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ORIGINAL ARTICLE

Analysis of Skin Color Variation using CIELAB Index: An Empirical Study from Delhi, India

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Abstract:

Skin color is a conspicuous trait regulated by complex metabolic processes and its significant diversity among Indian populations is quite remarkable making it an ideal choice for dermatological investigation. To elucidate skin pigment variation with respect to age, we studied 714 healthy individuals (aged 20-70 years) using CIELAB system. Skin reflectance was measured from the volar surface of upper arm using DSM II ColorMeter (Cortex Technology, Hadsund, Denmark) among population of Delhi, India to provide CIELAB color space values, L* (light/dark), a* (red/green), and b* (yellow/blue) followed by statistical analysis to examine the correlation between age and gender on skin on constitutive skin pigmentation. The studied parameters were observed to vary widely {L* (Range: 24.98-51.62, M=38.66, SD=4.41), a* (Range: 4.61-17.16, M=10.18, SD=2.03), and b* (Range: 20.16-34.83, M=28.93, SD=2.30)} across all age groups. ANOVA results suggest a statistically significant effect of age on skin lightness {$F(4,709)=124.1332$, $p<0.001$}, redness {$F(4,709)=20.0594$, $p<0.001$} and yellowness {$F(4,709)=95.1434$, $p<0.001$}. Positive correlation was observed between age and both hue (ho) {$r(712)=0.9027$, $p<0.001$} and chroma (C) {$r(712)=0.9224$, $p<0.001$}. Significant effects of gender were noticed on skin lightness among all age groups, along with skin redness below the age of 40 years ($p<0.001$). Notable color differences ($\Delta E*ab$) were witnessed among males and females across all age groups in the studied population. The age group 21-30 years was found to have the highest $\Delta E*ab$ value (3.5987), followed by 51-60 years (2.98), 31-40 years (2.5579), 61-70 years (2.1837), and 41-50 years (1.6639). We would like to highlight that skin lightness, redness, and yellowness differs significantly with age. Females were observed to be lighter in color as compared to males across all age groups. The findings of the current study would provide better understanding of skin color variation among Indian population.

Keywords: Skin pigmentation; Skin color; CIELAB index; Chromophores; Melanin.

Introduction:

Skin color varies widely among individuals, making it one of the most remarkable indicators of phenotypic diversity. Variation in skin pigmentation across populations has emerged as a result of evolutionary changes with respect to altered intensities of UV radiation (UVR) across geographic locations.[1] Melanin is the key pigment responsible for imparting color to the skin which is synthesized by a multistage biochemical process known as melanogenesis.[2] It occurs in highly differentiated skin cells or melanocytes that produce specialized intracellular vesicles called melanosomes. Skin color is controlled by the number, size, distribution, localization, and degree of melanosome aggregation.[3] Chromophores like carotene, bilirubin, hemoglobin etc. also have significant impact on the regulation of skin color. Various intrinsic and extrinsic factors also affect the inter- and intra-variation in skin pigmentation among populations.[1,4] Pigmentary changes in skin can be majorly classified as constitutive and facultative.[5,6] Constitutive skin color can be defined as the baseline levels of melanin and associated chromophores in absence of external stimuli, whereas, facultative skin color can be referred to as an elevated level of pigmentation contributed by the effect of UVR exposure, hormones, and growth factors on melanogenesis. The assessment of human skin color is a key descriptive factor in various clinical and scientific studies, extending its importance to the field of forensic science. Accurate evaluation of skin color can provide valuable information in several forensic contexts, such as bruise examination, wound examination, and forensic DNA phenotyping.[7,8] Researchers have utilized color scales, reflectance spectrophotometers and tristimulus colorimeters for assessment of skin tone and associated metrics.[9] Reflectance spectrophotometry has replaced the widely used color scales as it provides more precise, quantifiable, and rapid measurements without any associated bias of visual perception of color by the naked eye. Spectrophotometers can be used to define spectral characteristics of skin color based on reflectance and absorption of visible light (400-700nm) by major skin chromophores, usually in terms of melanin or erythema indices. Though the concentration of main chromophores usually differs from the actual appearance of skin color, its clinical exploration has not garnered much attention among researchers.[9] DNA phenotyping study has garnered much attention recently by forensic scientists which may be considered as a valuable investigative tool. Skin color is one of the most prominent phenotypic features and is

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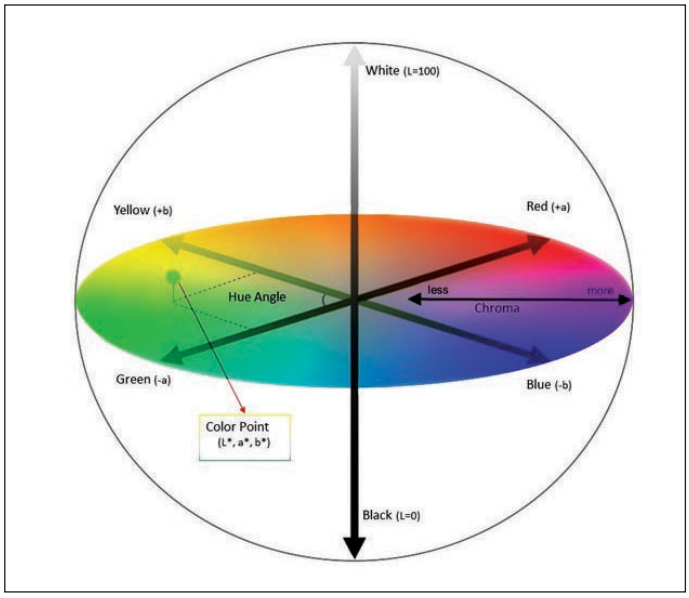

Figure 1. CIELAB color space diagram representing the color parameters L*, a*, b*, hue angle (ho) and chroma (C).

being extensively analyzed by geneticists to develop prediction tools.[10] Hence, it is imperative to understand the skin color variation among various populations.

The CIELAB or CIE*L*a*b** color space (Figure 1) is an internationally recognized system established by the Commission International d'Eclairage (CIE) for the evaluation of colored surfaces in terms of *L* a** and *b** indices. The measured *L** value has been recommended to correlate with change along a gray scale ranging from 0 (black) to 100 (white). The a* and *b** coordinates distinguish colors according to red vs. green and yellow vs. blue attributes, respectively. Skin pigmentation studies necessitate only the positive values for each coordinate. Therefore, in this study, *a** and *b** are used to describe the attributes of skin redness and yellowness. These coordinates can be used to define hue angle *(h^o)*, the psychometric correlate of visually perceived attributes of hue, corresponding to an angular position around a central point on a color space diagram that can be used to describe the relative amount of redness and yellowness. The color attribute of saturation also referred to as chroma *(C)*, is used to describe the intensity of color and can be measured by the distance from the *L** axis in the *a*b** plane. Along with absolute measurements for three attributes of perceived skin color, these chromatic parameters also enable the quantification of color differences *(ΔE)* between individuals or measured sites.

Figure 1. The present study has been carried out to assess the skin color variation among individuals residing in Delhi, India. Skin reflectance data were collected from healthy individuals (aged 20-70 years) using the CIE system to understand the differences in skin pigmentation with respect to age and its heterogeneity among males and females.

Material and methods:

Subjects: A total of 714 healthy unrelated volunteers (males=383, females=331), aged 20-70 years, belonging to Delhi, India were

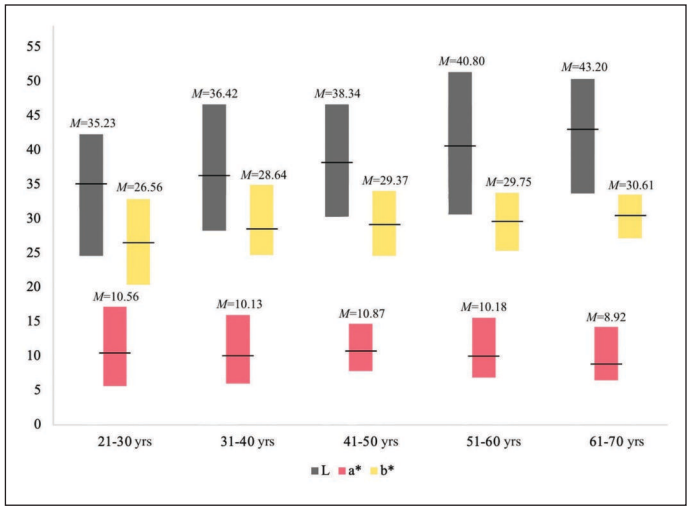

Figure 2. Distribution of CIELAB parameters (L*, a*, b*) of skin color among individuals aged 21-70 yrs, India. Bar length corresponds to the frequency distribution of the skin color parameters.

enrolled in this study via written consent. The subjects were further divided into five age groups: 21-30 years, 31-40 years, 41-50 years, 51-60 years, and 61-70 years. For all participants, at least three generations were reported to be born in Delhi. Volunteers with known pigmentation disorders, having tattoos at the assessment site or using topical medications/dietary supplements that may affect pigmentation were excluded from the study. The volunteers were advised not to be involved in any kind of vigorous physical activity at least 1hr prior to sample collection. Samples were collected during day time with optimum lighting conditions at room temperature (27°C-30°C) in air-conditioned rooms. The study protocol has been reviewed and approved by the Institutional Ethical Committee (Anth/2021-22/07/002).

Skin color measurements: Skin reflectance was measured in triplicates from the volar surface of non-dominant upper arm (least exposed to external factors affecting pigmentation like UVR) using DSM II ColorMeter (Cortex Technology, Hadsund, Denmark) after calibrating with a standard to provide numerical color values in CIELAB color space. Chromatic parameters included *L** (light/dark), *a** (redness), and *b** (yellowness). Furthermore, hue angle *(h^o)* and chroma *(C)* were calculated as *h^o*

Table 1: Distribution of skin reflectance data of Delhi population in terms of CIELAB parameters L*, a*, b*, hue angle (h^o), and chroma (C).

Subjects (Age group)	N (number of individuals)	Mean age ± SD (years)	Mean L* ± SD (Skin Lightness)	Mean a* ± SD (Skin redness)	Mean b* ± SD (Skin yellowness)	h^o (Hue angle)	C (Chroma)
21-30 years	148	26 ± 2.53	35.23 ± 3.30	10.56 ± 2.23	26.56 ± 2.61	68.27°	28.58
31-40 years	140	35.74 ± 2.98	36.42 ± 3.32	10.13 ± 1.92	28.64 ± 1.74	70.47°	30.37
41-50 years	162	44.24 ± 3.04	38.34 ± 3.07	10.87 ± 1.64	29.37 ± 1.79	69.67°	31.31
51-60 years	136	56.1 ± 2.70	40.80 ± 4.19	10.18 ± 1.77	29.75 ± 1.46	71.09°	31.44
61-70 years	128	64.12 ± 3.35	43.20 ± 3.00	8.92 ± 1.97	30.61 ± 1.38	73.74°	31.88

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Table 2. Skin color differences (ΔE*ab) with respect to CIELAB color parameters (L*, a*, b*, ho, and C) between male and female of studied population. Statistically significant p values (p<0.001) are highlighted in bold.

Subjects (Age group)	Gender	N (number of indivi-duals)	Mean age ± SD (years)	L* ± SD (Skin Lightness)	p value for L* differences (Statistical significance)	a* ± SD (Skin Redness)	p value for a* differences (Statistical significance)	b* ± SD (Skin Yellowness)	p value for b* differences (Statistical significance)	h^o (Hue angle)	C (Chroma)	ΔE*ab (Color differences between male and female)
21-30 years	Male	78	26.07 ± 2.54	36.30 ± 2.93	2.14 x 10^{-5}	11.86 ± 2.03	1.41 x 10-15	26.81 ± 2.69	0.2198	66.13°	29.31	3.5987
	Female	70	26.12 ± 2.43	34.04 ± 3.29		9.11 ± 1.69		26.28 ± 2.51		70.85°	27.81	
31-40 years	Male	74	35.09 ± 3.11	37.39 ± 3.39	1.85 x 10^{-4}	10.82 ± 1.96	2.86 x 10-6	28.41 ± 1.67	0.0952	69.10°	30.40	2.5579
	Female	66	34.53 ± 2.75	35.35 ± 2.89		9.36 ± 1.56		28.91 ± 1.79		72.01°	30.38	
41-50 years	Male	89	44.57 ± 3.13	39.06 ± 3.25	6.94 x 10^{-4}	11.04 ± 1.74	0.1387	29.23 ± 1.80	0.2702	69.25°	31.24	1.6639
	Female	73	44.41 ± 3.10	37.47 ± 2.61		10.66 ± 1.49		29.54 ± 1.78		70.14°	31.40	
51-60 years	Male	71	55.66 ± 2.73	42.18 ± 4..23	3.60 x 10^{-5}	10.53 ± 1.81	0.0175	29.87 ± 1.30	0.2948	70.53°	31.67	2.98
	Female	65	55.12 ± 3.04	39.30 ± 3.62		9.81 ± 1.65		29.61 ± 1.61		71.62°	31.19	
61-70 years	Male	71	64.04 ± 3.26	44.05 ± 2.59	3.55 x 10^{-4}	9.37 ± 1.67	0.0057	30.46 ± 1.34	0.1951	72.89°	31.86	2.1837
	Female	57	65.21 ± 3.14	42.13 ± 3.16		8.38 ± 2.19		30.78 ± 1.41		74.75°	31.90	

$= arctan\ (b/a)$, $C = [(a^*)^2 + (b^*)^2]^{½}$. Color differences (ΔE^*_{ab}) between males and females were computed as $\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$.

Statistical Analysis: Differences in skin lightness (L^*), redness (a^*) and yellowness (b^*) with respect to age among the studied population were computed using ANOVA. Pearson's correlation coefficient was computed to assess the causal relationship of hue and chroma with age. The effect of gender on chromatic parameters lightness L^*, h^o and C was evaluated using unpaired t-test. α-level of 0.5 was utilized and $p<0.001$ was considered significant.

Results:

The skin color distribution of 714 subjects from Delhi in terms of the CIELAB color parameters L^*, a^*, b^*, hue angle (h^o), and chroma (C) have been presented in Table 1. The L^* values ranged from 24.9847 to 51.6275 (M=38.6600, SD=4.4119). The mean L^* values were observed to increase with age, with the age group 21-30 years and 61-70 years being the lowest (M=35.23, SD=3.30) and highest (M=43.20, SD=3.00), respectively (Figure 2). The values on a^* axis ranged from 4.61 to 17.16 (M=10.1809, SD=2.0351). The 41-50 years age group exhibited the highest a* values (M=10.87, SD=1.64), while the lowest values were observed among individuals between 61-70 years (M=8.92, SD=1.97). The b^* values varied from 20.16 to 34.83 (M=28.9382, SD=2.3076). Significant increase can be observed in b^* values, similar to L^*, with the age groups of 21-30 years and 61-70 years showing the lowest (M=26.56, SD=2.61) and highest mean (M=43.20, SD=3.00), respectively. ANOVA results suggest a statistically significant effect of age on skin lightness $\{F_{(4,709)}=124.1332, p<0.001\}$, redness $\{F_{(4,709)}=20.0594, p<0.001\}$ and yellowness $\{F_{(4,709)}=95.1434, p<0.001\}$. Hue angle (h^o) and Chroma (C) was found to be lowest in the age group 21-30 years, which corresponds to more red and less saturated skin. Statistically significant positive correlation was observed between age and both h^o $\{r_{(712)}=0.9027, p<0.001\}$ and C $\{r_{(712)}=0.9224, p<0.001\}$.

Figure 2. Males (n=383) across all age groups were associated with numerically higher L^* and a^* values than females (n=331), while no such trend was observed with b^* values. To test the statistical significance of the hypothesis, an independent sample t-test assuming unequal variance was performed (Table 2). Significant effect of gender was observed on skin lightness. For all five age groups, males were found to be significantly darker as compared to females. Increased level of skin redness among males was found to be statistically significant below 40 years and is most evident in the age group of 21-30 years. A non-significant decline in a^* values can be seen among females of other age groups, indicating a very slight decrease in skin redness above 40 years. No statistically significant differences were observed in skin yellowness among males and females with respect to age. To study the pigmentary changes between male and female across all age groups, color differences (ΔE^*_{ab}) were evaluated. It was observed that the age group 21-30 years showed the highest ΔE^*_{ab} (3.5987) followed by 51-60 years (2.98), 31-40 years (2.5579), 61-70 years (2.1837), and 41-50 years (1.6639).

Discussion:

Both intrinsic and extrinsic factors play a crucial role in chronological ageing of skin.[11,12] Age-related pigmentary changes are primarily brought about by the cumulative effects of progressive loss of melanocyte naevi, elevated production of free radicals, decreased melanogenesis, melanocyte senescence, and exposure to UV radiation.[13,14] Changes in the concentration of a number of enzymes and antioxidants also play a significant role in the ageing process of the skin, leading to heterogeneous pigmentation.[15-17] Previous studies suggest an inverse relationship between age and proliferative activity of melanocytes leading to hypopigmentation of aged skin. Despite a decline in the number of active melanocytes, continuous UV exposure stimulates melanogenic activity, thereby increasing the number of DOPA positive melanocytes, resulting in hyperpigmentation.[18-20]

In the current study, skin lightness (L^*) was found to decrease with age, which may be explained by the long-term effects of UVR exposure and increased deposition of lipofuscin leading to irreversible persistent darkening of skin.[21,22] Our results also indicate an upward trend of skin yellowness (b^*) with advancing age. However, no such trend could be reported for skin redness (a^*) as the 41-50 years age group exhibited highest a^* values

while the age group 61-70 years showed the lowest values with a steep decline in skin redness. The results of the current study are supported by previous studies that indicated that Asian skin gets darker and more yellow with age, whereas Caucasian skin gets darker and redder with age.[23]

Significant color differences (ΔE^*_{ab}) were noted among males and females across all age groups in the studied population. Several research findings have indicated females to be lighter than males across populations, irrespective of geographic locations.[24-26] The observed patterns of sexual dimorphism have resulted from the sexual selection pressure for lighter than average skinned female sexual partners and natural selection to optimize the synthesis of cutaneous D3 vitamin high calcium requirements during pregnancy and lactation.[27] Although it is difficult to assess whether previous studies have controlled for potential confounding effects, the data based on analyses of unexposed skin areas could possibly rule out the argument that these variables account for the differences between males and females.[24,27] In India, research on the genetic basis of pigmentation in forensic DNA phenotyping is ongoing but in its nascent stage. Skin pigmentation details of individuals and skeletal remains can provide additional information to complement forensic anthropological or radiological studies which are routinely used for estimation of stature and age.[28-31] While these traditional methods offer crucial insights into the biological profile of the deceased, they may not be sufficient to generate individual's physical appearance. Analysis of genetic markers associated with skin pigmentation can provide a comprehensive understanding of the individual's phenotypic traits and ancestry leading to successful identification of individuals. Studies have been conducted to identify genetic markers that are associated with skin pigmentation in different population groups in India. However, the validity of predictions based on these markers is yet to be fully established and requires further research to improve accuracy.

Conclusion:

The study results strengthen the notion that skin color is diverse in nature and it darkens and becomes more yellow with advancing age. Females were found to bear lighter skin than males. However, significant association has been reported for skin lightness among all age groups along with skin redness among individuals below 40 years. Assessment of skin pigment variation along with underlying genetic make-up among populations would enhance our understanding towards a more accurate phenotyping prediction model. As skin pigmentation is a multifactorial trait which is influenced by both genetic and environmental factors, a large and diverse population size is needed to fully understand age related variation among male and female.

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