6.9	19.0 ± 1.8	–	–	–	–	–	–
13	Under eye, middle	14.5 ± 4.0	13.7 ± 3.0	26.7 ± 4.4	21.5 ± 3.1	–	–	–	<0.05	–	–
14	Outer eye canthus	18.0 ± 6.4	9.2 ± 1.7	19.3 ± 6.8	16.9 ± 3.3	–	–	–	–	–	–
	Cheek region	**15.5 ± 3.4**	**8.5 ± 2.0**	**17.3 ± 2.2**	**12.1 ± 1.1**	**<0.01**	**–**	**–**	**<0.001**	**<0.05**	**<0.05**
15	Cheek, lateral	14.3 ± 1.9	8.6 ± 2.1	16.2 ± 2.7	10.8 ± 1.9	–	–	–	–	–	–
18	Cheek, middle, oblique	28.9 ± 8.3	29.4 ± 7.9	26.1 ± 4.7	31.5 ± 3.4	–	–	–	<0.05	<0.05	–
19	Cheek, middle, oblique/lateral	23.5 ± 6.8	10.8 ± 2.4	23.7 ± 3.9	18.1 ± 0.8	–	–	–	<0.05	–	<0.05
20	Cheek, middle, lateral	19.2 ± 8.0	9.7 ± 2.4	19.0 ± 1.8	13.1 ± 0.4	–	–	–	<0.05	–	<0.05
23	Cheek, lower, oblique	18.6 ± 4.5	17.8 ± 2.8	25.7 ± 2.0	25.8 ± 5.2	–	–	–	–	–	–
24	Cheek, lower, oblique/lateral	15.7 ± 3.1	9.8 ± 3.1	18.6 ± 3.6	13.4 ± 2.2	–	–	–	<0.05	–	–
25	Cheek, lower, lateral	11.0 ± 1.9	6.5 ± 1.9	15.8 ± 2.7	10.4 ± 1.4	–	–	–	–	–	–
	Jaw region	**16.8 ± 3.4**	**8.3 ± 1.8**	**19.1 ± 3.0**	**15.9 ± 1.9**	**<0.05**	**–**	**–**	**<0.01**	**–**	**–**
26	Chin, central	12.8 ± 3.3	6.7 ± 1.6	13.7 ± 2.5	9.7 ± 1.1	–	–	–	–	<0.05	–
27	Jaw, anterior/oblique	21.4 ± 2.9	14.3 ± 3.6	25.3 ± 3.7	26.0 ± 3.1	–	–	–	–	<0.05	–
28	Jaw, oblique	22.3 ± 6.1	9.4 ± 2.3	20.3 ± 4.4	20.3 ± 1.8	<0.05	–	–	<0.05	<0.05	–
29	Jaw, oblique/lateral	13.3 ± 1.9	6.7 ± 1.5	16.1 ± 2.7	14.2 ± 2.7	–	–	–	<0.05	–	–
30	Jaw, lateral	11.9 ± 2.6	5.3 ± 1.2	16.1 ± 2.8	9.5 ± 1.9	–	–	–	<0.05	–	–
	Various										
11	Nose, bridge	17.7 ± 3.7	15.7 ± 4.6	25.8 ± 3.0	24.6 ± 2.9	–	–	–	–	–	–
16	Nose, apex	14.3 ± 1.9	8.6 ± 2.1	16.2 ± 2.7	10.8 ± 1.9	–	–	–	–	–	–
17	Nasolabial sulcus, top	20.4 ± 4.7	27.3 ± 7.8	31.9 ± 4.9	20.7 ± 1.8	–	–	–	–	–	–
21	Philtrum	11.8 ± 2.1	7.5 ± 1.4	14.4 ± 1.8	8.8 ± 1.1	–	–	–	–	–	–
22	Nasolabial sulcus, midpoint	36.3 ± 6.0	29.3 ± 5.5	23.3 ± 1.1	26.4 ± 4.0	–	–	–	–	–	–
(b) Capacitance											
	All sites	**41.5 ± 3.1**	**46.8 ± 1.2**	**37.4 ± 3.6**	**55.0 ± 1.3**	**–**	**<0.01**	**<0.001**	**–**	**<0.01**	**–**
	Forehead region	**43.9 ± 1.5**	**49.2 ± 2.3**	**53.7 ± 4.0**	**56.4 ± 1.5**	**–**	**–**	**<0.001**	**–**	**<0.001**	**–**
01	Forehead, central, upper	35.2 ± 1.4	47.3 ± 4.3	35.1 ± 9.0	56.0 ± 1.1	<0.05	–	<0.001	–	–	–
02	Forehead, central, middle	43.8 ± 4.1	50.3 ± 4.6	59.8 ± 4.4	57.2 ± 4.2	–	<0.05	–	–	–	–
03	Forehead, central, lower	43.8 ± 3.1	42.3 ± 3.6	60.9 ± 2.3	51.0 ± 5.8	–	<0.01	–	<0.01	–	–
04	Forehead, middle left, upper	40.8 ± 5.4	55.6 ± 2.1	45.5 ± 8.1	59.7 ± 4.0	<0.05	–	<0.05	–	–	–
05	Forehead, middle left, middle	37.8 ± 8.1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
06	Forehead, middle left, lower	43.7 ± 1.0	51.3 ± 4.1	63.3 ± 6.0	57.6 ± 2.3	–	<0.05	<0.01	–	–	–
07	Forehead, left, middle	50.8 ± 1.0	51.1 ± 3.6	n.a.	55.9 ± 2.7	–	n.a.	–	n.a.	–	n.a.
08	Forehead, left, lower	52.0 ± 3.0	44.9 ± 3.4	61.6 ± 6.6	57.8 ± 1.2	–	–	–	–	<0.05	–
10	Forehead, outer, level with eyebrow	48.5 ± 3.1	50.3 ± 1.5	53.1 ± 3.5	55.8 ± 1.7	–	–	–	–	<0.05	–
	Eye region	**57.0 ± 4.1**	**67.1 ± 2.7**	**62.6 ± 3.0**	**69.5 ± 2.6**	**–**	**–**	**<0.05**	**–**	**–**	**–**
09	Eyelid	61.4 ± 3.3	79.8 ± 3.1	70.2 ± 5.4	72.6 ± 3.7	<0.01	–	–	–	–	–
12	Under eye, inner corner	46.9 ± 7.6	59.5 ± 5.7	55.1 ± 2.5	63.7 ± 6.4	–	–	–	–	–	–
13	Under eye, middle	58.8 ± 5.1	65.0 ± 2.0	65.1 ± 4.1	74.4 ± 1.1	–	–	<0.05	–	<0.01	–
14	Outer eye canthus	61.1 ± 6.0	64.1 ± 3.3	60.0 ± 6.2	65.3 ± 3.0	–	–	–	–	–	–
	Cheek region	**35.9 ± 3.2**	**36.6 ± 1.6**	**45.1 ± 5.5**	**48.7 ± 3.3**	**–**	**–**	**<0.05**	**<0.05**	**<0.05**	**–**
15	Cheek, lateral	53.6 ± 5.2	39.4 ± 1.4	41.2 ± 3.8	55.2 ± 7	<0.05	–	–	–	–	–
18	Cheek, middle, oblique	18.1 ± 4.3	27.8 ± 10.5	24.6 ± 6.1	21.3 ± 5.8	–	–	–	–	–	–
19	Cheek, middle, oblique/lateral	35.3 ± 6.4	39.2 ± 6.0	43.9 ± 6.6	51.9 ± 6.5	–	<0.05	–	<0.05	–	–

Table III (continued)

Site #	Description of site	Chinese	Caucasians	Indians	Black Africans	*P* value of comparison					
						Ch vs. Ca	Ch vs. In	Ch vs. Bl	Ca vs. In	Ca vs. Bl	In vs. Bl
20	Cheek, middle, lateral	39.8 ± 6.0	46.5 ± 0.9	60.2 ± 4.2	60.0 ± 8.5	–	–	–	–	<0.05	–
23	Cheek, lower, oblique	35.1 ± 8.4	36.0 ± 6.9	56.4 ± 9.3	52.7 ± 3.4	<0.05	<0.05	–	–	–	–
24	Cheek, lower, oblique/lateral	18.0 ± 3.2	32.7 ± 4.7	44 ± 8.0	27.0 ± 12.2	–	–	–	–	<0.01	–
25	Cheek, lower, lateral	34.1 ± 7.1	32.5 ± 2.8	44.9 ± 8.7	48.3 ± 0.9	–	–	<0.001	–	<0.05	–
	Jaw region	**35.9 ± 3.2**	**36.6 ± 1.6**	**45.1 ± 5.5**	**48.7 ± 3.3**	**–**	**–**	**<0.001**	**–**	**<0.05**	**–**
26	Chin, central	33.4 ± 3.7	35.0 ± 3.8	40.1 ± 10.2	51.8 ± 2.7	–	–	<0.05	–	–	–
27	Jaw, anterior/oblique	45.6 ± 5.0	56.4 ± 2.6	54.5 ± 1.5	63.5 ± 4.5	–	–	–	–	–	–
28	Jaw, oblique	45.1 ± 5.7	56.7 ± 3.8	57.8 ± 4.3	63.0 ± 5.5	–	–	–	–	–	–
29	Jaw, oblique/lateral	45.2 ± 7.3	50.1 ± 7.4	55.1 ± 6.0	58.2 ± 3.2	–	–	<0.05	–	<0.05	–
30	Jaw, lateral	42.2 ± 5.3	44.9 ± 4.6	46.1 ± 6.1	60.4 ± 1.4	–	–	–	–	–	–
	Various										
11	Nose, bridge	26.9 ± 7.5	48.9 ± 5.9	39.2 ± 4.7	48.5 ± 6.4	–	–	–	–	–	–
16	Nose, apex	53.6 ± 5.2	39.4 ± 1.4	41.2 ± 3.8	55.2 ± 7.0	<0.05	<0.05	<0.001	-	<0.05	<0.01
17	Nasolabial sulcus, top	28.8 ± 4.3	43.8 ± 4.1	41.6 ± 3.0	58.2 ± 1.6	–	–	–	–	–	–
21	Philtrum	37.0 ± 4.9	31.0 ± 2.4	41.5 ± 6.0	46.9 ± 3.7	–	–	–	<0.05	<0.01	–
22	Nasolabial sulcus, midpoint	40.1 ± 8.2	27.6 ± 1.1	56.4 ± 9.0	52.2 ± 5.3	–	–	–	–	–	–

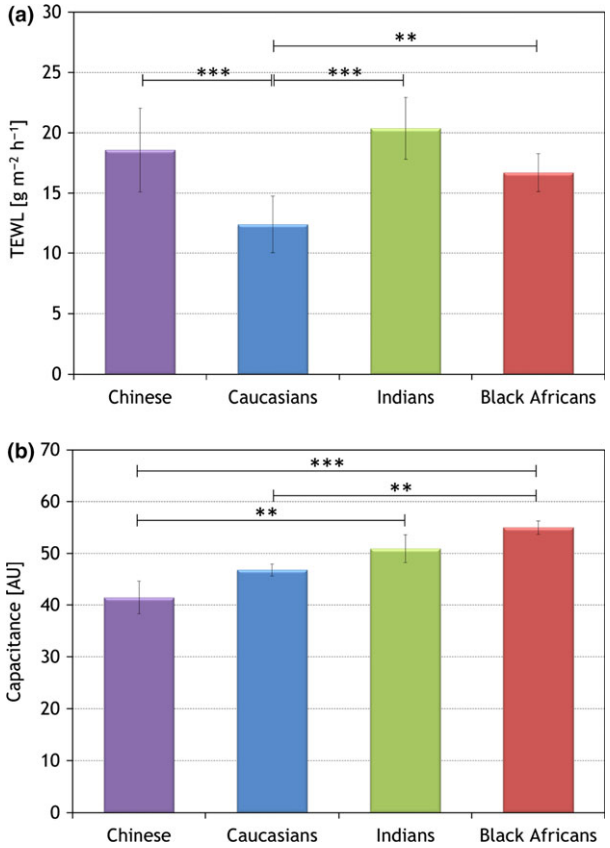

Figure 3 Comparison of overall transepidermal water loss (TEWL) (a) and capacitance values (b) for the four ethnic groups. Results represent mean ± SEM, $n = 4$ per group, individual means have been averaged from 30 facial measurements, $^{**}P < 0.01$, $^{***}P < 0.001$.

Like the TEWL results, the differences in the skin capacitance values between the different ethnic groups are visually more striking. Gradients of decreasing capacitance (Fig. 2) were found from:

Middle cheek to eye region and to central chin.

Top of the nasolabial fold to oblique/lateral jaw.

Lower forehead and outer eye canthus to upper forehead.

Discussion

It is clear from consumer research that we still do not completely meet the needs of consumers regarding skin moisturization [1]. A total of 40–72% of subjects have been classified as having dry skin which can vary with season and also facial location [1–6]. Moreover, visual and tactile roughness is not that easy to treat on the face [7]. In an attempt to understand the complexity of facial moisturization, several groups have performed a mapping analysis on five to six facial sites per half face [8–13]. Many differences in skin hydration and skin barrier properties have been observed in differences parts of the face (Table I). As can be observed not all studies agree and this may relate to the precise testing area measured and/or it might not be representative for that of the whole face. In an attempt to reconcile these differences, Lopez *et al.* [14] studied 90 facial areas in a small group of Caucasians and found that only minor variations between the measuring sites were observed for TEWL in the forehead and chin areas but a distinct gradient was observed in the paranasal zones with the lowest values for TEWL being on the cheek bones.

We have built on this approach by also comparing capacitance together with TEWL measurements on 30 pre-defined sites on one side of the face and decided to better visualize the data using a continuous map of the values by interpolating between the measurement values. We believe that just measuring one half of the face in subjects with normal skin is valid as a good correlation of measurements of TEWL between both sides of the face has been reported by others [11, 14]. Also for the first time, we decided to compare the

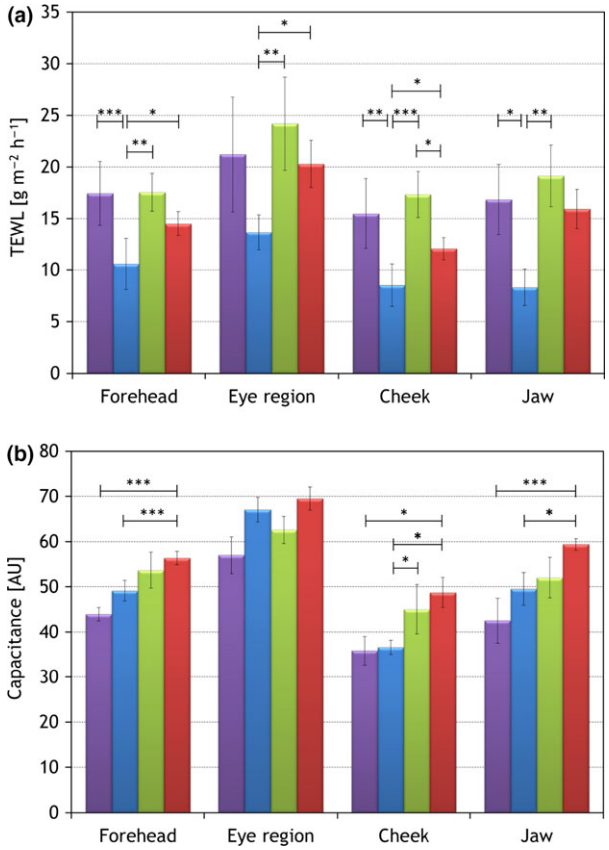

Figure 4 Comparison of the transepidermal water loss (TEWL) (a) and capacitance values (b) for the four ethnic groups averaged for the forehead, eye, cheek and jaw regions. Results represent mean ± SEM, $n = 4$ per group, individual means have been averaged from measurements of corresponding facial site (see Table III, $*P < 0.05$, $**P < 0.01$, $***P < 0.001$, purple bars, Chinese; blue bars, Caucasians; green bars, Indians; red bars, Black Africans.

measurements between four ethnic groups using this novel approach.

Subjects chosen present themselves with normal skin condition, that is not dry or rough and had no visual signs of ageing. Sixteen g m^{-2} h^{-1} was chosen as the 'normal' value for TEWL as we have previously shown minimal levels of SC serine proteases at this value indicating minimal levels of photodamage [19]. Forty AU was used as the 'normal' value for the capacitance measurements as values greater than 40 have been considered to be normally-hydrated skin [20] in younger age groups [21].

The complexity of skin hydration and barrier properties of facial skin is revealed by the individual measurements on the 30 defined facial sites among the four ethnic groups but more particularly by the visualization of these results in continuous TEWL and capacitance maps. The lack of concordance between skin hydration and TEWL is clearly apparent. Equally, it is very obvious that big differences in TEWL and hydration could be observed among the four ethnic groups depending on the facial site chosen. Moreover, like other studies it appears that the more darkly pigmented the skin the more hydrated it is but the opposite can be observed for skin barrier properties depending on facial location.

Naturally, when considering the overall data differences among the different ethnic groups were observed. Concerning hydration, the Black African was more hydrated compared with Caucasian skin which was consistent with the reports of others [9, 21–23] but not all [24–28]. Equally, the Black African and Indian subjects were more hydrated than the Chinese subjects. Depending upon region Galzote *et al.* [29] has found the opposite for Indian subjects. Equally, Sugino *et al.* observed that Asians were more hydrated than other ethnic groups [30] and Hillebrand *et al.* [21] found East Asians to be more hydrated than Caucasians. As we are testing subjects living in the same area, we are excluding the differential effects of climate conditions in different geographical locations. Concerning TEWL, the skin barrier properties were better in the order Caucasian > Black African > Chinese > Indian. It would appear, at least for the face, that skin pigmentation does not correlate with improved skin barrier properties as has been shown for the extremities [31, 32]. This finding is consistent with the recent report on facial skin barrier properties reported by Voegeli *et al.*

Table IV Comparison of subgrouped facial sites for the four ethnic groups. Results represent mean ± SEM, dash $P > 0.05$. (a) transepidermal water loss (TEWL) data, (b) capacitance data. F, forehead region; E, eye region; C, cheek region; J, jaw region

					***P* value of comparison**					
Subject group	**Forehead**	**Eye region**	**Cheek**	**Jaw**	**F vs. E**	**F vs. C**	**F vs. J**	**E vs. C**	**E vs. J**	**C vs. J**
(a) TEWL										
Chinese	17.4 ± 3.1	21.2 ± 5.6	15.5 ± 3.4	16.8 ± 3.4	–	–	–	–	–	–
Caucasians	10.6 ± 2.5	13.7 ± 1.7	8.5 ± 2.0	8.3 ± 1.8	–	–	–	<0.001	<0.01	–
Indians	17.5 ± 1.8	24.2 ± 4.5	17.3 ± 2.2	19.1 ± 3.0	<0.05	–	–	<0.05	–	–
Black Africans	14.5 ± 1.2	20.3 ± 2.3	12.1 ± 1.1	15.9 ± 1.9	<0.001	<0.05	–	<0.001	–	–
(b) Capacitance										
Chinese	43.9 ± 1.5	57.0 ± 4.1	35.9 ± 3.2	42.5 ± 5.0	<0.001	<0.01	–	<0.001	<0.001	–
Caucasians	49.2 ± 2.3	67.1 ± 2.7	36.6 ± 1.6	49.5 ± 3.6	<0.001	<0.001	–	<0.001	<0.001	<0.001
Indians	53.7 ± 4.0	62.6 ± 3.0	45.1 ± 5.5	52.0 ± 4.5	<0.05	<0.05	–	<0.001	<0.05	–
Black Africans	56.4 ± 1.5	69.5 ± 2.6	48.7 ± 3.3	59.4 ± 1.2	<0.001	<0.05	–	<0.001	<0.01	<0.001

[9]. Again, this general ranking can be consistent as well as inconsistent with the literature (reviewed in [9]). We believe that these inconsistences are related to the precise measuring facial location and the complexity of the SC on the face compared with other body sites [33] together with the subtle differences in the SC properties in the different ethnic groups [34].

In this preliminary study, we chose to perform individual Student's *t*-tests on the colour mapping images due to the low numbers of subjects in each ethnic group ($n = 4$). Analysis of variance with a *post hoc* Bonferroni test could have been conducted but the levels of significance to pass this test would have been extremely high. We accept that we do not know which of these testing sites are precisely statistically significant but it highlights the importance of the striking visually impactful differences observed on the colour mapping images. Clearly, there are overall differences in TEWL and capacitance. The average of each of the measures of each testing site including standard error of the mean is shown in Fig. 3a,b together with Table III as well as averaging defined facial zones (forehead, eye region, cheek and jaw) in Table IV and statistical differences between the different ethnic groups and between zones within the same ethnic group are clearly apparent. These differences further support the variations observed in the colour mapping images Fig. 2.

Not only does our pilot study highlight the complexity of the properties of facial skin regions and the need for very precise studies on facial skin properties among different ethnic groups, it also exposes the lack of comparative information that can be obtained from the testing of moisturizers on volar forearm skin [12]. Perhaps this is one of the reasons why facial dry skin is still an major unmet consumer need [1]. Nevertheless, the underlying biochemical differences in the SC in these facial locations between the different ethnic groups are not well understood and will be the subject of ongoing studies. Equally, in future studies this approach will be used to understand the effects of moisturizers on facial skin properties in different ethnic groups.

In conclusion, although there are indications that measurements of TEWL and skin capacitance vary on the different parts on the face there is no previous literature on the complexity of facial TEWL and skin capacitance gradients in different ethnic groups. Our facial maps not only demonstrate the need for precise facial measurements and study designs but also that facial skin care application concepts for the different skin ethnicities need to consider facial anatomical locations.

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Conflicts of interests and disclosures

RV is an employee of DSM, AVR is a consultant to DSM and PS is an employee of Newtone and BS report no conflicts of interest.

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