Development of a Skin Color Evaluation Method Based on Hyperspectral Imaging Using Erythema and Melanin Indices

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ABSTRACT

In the fields of cosmetic science and dermatology, image-based quantification of erythema and melanin is indispensable. Erythema and melanin indices express the levels of hemoglobin and melanin derived from reflectance data from the skin at specific wavelengths, and have been widely used. However, the conventional method evaluates average levels of hemoglobin and melanin without spatial distributions, and the interdependence of the erythema and melanin indices has remained an issue. To solve these problems, we first used a hyperspectral image to perform evaluations in a two-dimensional manner. Second, we checked for the interdependence of erythema and melanin indices in conventional equations by imaging method, and developed a modified algorithm that separates these indices more accurately than conventional methods. Accurate mapping images of hemoglobin and melanin were achieved using the proposed algorithm. Furthermore, spatial distribution of hemoglobin and melanin was quantitatively evaluated with the erythema and melanin indices images. Our proposed imaging method was demonstrated to be useful for the evaluation of the features of skin appearance.

KEYWORDS: erythema (hemoglobin), melanin, hyperspectral imaging.

INTRODUCTION

Cosmetics, such as skincare items, are expected to provide healthy and beautiful skin. Therefore, numerous studies on skin appearance have been carried out from physical and psycho-physical perspectives. In particular, the characterization of skin appearance from the chromatic perspective has been one of the most important research topics[1-4], because skin appearance is closely influenced by its chromatic features. These chromatic features derive mainly from the levels of skin chromophores (*i.e.*, amounts of mainly hemoglobin and melanin), and the spatial unevenness (two-dimensional spatial distribution) of the chromophores. Consequently, the characterization of skin appearance should satisfy the following two requirements: 1) chromatic features of the skin are physiologically evaluated based on levels of hemoglobin and melanin ("physiology-based evaluation"); and 2) the chromatic features of skin are evaluated in a two-dimensional manner ("image-based evaluation"). Based on this background, our study proposes an image-based method for analyzing the chromatic features of skin based on levels of hemoglobin and melanin. Regarding (1), we used the "erythema (hemoglobin) and melanin indices" proposed in 1980s[5-8], which have been widely utilized to quantitatively describe the chromatic features of skin in the fields of cosmetics and medicine[9,10]. This method transforms spectral data from skin into hemoglobin and melanin levels. However, as pointed out in several previous studies, the interdependence of these erythema and melanin indices remains an issue[11]. To solve this problem, we developed a modified algorithm that separates these indices more accurately. Regarding (2), we used a hyperspectral imaging camera to acquire skin spectral data in a two-dimensional manner. By applying our modified algorithm for indices to acquired hyperspectral images, spatial distributions of hemoglobin and melanin were characterized quantitatively.

THEORY

Apparent absorbance of skin (A) is converted from skin reflectance (R) and defined as:

$$= \log_{10}\left({}^{1}/_{R}\right). \tag{1}$$

EI: Erythema index

Hemoglobin shows high absorption in the wavelength range around 560 nm and low absorption around 650 nm. Therefore, EI1 was calculated from difference of absorption between 560 nm and 650 nm.

$$EI1 = 100(A_{560} - \ {}_{650}). \tag{2}$$

EI2 is a parameter that is proportional to the area under the hemoglobin absorption curve when an artificial baseline is drawn between 510 nm and 610 nm.

$$EI2 = 100[A_{560} + 1.5(A_{543} + \ {}_{576}) - 2(A_{510} + \ {}_{610})]. \tag{3}$$

MI: Melanin index

Absorption by hemoglobin is small in the wavelength range of 620 to 700 nm. As a result, A in this region is a linear function for skin melanin quantity alone. MI1 is thus taken as the slope in this range.

$$MI1 = 100(A_{ave620\sim640} - \ {}_{ave670\sim690}). \tag{4}$$

EXPERIMENTAL

The imaging system comprised a hyperspectral imaging sensor (NH-7, Eba-japan, Japan) and Dome Lights (CCS, Japan) (Figure 1). By using the imaging system, two experiments were carried out. Firstly, EI or MI images computed with the equations mentioned above ((2) – (4)) and a developed equation of MI were compared with one another, in order to determine which equation is accurate through the following experiments.

(a) UVB irradiation to increase level of melanin
(b) Application of methyl-nicotinate to increase level of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb)
(c) Occlusion of the finger to increase level of Hb

Secondly, it was verified whether the chosen equations were appropriate for EI and MI images of face.

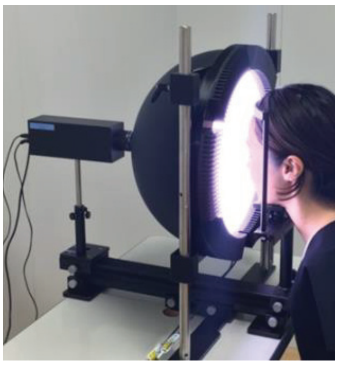

Figure 1: imaging system.

RESULTS AND DISCUSSION

As shown in Figure 2a, increase of HbO_2 and Hb by application of methyl-nicotinate was observed in the EI images computed with EI1 and EI2. However, the EI1 unsuccessfully separated melanin and hemoglobin, since pigmentation of melanin derived from UVB irradiation and spots appeared as hemoglobin (arrows and dotted region). In contrast, EI2 accurately separated melanin and hemoglobin.

As shown in Figure 2b, increase of melanin by UVB irradiation was observed in the MI images computed with MI1 and MI2. However, Hb derived from veins and congestion appeared as melanin (arrows and dotted region) in the MI image computed with MI1, the conventionally used equation. This was because in the wavelength range of MI1, Hb absorbs light, whereas HbO_2 absorbs less (Figure 3c, d). Therefore, the modified equation, MI2, was developed using isosbestic points of HbO_2 and Hb to exclude influence of HbO_2 and Hb (Figure 3a, b). In this equation, extinction coefficients for HbO_2 and Hb between two isosbestic points are regarded as equivalent. As a result, the effects of absorption by HbO_2 and Hb may be negligible in the wavelength range of MI2. By using MI2, the MI images successfully separated from HbO_2 and Hb were obtained (Figure 2b).

$$MI2 = 100(1.2 \times {}_{530} - {}_{570}). \tag{5}$$

Through this comparison, a more appropriate equation for EI was determined, and a novel equation for MI was developed. The equations EI2 and MI2 sufficiently separated hemoglobin and melanin for face images (Figure 2). Therefore, we concluded that EI2 and MI2 satisfied with our purpose for imaging of EI and MI independently of each other.

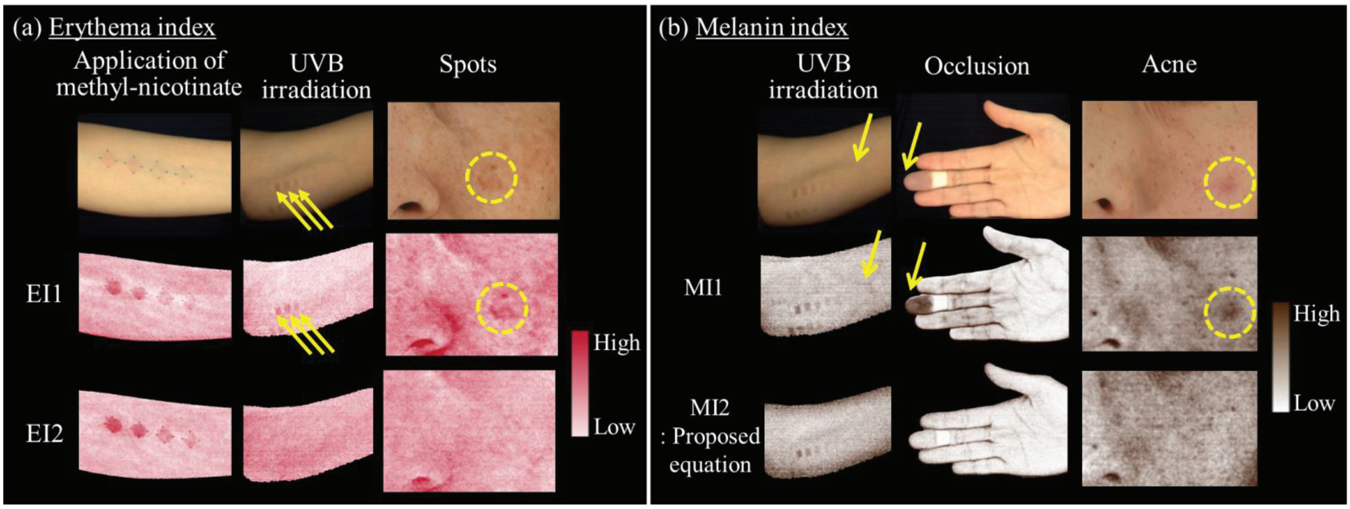

Figure 2: Index images of (a) erythema and (b) melanin.

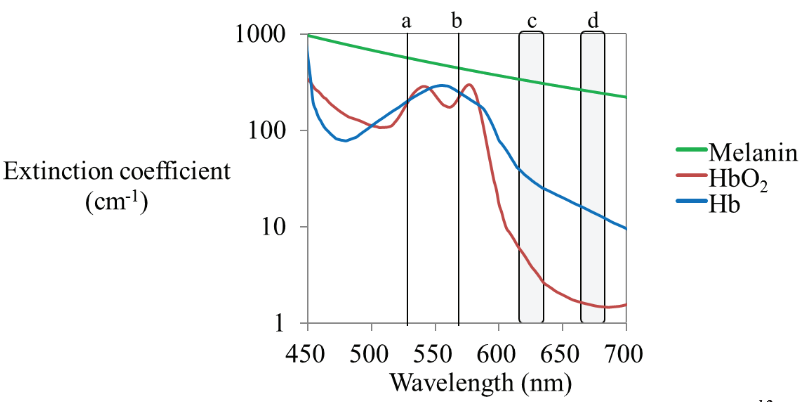

Figure 3: Extinction coefficients of melanin, HbO_2, and Hb .[12]

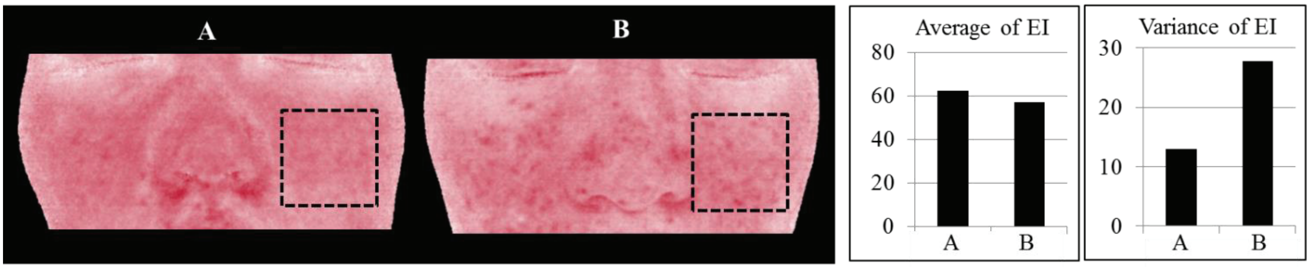

Figure 4: Average value and variance value of EI images.

Figure 4 shows EI images of two women whose skin appearance was completely different. Although the average value in dotted region of A and B was close, in contrast, the variance value in the region, which expressed spatial unevenness, was clearly different between A and B. Thus, it was difficult to discriminate features of skin appearance between A and B without information about spatial distribution. This result suggested that imaging of hemoglobin and melanin is useful for the evaluation of skin appearance.

CONCLUSION

This study proposed a novel image-based method for quantifying hemoglobin and melanin. A more appropriate equation for EI was chosen, and a modified algorithm that separates MI from hemoglobin more accurately was developed. By using the proposed algorithm, accurate mapping images of hemoglobin and melanin were achieved. Our image-based method enabled us to quantitatively evaluate spatial distribution of hemoglobin and melanin, and was demonstrated to be useful for the evaluation of the features of skin appearance.

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