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ORIGINAL ARTICLE

Effects of under-eye skin and crow's feet on perceived facial appearance in women of five ethnic groups

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Abstract

Objective: Age-related skin changes in the periorbital region caused by intrinsic (e.g. atrophy of collagen and fat) and extrinsic (e.g. sun exposure) factors, including skin wrinkling, hyperpigmentation, dark circles and lateral canthal lines ('crow's feet'), are a concern for women. We investigated the impact of under-eye skin and crow's feet on perceptions of women's faces in different ethnic groups.

Methods: Facial images of women ($n=180$) from five ethnic groups were rated for age, health and attractiveness by naïve assessors of the same ethnic group ($n=120$). Digital image analysis was used to quantify visible skin characteristics in two facial regions, that is, under the eyes (colour, gloss, tone evenness and wrinkles) and in the crow's feet region (wrinkles only). Skin image measurements were used to predict face ratings in the full sample and separately by ethnicity.

Results: Ethnic differences were detected for measurements of skin colour, gloss, tone evenness and wrinkles – the latter under the eyes and in the crow's feet region. Correlational and regression analysis indicated a major role of wrinkles (both regions) in predicting rated age, health and attractiveness from the facial portraits across ethnic groups, with some variation in the types or the predictive magnitude of skin characteristics.

Conclusion: The predictive utility of under-eye wrinkles and crow's feet for rated age, health and attractiveness correspond to women's reported concern with under-eye bags, dark circles and crow's feet. Despite some ethnic differences in these features, their impact on women's facial appearance ratings is similar across ethnic groups.

KEYWORDS

age, attractiveness, ethnicity, health, periorbital skin

Résumé

Objectif: les modifications cutanées liées à l'âge dans la région périorbitaire causées par des facteurs intrinsèques (par ex. atrophie du collagène et de la graisse) et extrinsèques (par ex. exposition au soleil), y compris les rides de la peau, l'hyperpigmentation, les cernes et les rides canthales latérales («pattes d'oie»), sont une préoccupation pour les femmes. Nous avons étudié l'impact de la peau sous les yeux et des pattes d'oie sur la perception des visages des femmes dans différents groupes ethniques.

Méthodes: les images de visage de femmes ($n=180$) de cinq groupes ethniques ont été évaluées pour l'âge, la santé et l'attractivité par des évaluateurs naïfs du même groupe ethnique ($n=120$). L'analyse d'images numériques a été utilisée pour quantifier les caractéristiques visibles de la peau dans deux régions du visage, c'est-à-dire sous les yeux (couleur, brillance, uniformité du teint et rides) et dans la région des pattes d'oie (rides uniquement). Des mesures d'imagerie cutanée ont été utilisées pour prédire les évaluations de visage dans l'échantillon complet et séparément par origine ethnique.

Résultats: des différences ethniques ont été détectées pour les mesures de la couleur de la peau, de la brillance, de l'uniformité du teint et des rides—ces dernières sous les yeux et dans la région des pattes d'oie. L'analyse de corrélation et de régression a indiqué un rôle majeur des rides (dans les deux régions) dans la prédiction de l'âge, de la santé et de l'attractivité évalués à partir des portraits faciaux dans les groupes ethniques, une certaine variation des types ou de l'ampleur prédictive des caractéristiques cutanées.

Conclusion: l'utilité prédictive des rides sous les yeux et des pattes d'oie pour l'évaluation de l'âge, de la santé et de l'attractivité correspond à l'inquiétude signalée par les femmes concernant les poches sous les yeux, les cernes et les pattes d'oie. Malgré certaines différences ethniques dans ces caractéristiques, leur impact sur les évaluations de l'apparence du visage des femmes est similaire dans tous les groupes ethniques.

INTRODUCTION

In a recent online survey of >15 000 women and men (21–75 years) from 18 countries including ~1300 aesthetic physicians [1], respondents indicated (from a list of 26 facial features) being 'very' or 'extremely concerned' with under-eye bags and dark circles (36%), crow's feet wrinkles (34%) and forehead wrinkles (31%). Uneven skin tone was another feature participants indicated high or extreme concern about (31%). These findings corroborate previous evidence on the role of the periorbital region in perceptions of attractiveness, especially for women. However, a discrepancy was detected between the rankings of respondents and aesthetic physicians—the latter underestimated the significance of under-eye bags and dark circles (31% of respondents vs. 16% of physicians ranked it #1 of their top 5 concerns).

The high number of participants concerned with skin changes in the periorbital area prompted us to examine this region using data from a multi-ethnic and multi-centre study [2]. As Freitag and Cestari [3] note, dark circles and crow's feet are commonly reported concerns in cosmetic and dermatological practice. Neither feature is health-threatening nor associated with morbidity but affects an individual's well-being and gives them a tired, sad or hungover look. Dark circles are bilateral, round and homogeneous pigmentation macules in the infraorbital region [3]. The aetiology of dark circles is multifactorial and includes low thickness of periorbital skin [4], the loss of periorbital volume, shadowing due to skin laxity, dermal hyperpigmentation and increased density of subcutaneous vasculature [5]. Crow's feet (lateral canthal lines) is the term used to describe the wrinkles at the outer corners of the eyes. They form from muscle contraction due to blinking and emotional expression (e.g. smiling and laughter). As such, crow's feet are (temporarily) visible at younger ages, but when the skin becomes lax with increasing age mainly due to structural dermal changes in elastin and collagen [6], they are also visible at rest. Since crow's feet develop earlier than other age-related wrinkling, women consider the periorbital area the most bothersome facial region [1], and the area first targeted for treatment [7]. Several therapeutic options are offered to address periorbital cutaneous and structural changes, including skin laxity and pigmentary changes, ranging from dermal (hyaluronic acid) fillers, botulinum toxin injection, topical pharmacological agents [8] and (wavelength tuneable) laser treatment [5, 9, 10].

Despite shared concerns over periorbital skin issues reported by respondents (and physicians) from several ethnicities [1], it is unclear whether phenotypic changes in this region impact the perception and assessment of facial appearance similarly in different ethnic groups. In addition to individual differences, variation across ethnicities in the susceptibility to age-related skin changes has been documented [11–13] and is attributable, in part, to structural, functional and environmental differences [14–16]. Concerning geographical and environmental effects on skin properties, Kim et al. [17] reported regional differences in skin characteristics and wrinkles of young women from four locations in China. These include crow's feet, such that women from Beijing had deeper and larger wrinkles compared to smaller and shallower wrinkles in women from Guangzhou. Regional differences suggest the impact of climatic variation on the skin in addition to individual differences in lifestyle habits [18, 19].

Evidence from a multi-ethnic and multi-centre study [2, 20] indicates cross-cultural variation (and consistency) in assessments of female facial appearance. Female and male (naïve) assessors identifying with one of five ethnicities (Chinese, Japanese, French, Indian and South African) judged digital portraits of women within and across ethnicities for age, health and attractiveness. Facial health and attractiveness judgements were more varied across assessor ethnicities than were age judgements, suggesting differential effects of visible skin features on the perceptions of age, health and attractiveness, within and between ethnic groups. Subsequent research using the same facial images and assessors indicated that facial wrinkling and sagging—assessed from skin image analysis of the full face—were the best predictors of face ratings across ethnic groups, with some differences in the type or predictive magnitude of skin features [21]. Skin tone evenness and gloss had an additional predictive role in accounting for variation in health ratings of women's faces.

In the present study, we focused on the periorbital area, specifically on two facial regions defined by Voegeli et al. [21], that is, the region under the eyes, and the crow's feet region. We examined whether age, health and attractiveness ratings of women's faces in five ethnic groups can be predicted from skin image measurements under the eyes and in the crow's feet region. Considering previous reports from the multi-ethnic and multi-centre study [2, 21, 22] in addition to the literature on ethnic differences in skin properties [15, 23–25], we expected to identify differences between ethnic groups in skin image measurements for these two specific facial regions. Concerning the associations between face ratings and skin image measurements under the eyes and in the crow's feet region, we predicted the largest associations with facial wrinkles, especially for age ratings. To identify ethnicity-dependent variation in the predictors of face ratings (or their magnitude), we conducted a preliminary analysis to assess the relationship between face ratings and skin image measurements (under the eyes and crow's feet) split by ethnic group. We note that these findings should be interpreted with caution given the lower statistical power resulting from small sample sizes for the ethnic subgroups.

METHODS

Study sample

Digital facial images of women and rating data were obtained in five locations: Guangzhou (China), Tokyo (Japan), Lyon (France), New Delhi (India) and Cape Town (South Africa). In each location, identical experimental equipment was used, and standardized protocols were administered as part of a multi-ethnic and multi-site project on the perception of female facial appearance. To date, study findings have been presented in six reports [2, 20–22, 26, 27], including three in this journal [21, 22, 27]. Thus, we keep the description of the methods brief, but sufficiently detailed so that consultation with previous articles is not required to understand the current report.

Women from five ethnic groups ('participants'; $n = 526$) aged 20–69 years were recruited: Chinese ($n = 106$), Japanese ($n = 100$), French ($n = 105$), Indian ($n = 100$) and South African ($n = 115$). Participants were equally distributed around the mean ages of 10-year cohorts. Their facial skin tone corresponded to the following phototypes on the Fitzpatrick [28] scale: Chinese II–IV, Japanese II–IV, French II–III, Indian IV–V and South African V–VI. Women were screened before recruitment and provided written informed consent. The study was approved by the Reading Independent Ethics Committee (RIEC), Woodley (UK) and the ACEAS Independent Ethics Committee, Ahmedabad (India).

Facial imaging

Participants were imaged in frontal view with eyes open and a neutral facial expression using the ColorFace® system (Newtone Technologies, Lyon, France). As a requirement for skin image analysis from portraits (for details, see [21]), facial images were recorded under different Brewster (polarization) angles.

Face ratings

Facial images from a subset of 180 women (36 in each ethnic group) were selected, following independent quality control by three investigators and random stratified sampling for participant/assessor ethnicity, assessor gender and age cohort. Each ethnic group included participants aged 20–65 years and age-matched assessors. Assessors were equally distributed around the mean ages of 15-year cohorts (see [2]). Images were presented on 27″ (68.6 cm) colour-calibrated LCD monitors (ColorEdge CG277, Eizo, Hakusan, Japan). Female and male assessors (120 in each ethnic group) rated the images for perceived age (in years), health and attractiveness on continuous scales ranging from 0 to 100 (0 = low on attribute, 100 = high on attribute) in the study centres where the facial images were recorded. The portraits were judged sequentially (with attributes in blocks), and each assessor rated 90 randomly selected images per attribute, balanced across (age, ethnicity and gender) cohorts. Thus, each image was assessed ~300 times. In the analyses of the present study, we considered only the face ratings provided by raters of the same ethnicity as the women's (participant's faces) ethnicity.

Skin image measurements

The skin image measurements have been described in detail in previous reports [21, 27]. Nine regions of interest (ROIs) in the digital portraits were defined in addition to the 'full face' area. Here, we focus on the region under the eyes and the crow's feet region (Figure 1). The two ROIs differed markedly in size. We did not consider it sensible to quantify skin colour, gloss and tone evenness in the crow's feet region but focused on the measurements of wrinkles. In the region under the eyes, comprising the lower eyelid and infraorbital hollow, we measured skin colour, specular/contrast gloss, tone evenness and wrinkles.

In brief, skin colour was measured in red, green and blue (RGB) colour values, then converted into CIELAB (colour space) L^*, a^* and b^* scores [29] and averaged for the ROI. L^* refers to perceptual lightness (ranging from 0 [black] to 100 [white]), a^* refers to the red–green axis (positive = red, negative = green), and b^* describes the blue–yellow axis (positive = yellow, negative = blue). Contrast gloss denotes the difference between the mean intensities of bright and matte pixels – a higher contrast gloss corresponds to higher gloss visibility. Specular gloss quantifies the mean luminance of bright pixels in the image, and a higher score indicates higher gloss intensity. Skin tone evenness employed Haralick et al.'s [30] approach to quantifying information from the spatial arrangement of pixels in an image. In the present study, we computed two features based on grey-level co-occurrence matrices, that is, homogeneity and contrast. Both measures capture the similarity versus dissimilarity of adjacent pixels. In even skin tones, homogeneity scores are high, and contrast scores are low. The assessment of wrinkles used an algorithm that identifies anisotropic elements (i.e. line detection) and retains visible lines ('wrinkles') based on thresholding. We computed three wrinkle characteristics: (i) length (in pixels), with a lower value corresponding to smaller wrinkles; (ii) density, defined as the ratio between the number of segmented pixels and the size of the ROI (a higher value denotes more wrinkles); and (iii) volume, that is, the difference in luminosity between the segmentation and the surrounding area (smaller values indicate lower wrinkle visibility).

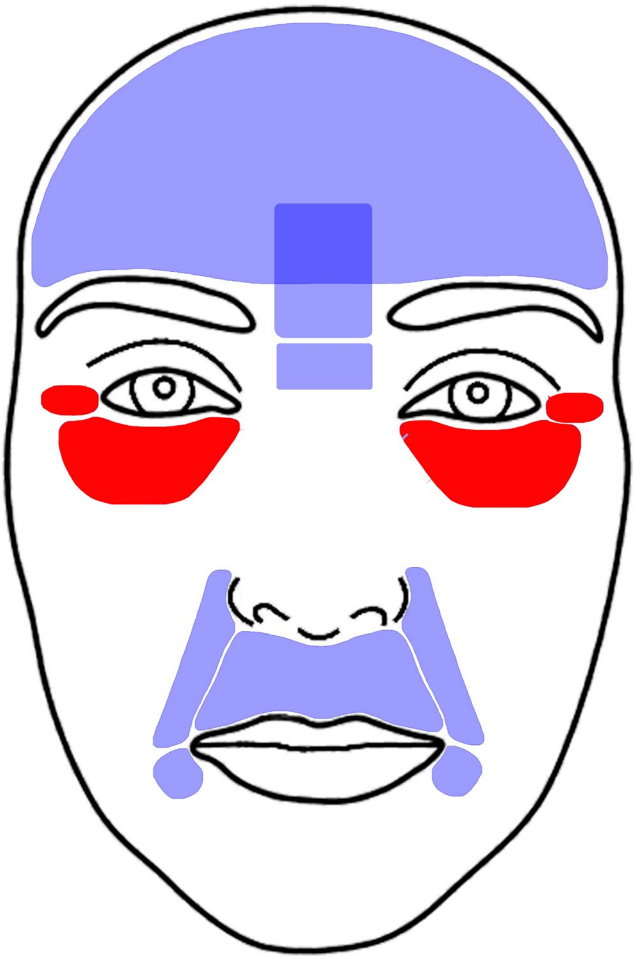

FIGURE 1 Schematic of the regions of interest defined by Voegeli et al. (2023) for skin image measurements, with the two regions (under the eyes and crow's feet) included in the present study in red.

STATISTICAL ANALYSIS

We report descriptive statistics (*Mean* and *SD*) for face ratings, and skin image measurements by ethnicity. Visual inspection of histograms and tests for goodness of fit indicated deviations from normal distribution for some variables. Therefore, we decided to perform the statistical analysis at the conservative (i.e. non-parametric) level. To investigate ethnic differences, Kruskal–Wallis tests (*H*-tests; [31]) were performed with face ratings and skin image measurements as the dependent variables. Associations between face ratings and skin image measurements were assessed with correlational statistics (Spearman's *rho*; [32]). Multiple regression analysis was performed to identify predictors of face ratings among skin image measurement variables (for using ordinal variables in regressions, see [33, 34]). We report R^2 (coefficient of determination) for the proportion of variance in dependent measures that can be explained by independent variables (i.e. predictors). The alpha level was set to 0.05. Analyses were performed using IBM SPSS 26 (IBM Corp.) and JMP 16 (SAS Institute Inc.).

RESULTS

Face ratings

Assessors' image ratings of women's faces (and self-ratings) have been reported in detail previously [2, 21, 22, 27]. Therefore, we keep these findings brief to avoid redundancy but make them readily accessible to readers of the present article.

Table 1 reports the means (and *SD*s) for age, health and attractiveness ratings. Assessors' ratings of age and attractiveness did not differ between ethnic groups (age: $H=3.35$, $df=4$, $p=0.50$; attractiveness: $H=8.03$, $df=4$, $p=0.09$). Health ratings differed between ethnic groups ($H=50.26$, $df=4$, $p<0.001$), with Indian and South African ratings being lower than those of other ethnicities, and no differences between Chinese, Japanese and French assessments (all ps >0.05).

Skin image analysis

Table 2 reports the means (and *SD*s) for skin image measurements, by ethnic group. As for face and self-ratings, ethnic differences and age-related changes in skin features have been reported elsewhere [21, 26, 27]. In the present report, we focus on the principal effects to justify the performance of statistical tests by ethnic group.

Under eyes

Colour. Ethnic differences were found in the three colour components (L^* $H=127.54$, $df=4$, $p<0.001$; a^* $H=66.17$, $df=4$, $p<0.001$; b^* $H=46.82$, $df=4$, $p<0.001$), with lower L^* and higher a^* scores for Indian and South African women compared to other ethnic groups. The lowest b^* scores were observed in French women and no differences between Chinese, Indian and South African women.

Gloss. Contrast gloss ($H=117.67$, $df=4$, $p<0.001$) and specular gloss ($H=119.28$, $df=4$, $p<0.001$) showed ethnic differences. In South African women (followed by Indian women), contrast gloss was higher and specular gloss lower than in other ethnic groups (with no differences between Chinese, Japanese and French women).

Tone Evenness. There were ethnic differences in skin tone evenness for homogeneity ($H=121.72$, $df=4$, $p<0.001$) and contrast ($H=116.37$, $df=4$, $p<0.001$). Chinese, French and Japanese women scored higher in skin homogeneity and lower in contrast than Indian and South African women (with no differences between Chinese, Japanese and French women).

Wrinkles. Ethnic differences were detected with the three wrinkle measures (density $H=63.62$, length $H=46.35$, volume $H=74.32$; for each test $df=4$, $p<0.001$). For density, South Africa > India = France > Japan = China; for length, India = France = South Africa > Japan = China; for volume, South Africa > India = France > Japan = China.

Crow's feet

Wrinkles. As for the crow's feet region, there were ethnic differences for the three measures (density $H=20.03$, length $H=22.18$, volume $H=22.92$; for each test $df=4$, $p<0.001$). For density, South Africa = China

TABLE 1 Descriptive statistics (*Mean* and *SD*) for age, health and attractiveness ratings split by ethnic group ($n=36$ each).

	Chinese	Japanese	French	Indian	South African
Age					
Mean	43.9	43.4	45.4	46.5	48.0
SD	10.6	13.9	15.1	12.1	12.1
Health					
Mean	60.6	63.0	63.6	47.8	52.8
SD	8.0	8.6	11.6	11.2	10.5
Attractiveness					
Mean	42.7	38.2	41.3	37.3	38.0
SD	8.9	7.9	13.8	9.3	9.2

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TABLE 2 Descriptive statistics (*Mean* and *SD*) for the skin image measurements under the eyes and crow's feet split by ethnic group ($n=36$ each).

	Chinese	Japanese	French	Indian	South African
Under the eyes					
Colour					
*L**	60.9 (4.1)	62.1 (3.7)	61.6 (3.8)	49.3 (5.4)	38.9 (6.3)
*a**	14.2 (1.5)	13.1 (1.3)	13.9 (1.8)	15.9 (0.8)	15.4 (2.1)
*b**	19.9 (2.5)	19.2 (2.7)	15.4 (3.0)	19.7 (1.6)	19.6 (3.3)
Gloss					
Contrast	5.4 (1.0)	5.7 (1.2)	5.6 (1.1)	8.5 (1.6)	10.4 (1.7)
Specular	67.6 (4.0)	67.0 (3.6)	66.5 (3.3)	59.1 (4.2)	49.2 (6.7)
Skin tone evenness					
Homogeneity	0.09 (0.008)	0.09 (0.007)	0.09 (0.007)	0.07 (0.006)	0.07 (0.005)
Contrast	354.3 (95.0)	329.7 (75.5)	375.0 (116.2)	787.3 (234.2)	724.9 (194.9)
Wrinkles					
Density	1.1 (0.9)	1.5 (1.3)	2.3 (1.4)	3.0 (1.7)	3.8 (1.9)
Length	333.1 (325.7)	452.1 (453.6)	860.9 (550.3)	930.3 (580.8)	824.4 (367.5)
Volume	3.6e4 (4.2e4)	4.4e4 (5.8e4)	9.2e4 (7.0e4)	14.7e4 (11.7e4)	20.0e4 (10.8e4)
Crow's feet					
Wrinkles					
Density	4.6 (3.6)	1.9 (2.5)	3.0 (3.8)	2.6 (4.2)	5.3 (4.6)
Length	158.6 (142.0)	31.7 (42.2)	124.7 (183.2)	82.1 (149.0)	131.7 (138.4)
Volume	6.4e4 (7.2e4)	1.2e4 (1.8e4)	4.2e4 (7.2e4)	2.5e4 (1.8e4)	5.3e4 (6.2e4)

TABLE 3 Correlations (Spearman's *rho*) between assessor ratings of age, health and attractiveness and the skin image measurements ($n=180$).

	Age	Health	Attractiveness
Under the Eyes			
*L**	−0.31**	0.60**	0.27**
*a**	0.16*	−0.35**	−0.04
*b**	0.07	−0.15*	0.03
Contrast gloss	0.28**	−0.55**	−0.28**
Specular gloss	−0.27**	0.54**	0.28**
Tone evenness (homogeneity)	−0.17*	0.49**	0.16*
Tone evenness (contrast)	0.14	−0.47**	−0.12
Wrinkle (length)	0.54**	−0.50**	−0.46**
Wrinkle (density)	0.33**	−0.40**	−0.30**
Wrinkle (volume)	0.41**	−0.51**	−0.38**
Crow's Feet			
Wrinkle (length)	0.61**	−0.40**	−0.44**
Wrinkle (density)	0.59**	−0.38**	−0.44**
Wrinkle (volume)	0.61**	−0.38**	−0.44**

*$p<0.05$. **$p<0.001$ (two-tailed).

> France = India = Japan; for length and volume, China = South Africa = France > India > Japan.

Associations between Face Ratings and Skin Image Measurements.

Correlations

Table 3 presents (rank) correlations between assessor ratings of age, health and attractiveness and the skin image measurements, including the region under the eyes and crow's feet region, for the full sample (i.e. all ethnic groups). Face ratings (all attributes) were significantly associated with skin image measurements. A general finding is that wrinkles (length, density and volume) correlated positively with age and negatively with health and attractiveness ratings. These findings were detected for both ROIs—under the eyes and crow's feet. Thus, longer (total) wrinkle length, higher wrinkle density and larger wrinkle volume were considered older, less healthy and less attractive.

Robust associations were detected between face ratings and skin gloss. Contrast gloss correlated positively with perceived age and negatively with health and attractiveness. The opposite pattern of associations was found for specular gloss. This suggests that skin brightness decreases with age, leading to lower glow/radiance, perceived as less healthy and attractive.

Skin tone evenness produced mixed findings. The largest relationship was found between health ratings and skin tone evenness (positive with homogeneity and negative with contrast). Smaller correlations were detected for age and attractiveness (positive with homogeneity and negative with contrast). Collectively, these associations suggest: (i) positive assessments of age (i.e. youthfulness), health and attractiveness with even skin tone and relationships in the opposite direction with skin contrast; and (ii) skin tone evenness is a stronger health cue than age and attractiveness.

Concerning skin colour, the largest correlations were detected between L^*, a^* and b^* and health ratings (positive with L^* and negative with a^* and b^*). In addition, L^* correlated negatively with age and positively with health and attractiveness ratings, suggesting an age-related decline in skin lightness and positive assessments of lighter skin, especially concerning health.

Regression analysis

Exploratory regression analysis indicated multicollinearity among several independent variables, leading to variance inflation factors (VIFs) >10 for these variables. Specifically, L^* correlated with specular gloss ($rho = 93$, $p < 0.001$) and contrast gloss ($rho = -0.83$, $p < 0.001$) and the two gloss measures were negatively correlated ($rho = -0.79$, $p < 0.001$). Skin tone homogeneity correlated negatively with contrast ($rho = -0.96$, $p < 0.001$). Wrinkle density, length and volume were highly intercorrelated for measurements under the eyes (all $rho \leq 0.90$, all ps < 0.001) and in the crow's feet region (all $rho \leq 0.98$, all $ps < 0.001$). Therefore, we excluded redundant variables from the regression analysis to address the multicollinearity problem.

We z-scored ('studentized') the variables and calculated the mean of wrinkle density, length and volume, retaining one wrinkle score for the infraorbital and the crow's feet region, respectively.

Full Sample. Three regressions were performed, with $n = 180$ participants (i.e. all ethnic groups) and separately for the three attributes as dependent variables. The independent variables were L^*, a^*, b^*, tone evenness (homogeneity), wrinkles under the eyes and crow's feet. Table 4 reports the (unstandardized and standardized) coefficient statistics (B, SE B and *beta*) and the slope (t) for the significant predictors of face ratings. The regression models were significant for age ($F = 23.67$, $p < 0.001$, $R^2 = 0.45$), health ($F = 21.14$, $p < 0.001$, $R^2 = 0.42$) and attractiveness ($F = 10.45$, $p < 0.001$, $R^2 = 0.27$). The VIFs for the independent variables in the regressions were all <3.6 and tolerance >0.28. Considering all ethnic groups together, the regressions indicated a major role of wrinkles in predicting female age, health and attractiveness from facial portraits. Wrinkles under the eyes and in the crow's feet region predicted age and attractiveness, and crow's feet predicted health ratings (the wrinkle score for under-eyes approached significance, with $\beta = -0.14$, $p = 0.057$).

Ethnic Groups. Considering 'ethnic group' as a dummy variable in the regressions indicated significance for health ($t = 2.02$, $\beta = 0.16$, $p < 0.05$) but not for age ($t = 0.86$, $\beta = 0.07$, $p = 0.393$) or attractiveness ($t = -1.34$, $\beta = -0.12$, $p = 0.183$). Together with the ethnic differences in facial skin image measurements, this suggested ethnicity-specific predictions of face ratings from skin image measurements for at least one attribute (health). To explore this possibility, we

TABLE 4 Coefficient statistics for skin image measures significantly predicting facial age, health and attractiveness ratings in the multiple regressions ($n = 180$).

Variable	B	SE B	β	t	p
Age					
Wrinkle under the eyes	0.26	0.08	0.25	3.46	<0.001
Wrinkle crow's feet	0.58	0.11	0.56	9.12	<0.001
Health					
Wrinkle crow's feet	−0.28	0.07	−0.27	−4.31	<0.001
Attractiveness					
Wrinkle under the eyes	−0.23	0.09	−0.22	−2.68	<0.01
Wrinkle crow's feet	−0.36	0.07	−0.35	−4.93	<0.001

performed the regressions again (with the same variables), but this time split by ethnic group. Conclusions based on the findings from this step are preliminary and must be made with caution due to the smaller sample sizes of the (ethnic) sub-groups ($n=36$ each).

To keep this report concise, and to maintain the exploratory character of this analysis, we summarize the principal findings without reporting the detailed coefficient statistics. Concerning age assessments, the regressions were significant for all five ethnic groups (China: $F=8.14$, $p<0.001$, $R^2=0.63$; Japan: $F=9.30$, $p<0.001$, $R^2=0.66$; France: $F=10.78$, $p<0.001$, $R^2=0.69$; India: $F=11.47$, $p<0.001$, $R^2=0.70$; South Africa: $F=4.32$, $p<0.01$, $R^2=0.47$). The significant coefficients included crow's feet in all ethnic groups. In Japanese and French women, wrinkles under the eyes were an additional predictor (positive), and in Indian women, L^* was also a significant (negative) predictor for age ratings. Similar findings were obtained for health ratings in the summary models for the five ethnic groups (China: $F=5.41$, $p<0.001$, $R^2=0.53$; Japan: $F=8.08$, $p<0.001$, $R^2=0.63$; France: $F=2.81$, $p<0.05$, $R^2=0.38$; India: $F=17.24$, $p<0.001$, $R^2=0.78$; South Africa: $F=4.26$, $p<0.01$, $R^2=0.47$). Crow's feet were a significant predictor (negative) in Chinese, Japanese and Indian women. Wrinkles under the eyes was an additional predictor (negative) in Japanese women, L^* was an additional predictor (positive) in Indian women, and b^* was an additional predictor (positive) in South African women. In French women, no single predictor contributed significantly to the overall model (although the *betas* for wrinkles and tone evenness were negative), and of all ethnic groups, R^2 was lowest for French women. Significant models also were obtained for attractiveness ratings in all five ethnic groups (China: $F=6.55$, $p<0.001$, $R^2=0.58$; Japan: $F=4.31$, $p<0.01$, $R^2=0.47$; France: $F=4.06$, $p<0.01$, $R^2=0.46$; India: $F=15.66$, $p<0.001$, $R^2=0.76$; South Africa: $F=6.23$, $p<0.001$, $R^2=0.56$). Crow's feet significantly predicted (negatively) attractiveness ratings in Chinese, Japanese and Indian women. Wrinkles under the eyes were an additional predictor (negative) in Japanese women. In South African women, b^* was an additional predictor (positive) of attractiveness. As with health, no single predictor contributed significantly to the overall model ($\beta=-0.35$ for wrinkles under the eyes approached significance at $p=0.058$; similarly for tone evenness, $\beta=-0.44$, $p=0.051$).

DISCUSSION

The current study reveals ethnic differences in several skin characteristics measured from facial images of women under the eyes and in the crow's feet regions. In Indian and South African women, lower L^* (lightness) and a^* (redness) scores were detected from measurements under the eyes compared to Chinese, Japanese and French women. South African and Indian women showed lower gloss (perceived brightness) and lower scores for skin tone evenness than women of other ethnic groups. Wrinkles under the eyes were pronounced in South African women (as indicated by density and volume measurements). Wrinkles in the crow's feet region showed ethnic differences, with similar scores for South African, Chinese and French women that were higher than for Indian and Japanese women. Thus, skin image measurements under the eyes and in the crow's feet regions corroborate previous evidence from the same measurements in the full face and additional facial regions ([21]; also, see Figure 1). This could have been inferred, at least in part, from Voegeli et al.'s [21] analysis of ethnic differences in wrinkle measurements from facial portraits, which included the region under the eyes and the crow's feet region. However, the present study indicates ethnic differences in skin image measurements in only these two regions and extends the evidence to skin colour, gloss and tone evenness. Although the skin of all ethnic groups is subjected to photoaging, it has been suggested that in the lightly pigmented skin of Caucasians, skin wrinkling and sagging signs occur earlier and are greater than in other skin types and pigmentary problems are greater for darker skin [15]. The current findings do not suggest that this applies to periorbital skin, as we detected greater signs of skin ageing in South African (and Indian) women compared to other ethnic groups. Ethnic differences in participants' ages could not account for this observation due to the random stratified sampling using age cohorts (the ANOVA with chronological age as the dependent variable indicated no ethnic difference; $F=0.002$). Therefore, a preliminary conclusion is that the protective effect against UV damage from higher epidermal melanin in darker skin (among other ethnic differences in skin properties; [11]) does not apply in the same way to periorbital skin as it has been reported for other facial (or body) regions (Figure 2).

Because of its specific structure, the skin in the eye region is one of the most difficult to address in clinical diagnosis and aesthetic treatment [35, 36]. The skin around the eyes is thinner than in other facial regions and has fewer sebaceous glands, making it more vulnerable to intrinsic and extrinsic ageing effects, ranging from genetics to lifestyle habits [37]. In addition, the periorbital region is unique in the impact of mimic muscle activity on skin contraction. The average person performs ~15 000 involuntary and spontaneous eye blinks per day [38], leading to considerable stress on the thin epidermis and dermis. The dynamic lines, particularly the crow's feet wrinkles, which appear during mimic

FIGURE 2 Sample images of younger, middle-aged and older female participants' eye areas, including the regions where the skin image measurements were performed (under the eyes and crow's feet). From top to bottom (in rows): Chinese, Japanese, French, Indian and South African women.

muscle contraction are temporary at younger ages but become static over time and are a primary sign of ageing. This explains the high concern reported particularly by women aged >40 years who are dissatisfied with their appearance. Kane et al. [39] reported that in a sample of 1392 patients with mixed ethnic backgrounds (mean age ~ 50 years), 76% were 'very unsatisfied' or 'unsatisfied' with their crow's feet at maximum smile and 77% were 'very unsatisfied' or 'unsatisfied' at rest. Only ~15% believed that they looked younger than their chronological age. A similar high concern with periorbital wrinkles and crow's feet has been reported from within-subject variation (with and without make-up) in a sample of Japanese women (30–54 years) [40]. Periorbital skin (and nasolabial folds) had the largest impact on facial signs of ageing (from a list of 14 features) in younger and older age, as detected by an AI-based automated grading system using (Asian) skin atlases as a reference [41, 42]. An interesting observation in the present study was the similar high scores in crow's feet wrinkles in Chinese and South African women (but not so for wrinkles under the eyes). Previous research reports ethnic differences between Chinese and Caucasian (French) skin ageing, with delayed wrinkle onset in Chinese women [43]. For example, in the age group 30–40 years, crow's feet were prevalent in nearly 100% of French women, whereas in Chinese women the prevalence was about 50%. Moreover, in French women, the age-related increase in crow's feet wrinkling was linear but showed a spurt in Chinese women aged 41–50 years. Similar differences have been reported for comparisons of Chinese and Japanese (Chinese>Japanese) women's wrinkling in the periorbital area [44], leading to the development of specific crow's feet grading systems for Chinese individuals [45–47]. The mean age of women from each ethnic group in the present study was ~45 years, which falls within the age group for which the greatest acceleration in crow's feet wrinkling has been reported [43]. The same study suggested that ethnic differences in the speed of age-related wrinkling depend on the facial region. Our findings suggest that crow's feet might be a concern, particularly in Chinese (and South African) women (Figure 3).

In the current study, we examined whether the objective assessment (from image measurements) of skin under the eyes and in the crow's feet region predicts subjective ratings of age, health and attractiveness of women's portraits. Thus, in contrast to studies that asked respondents about their concern with periorbital skin problems, or studies that graded skin features by comparing them with visual scales, we took advantage of the ratings from many (female and male) raters of women's faces by members of the same ethnic group. This should avoid stereotyping effects (i.e. 'colourism'; [48])

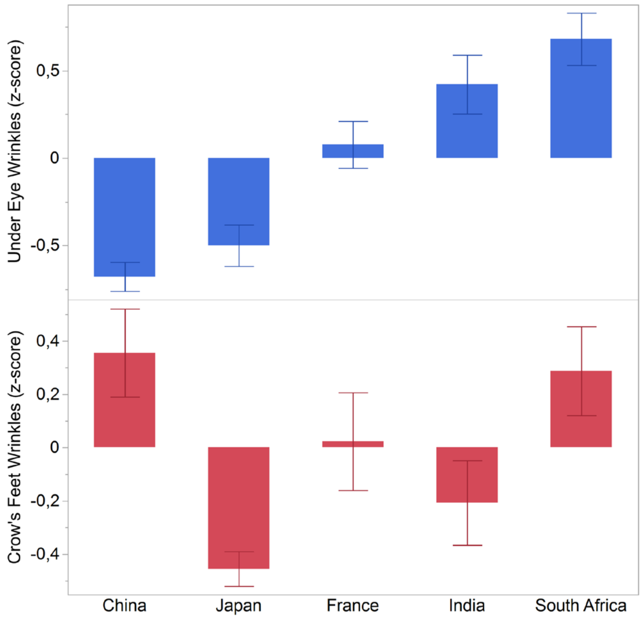

FIGURE 3 Ethnic differences (M ± SEM) of wrinkle measurements under the eyes and in the crow's feet region. The dependent variables were studentized (*z*-scored) and averaged from measurements of wrinkle density, length and volume.

observed in an analysis of the multi-ethnic and multi-centre study (face) ratings between ethnic groups, that is, women judged by lay assessors from ethnicities other than their own [2]. Correlational statistics indicated several associations between face ratings and skin features. Wrinkles under the eyes and crow's feet correlated negatively with age, health and attractiveness in the full sample (i.e. all ethnic groups). The largest correlation coefficients were observed between crow's feet and age ratings. This corresponds with women's concerns and self-perceived age [1, 39, 41], suggesting that crow's feet wrinkles are a primary facial sign of ageing. Previous research with British women indicated that facial wrinkles have a greater impact than skin tone evenness on perceptions of age whereas uneven skin colouration affects health ratings more strongly [49].

The differential effects of facial wrinkles and skin tone evenness on the perceptions of facial age and health are also reflected in larger associations of skin colour, gloss and tone evenness with health ratings (compared to age and attractiveness ratings). Higher lightness, gloss and skin tone evenness showed positive relationships with facial health ratings. Colours a^* and b^* correlated negatively with health ratings, indicating that lower redness and lower yellowness of periorbital skin negatively impact perceived health. Skin lightness and (specular) gloss (in addition to tone evenness) showed correlation coefficients about twice the size of a^* and b^* associations with health ratings, which could indicate that a smooth and shiny appearance of skin under the eyes applies to women independent of phototype.

To determine whether periorbital skin features can predict age, health and attractiveness ratings of women's faces, we performed regressions with face ratings as dependent variables and skin image measurements as independent variables. Significant models were detected for all three attributes in the full sample (i.e. all ethnic groups). Thus, face ratings could be predicted from periorbital skin features. Wrinkles under the eyes and crow's feet were the primary predictors of face ratings. The lack of significance for colour, gloss and skin tone evenness as predictors of face assessments from lay assessors suggests that non-experts invest particular attention to periorbital wrinkles in judgements of female facial appearance. Porcheron et al. [50] manipulated Chinese and French women's facial images by removing several age-related skin features including dark circles and spots, and wrinkles/sagging. In Chinese women, the removal of dark circles had a greater impact on age perception than the retouching of wrinkles/sagging, whereas in French women, the opposite effect was found (also, see [43]).

Such evidence suggests that the relative contributions of skin features to perception differ between ethnicities. The findings of the present study provide little evidence for this assumption regarding age and attractiveness assessments. However, considering ethnicity as a dummy variable indicated significance (of ethnic group) for ratings of women's health. Follow-up tests to determine skin features that predict face ratings corroborated the predictive utility of wrinkles under the eyes and crow's feet in all ethnic groups. In principle, this applies to all ethnic groups and the three attributes, although some variation was observed across ethnic groups in the magnitude of periorbital wrinkles as predictors. In addition, skin lightness (L^*) under the eyes positively predicted age (negative) and health (positive) ratings in Indian women. Skin yellowness (b^*) predicted health and attractiveness in South African women (see also [51]). There was no single significant skin feature predicting face ratings in French women, although the regression models for age, health and attractiveness were significant. This could indicate that French assessors did not place a strong emphasis on a single feature (such as periorbital wrinkles) but used a more balanced approach in ratings of women's facial appearance (Figure 4).

In conclusion, the present study indicates that in women of five ethnic groups age, health and attractiveness ratings from facial portraits can be predicted from wrinkles under the eyes and crow's feet. There is some variation across ethnic groups in the predictive utility and magnitude. Skin lightness and colour play an additional

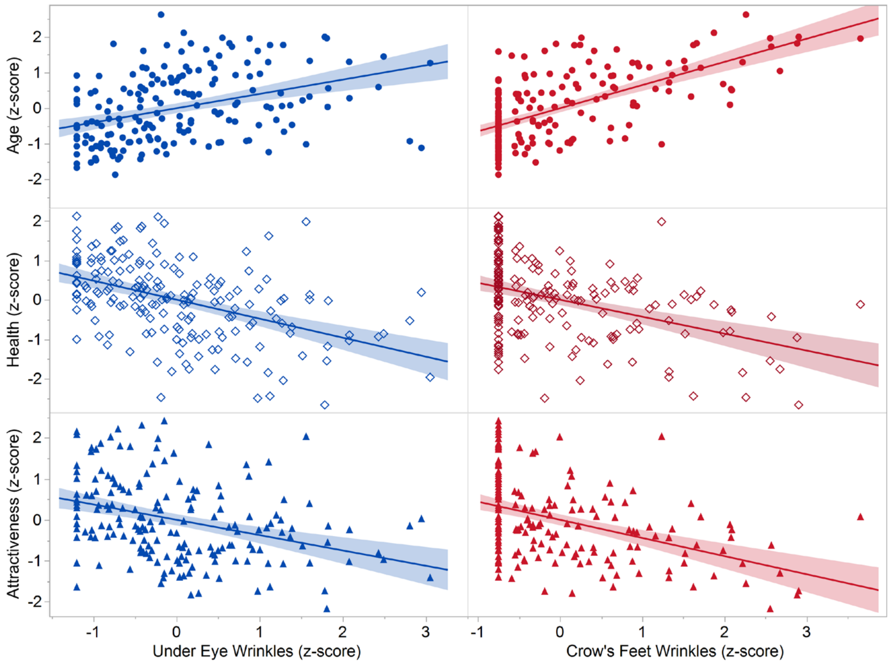

FIGURE 4 Linear relationships of wrinkles under the eyes and crow's feet region with age, health and attractiveness ratings of women's facial portraits (full sample). The variables were studentized (*z*-scored) and the skin features were averaged measurements of wrinkle density, length and volume.

role, especially in perceptions of health. The primary role of wrinkles under the eyes and crow's feet in perceptions of women's age, health and attractiveness across ethnic groups corresponds to survey data and self-assessments indicating high concern about age-related skin changes and problems in the periorbital region.

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CONFLICT OF INTEREST STATEMENT

RV and RC are employees of DSM-Firmenich, and BF is a consultant to DSM-Firmenich. TKS states no conflict of interest.

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