New Insights into Skin Appearance and Measurement

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When viewing the human face, the eye is drawn automatically to the areas of uneven topography and high color contrast, and the perception of skin age and attractiveness is dependent on these features. Although it is well recognized that topographic features, such as lines and wrinkles, contribute to the perceived age of skin and many cosmetic procedures are directed toward modifying these, the contribution of color contrast to the perceived age of skin has been less widely studied. A new technique, spectrophotometric intracutaneous analysis, is able to measure and characterize the distribution of chromophores in aging human skin and represents a significant advance in evaluation of the role color contrast plays in perception of the aging human face. This technique may be useful in the assessment of cosmetic interventions to reduce the appearance of aging by modification of skin color.

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INTRODUCTION

Humans view the world through eyes that are drawn to areas of high contrast. It has been determined experimentally that the minimum discernible difference in grayscale level that the human eye can detect is about 2% of full brightness (Blackwell, 1946; Campbell and Robson, 1968). This outstanding contrast sensitivity allows us to perceive the world around us in great detail; indeed, without contrast we would effectively be rendered blind. In simple terms, we view the world through edges created by contrast.

This understanding of human vision is critical to the understanding of how we perceive those around us. Specific changes in the properties of facial skin provide visual cues that signal the progression of aging. In young skin, reflection from the skin surface is largely diffuse, and this effect contributes to the perception of young skin as soft and firm (Matts and Solechnick, 2000). With increasing age and cumulative photodamage, this natural ''soft focus'' effect is lost, increasing the perceived age of the skin. In addition, contrast is increased as a result of shadows formed by the development of topographical features such as lines, furrows, and wrinkles, further increasing the perceived age.

Although cosmetic approaches to aging skin often focus on the reduction of the contrast created by these topographical features, color also plays an important role in the perception of age, health, and beauty. It has been firmly established that the processes of intrinsic and, particularly, extrinsic aging drive a steady accumulation of enlarging, localized concentrations of the two colored skin chromophores melanin and hemoglobin (American Academy of Dermatology, 1988; National Institutes of Health, 1989; Montagna and Carlisle, 1990; Griffiths, 1992; Ryan, 2004). When of sufficient size and intensity, colored features also create contrast and increase the apparent age of skin. This increase, in contrast, due to color is independent of the effects of topographical features and is particularly common in sun-exposed areas, such as the face, neck, and décolletage.

Recent research in this area has led to the development of a new approach to the measurement of the molecular basis of color contrast in skin and its effect on the perception of age, health, and attractiveness. This new technology also provides a means to measure the effectiveness of agents intended to reduce the apparent age of skin by modifying color distribution.

MEASUREMENT OF THE MOLECULAR BASIS OF COLOR CONTRAST IN SKIN

Human skin color is dependent almost exclusively on the concentration and spatial distribution of the chromophores melanin and hemoglobin, with melanin playing the dominant role (Anderson and Parrish, 1981; Bashkatov *et al.*, 2005). Objective approaches to determining skin color *in vivo* have been based on spectrophotometric or colorimetric approaches and various digital imaging and image analysis techniques, as reviewed in full by Pierard (1998). Although these techniques provide objective measurements of skin color, they are not able to separate fully the contributions of individual chromophores.

A new measurement technique, spectrophotometric intracutaneous analysis (SIA) (SIAscopy), was developed originally by Cotton and Claridge (1996) and modified by Astron

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Abbreviations: NCS, noncontact SIA measurement; SIA, spectrophotometric intracutaneous analysis

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Clinica (Cambridge, UK). This technique operates on the principle of chromophore mapping, that is, the *in vivo* measurement of the concentration and distribution of eumelanin, oxyhemoglobin, and dermal collagen to produce concentration maps of these chromophores. This commercially available instrument has been shown to have excellent sensitivity and specificity in the early identification of malignant melanoma and can be readily applied to the evaluation of normal, healthy skin as well (Moncrieff *et al*., 2002; Cotton and Claridge, 1996; Cotton *et al*., 1997). The SIA technique creates a high-resolution composite white light image of the skin over a defined area and provides four additional, mutually exclusive chromophore maps that display the concentration of epidermal melanin and hemoglobin, collagen, and melanin in the papillary dermis, pixel by pixel (Figure 1).

The contact SIA measurement uses a handheld scanner with a flat glass-fronted probe that is placed in contact with the skin using light, but firm, pressure. A noncontact SIA measurement (NCS) that overcomes the limitations of a skin contact probe is also available. By necessity, this approach must be insensitive to the effects of local geometry and illumination intensity; in other words, the unavoidable artifacts of measuring three-dimensional objects rather than flat surfaces.

The NCS technique uses a conventional (although finely calibrated) digital camera and lighting system (Matts *et al*., 2006b) and may be used to acquire eumelanin and oxyhemoglobin chromophore maps. In deploying NCS, the camera is treated not so much as an imaging device, but rather as a three-waveband spectrometer. The spectral power distribution of the light source and the raw response of the camera charge-coupled device sensor are determined accurately over the visible range (400–700 nm) and are supplied as calibration data to the NCS algorithms, based on the SIA mathematical model of light transport within skin. In short, for every pixel of the original raw image, NCS calculations are performed to yield specific concentrations of eumelanin and oxyhemoglobin. When pixels are recombined as an array, a parametric grayscale concentration map is produced. An example of the image produced by the NCS technique as applied to a whole face can be seen in Figure 2.

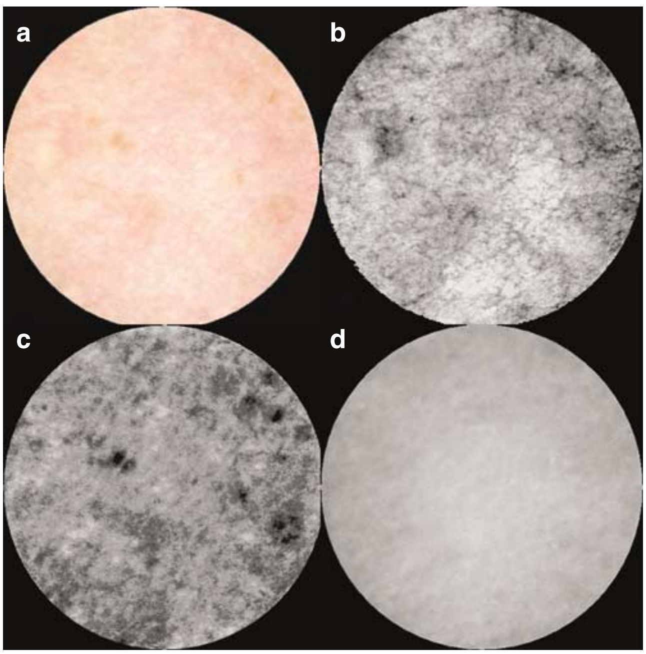

Figure 1. Example of SIAscope chromophore maps (12 mm diameter). (**a**) Composite white light image, (**b**) oxyhemoglobin concentration map, (**c**) eumelanin concentration map, and (**d**) collagen concentration map.

In a recent double-blind study, we used NCS to measure the effects on melanized hyperpigmented spots of a vehicle containing 2% *N*-acetyl glucosamine and 4% niacinamide compared with a vehicle control, applied topically, full face, twice daily for 8 weeks, to two groups of 100 females 40–60 years of age (Matts *et al*., 2006a). Analysis of the resulting NCS melanin maps demonstrated a clear treatment effect of the *N*-acetyl glucosamine/niacinamide combination, resulting in a significant ($P<0.05$) reduction in the melanin spot area and a significant ($P<0.05$) increase in melanin evenness compared with the vehicle control. A second study found an excellent correlation between NCS-derived melanin concentrations and eumelanin concentrations in human skin biopsies spanning Fitzpatrick skin types I–VI (Matts *et al*., 2007a). These studies demonstrate that large field chromophore mapping by NCS brings a new level of sensitivity and specificity to the measurement of human skin color and constitutes a step forward in the measurement of aging human skin.

COLOR CONTRAST IN THE PERCEPTION OF AGE, HEALTH, AND ATTRACTIVENESS

New objective measures, such as NCS, now allow us to separate and quantify the principal components of skin color; however, the contribution of color to the visual perception of age has, until recently, remained largely unstudied. Other aspects of facial appearance and their relationship to perceived age or attractiveness, however, have been evaluated. Two recent studies found a positive association between homogeneity of skin features and perceived attractiveness. Fink *et al*. (2001) demonstrated that women's facial skin texture affects male judgment of facial attractiveness and found that homogeneous skin (that is, an even distribution of features relating to both skin color and skin surface topography) is most attractive. More recently, Jones *et al*. (2005) demonstrated that the ratings of attractiveness of small areas of skin imaged from the left and right cheeks of male facial images significantly correlated with the ratings of facial attractiveness. It was also found that apparent health of skin influences male facial attractiveness, independent of shape information. It is important to note that none of these studies differentiated between the effects of surface topography and color distribution.

To investigate the role of color distribution to perception of age, attractiveness, and health, we obtained high-resolution digital images of 169 Caucasian women aged between 10 and 70 years (Fink *et al*., 2006). Crosspolarized lighting was used to eliminate fine surface texture in this imaging stage. The resulting images were processed using a unique series of digital manipulations to remove any contrast attributable to low-frequency topographical features such as lines and furrows. Two-dimensional color maps were then created by fitting the resulting image to a standard two-dimensional template. In this stage, facial features (for example, pupils, mouth gap, and so on) were standardized geometrically by fitting these to fixed addresses within the template. Three-dimensional facial images were generated from two-dimensional color maps, by fitting the template grid on to a shape-standardized wireframe mesh. In this process, we added standardized facial features (eyes, nose, mouth, ears, hair, and so on) such that the resulting dataset comprised 169 three-dimensional head and face combinations, standard in every respect apart from the subject's original skin color distribution. Examples of the images produced by this process are shown in Figure 3. These images were shown to 430 people aged 13–76 years in Germany and Austria. The participants, who were unaware of the ages of the subjects, were requested to estimate the biological age of each face within a range from 10 to 60 years. In addition, participants were asked to rate each face for a total of 15 aspects of perceived attractiveness and health and apparent skin condition using a 10-point rating scale for each aspect (including ''youthfulness,'' ''softness,'' ''smoothness''). The estimated biological age (aggregated estimates from all judges for each face) of facial images ranged from 17.8 to 36.7 years, a span of some 20 years. There was a highly significant positive correlation between the actual biological age of the subjects who provided facial images and the corresponding estimated age of their three-dimensional shape-standardized faces varying only in visible skin color distribution ($\rho = 0.721$, $P < 0.01$, two-tailed). Significant negative correlations emerged between the estimated facial age and the global face attributes (attractive: $\rho = -0.527$, $P < 0.01$; healthy: $\rho = -0.520$, $P < 0.01$; youthful: $\rho = -0.860$, $P < 0.01$). This study demonstrated that skin color distribution can influence perceived age within a range of 20 years, independent of any effects of facial form, feature, and skin surface topography. Skin color distribution also influences perceived attractiveness, youth, and health, possibly because color contrast may signal aspects of the underlying health of an individual that are relevant for mate choice.

In a separate analysis (Matts *et al.*, 2007b), cropped skin cheek images taken from 170 women, who participated in the study above, were blind-rated for attractiveness, healthiness, youthfulness, and biological age by 353 participants. These skin images and corresponding melanin/hemoglobin concentration maps were analyzed objectively for homogeneity. Homogeneity of unprocessed images correlated positively with perceived attractiveness, healthiness, and

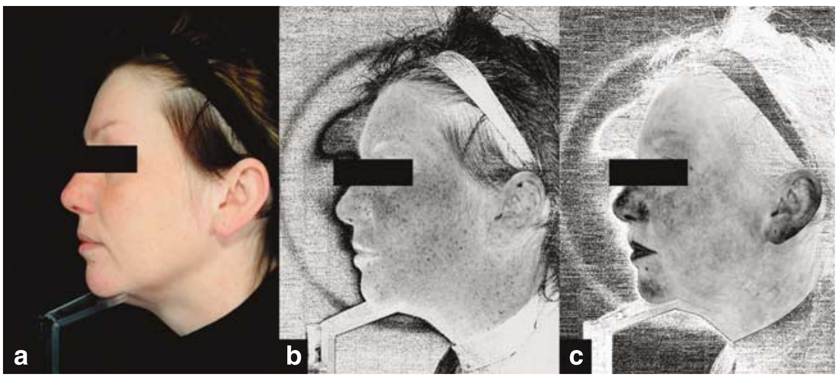

Figure 2. Example of full-face Non-Contact SIAscope chromophore maps (female subject aged 35 years). (**a**) Original crosspolarized white light digital photograph, (**b**) eumelanin concentration map, and (**c**) oxyhemoglobin concentration map.

Figure 3. Examples of three images with standardized facial form, feature, and topography with skin color distribution of the original Caucasian female faces as the single-variable difference.

youthfulness (all $r>0.40$; $P<0.001$), but negatively with estimated age ($r=-0.45$; $P<0.001$). Homogeneity of hemoglobin and melanin maps was positively correlated with that of the unprocessed images ($r=0.92$, 0.68; $P<0.001$) and negatively correlated with the estimated age ($r=-0.32$, -0.38; $P<0.001$). Linear regression analyses, with estimated age of individuals from corresponding skin image samples and actual biological age as dependent variables and homogeneity measures of hemoglobin and melanin chromophore maps as independent variables, revealed overall significant models with melanin, but not with hemoglobin, chromophore maps as a significant predictor of both estimated and actual biological age (estimated age: F[2, 167] = 15.64, $P<0.001$); actual age: F[2, 167] = 14.65, $P<0.001$).

CONCLUSION

Color contrast in human skin, formed by the local distribution and concentration of the chromophores melanin and hemoglobin, plays a major role in perception of age, health, and attractiveness. Strategies to improve the appearance of aging skin, therefore, need to focus not only on contrast created by form and topography, but also on contrast created by color distribution and the chromophore targets responsible for these changes.

CONFLICT OF INTEREST

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REFERENCES

American Academy of Dermatology Consensus Conference (1988) Photo-aging/photodamage as a public health concern, March 3–4

Anderson RR, Parrish JA (1981) The optics of human skin. *J Invest Dermatol* 77:13–9

Bashkatov AA, Genina EA, Kochubey VI, Tuchin VV (2005) Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000 nm. *J Phys D Appl Phys* 38:2543–55

Blackwell HR (1946) Contrast thresholds of the human eye. *J Opt Soc Am* 36:24–643

Campbell FW, Robson JG (1968) Application of Fourier analysis to the visibility of gratings. *J Physiol* 197:551–66

Cotton SD, Claridge E (1996) Developing a predictive model of human skin colouring. *Proc SPIE* 2708:814–25

Cotton SD, Claridge E, Hall PN (1997) Non-invasive skin imaging. In: *Proceedings of Information Processing in Medical Imaging* (Duncan J, Gindi G, eds), LNCS 1230. Springer, 501–6

Fink B, Grammer K, Matts PJ (2006) Visible skin colour distribution plays a major role in the perception of age, attractiveness and health in female faces. *Evol Human Behav* 27:433–42

Fink B, Grammer K, Thornhill R (2001) Human (Homo sapiens) facial attractiveness in relation to skin texture and colour. *J Comp Psychol* 115:92–9

Griffiths CEM (1992) The clinical identification and quantification of photodamage. *Br J Dermatol* 127(Suppl 41):37–42

Jones BC, Perrett DI, Little AC, Boothroyd L, Cornwell RE, Feinberg DR *et al.* (2005) Menstrual cycle, pregnancy and oral contraceptive use alter attraction to apparent health in faces. *Proc R Soc Lond B Biol Sci* 272:347–54

Matts PJ, Solechnick ND (2000) Predicting visual perception of human skin surface texture using multiple-angle reflectance spectrophotometry (abstract). American Academy of Dermatology 58th Annual Conference.

Matts PJ, Dykes PJ, Marks R (2007a) The distribution of melanin in skin determined *in vivo*. *Br J Dermatol* 156:620–8

Matts PJ, Fink B, Grammer K, Burquest M (2007b) Colour homogeneity and visual perception of age, health and attractiveness of female facial skin. *J Am Acad Dermatol* 57:977–84

Matts PJ, Miyamoto K, Bissett DL, Cotton SD (2006a) The use of chromophore mapping to measure the effects of a topical *N*-acetyl glucosamine/niacinamide complex on pigmentation in human skin (abstract). American Academy of Dermatology 64th Annual Conference

Matts PJ, Miyamoto K, Hillebrand GG (2006b) Digital imaging as an effective means of recording and measuring the visual signs of skin ageing. In: *Bioengineering of the skin: skin imaging and analysis. Dermatology: clinical & basic science series/31* (Wilhelm KP, Elsner P, Berardesca E, Maibach HI, eds), New York: Informa Healthcare USA Inc., 423–46

Moncrieff M, Cotton SD, Claridge E, Hall PN (2002) Spectrophotometric intracutaneous analysis—a new technique for imaging pigmented skin lesions. *Br J Dermatol* 146:448–57

Montagna W, Carlisle K (1990) Structural changes in ageing skin. *Br J Dermatol* 122(Suppl 35):61–70

National Institutes of Health (1989) Consensus Development Conference Statement: Sunlight, Ultraviolet Radiation, and the Skin 7:8–10

Pierard GE (1998) EEMCO guidance for the assessment of skin colour. *J Eur Acad Dermatol Venereol* 10:1–11

Ryan T (2004) The ageing of the blood supply and the lymphatic drainage of the skin. *Micron* 35:161–71