Research

Facial skin color assessment and proposed skin shade guide for maxillofacial prosthesis using cluster analysis in a cohort of Indian adults

Priyadarshani Gulabrao Pawar, Anjali Borle, Pradnya R. Patil[1], Rohit M. Patil[2], Priyanka S. Gadakh[3], Gita Rani[4]

Department of Prosthodontics Sharad Pawar Dental College and Hospital, Wardha, [1]Department of Periodontology, SMBT Institute of Dental Sciences and Research, [3]Happy 32 Dental Clinic, New Nashik, [2]Department of Prosthodontics, JMF ACPM Dental College, Dhule, Maharashtra, [4]Department of Prosthodontics, ITS Dental College, Ghaziabad, Uttar Pradesh, India

Abstract

Aim: The precise estimation and replication of skin color are crucial for maxillofacial prosthesis. The study aimed to evaluate facial skin color with a colorimeter and suggest a skin shade guide and formula for color estimation.

Settings and Design: An observational study conducted in the department of prosthodontics.

Materials and Methods: Study was conducted on 368 individuals of Indian origin in age range of 20–45 years. The facial skin color was assessed in malar regions using SkinColorCatch colorimetric device and individual topography angle (ITA) and CIELAB $L^*a^*b^*$ values were noted.

Statistical Analysis Used: K-means clustering was utilized to propose a shade guide for maxillofacial prosthesis with 24 skin shades. Logistic regression analysis was conducted to propose a formula to estimate skin shade of the individuals.

Results: Based on cluster analysis, 368 subjects were divided into three clusters with similar characteristic as Cluster 1 with dark skin color in 88 (23.91%) subjects, Cluster 2 with medium skin color in 224 (60.87%) subjects, and Cluster 3 with light skin color in 56 (15.22%) subjects. The mean ITA and $L^*a^*b^*$ values for cluster 1 were $-47.04° \pm 14.77°$, 34.53 ± 4.31, 8.55 ± 2, 11.42 ± 3.7033, respectively. The mean ITA angle and $L^*a^*b^*$ values for Cluster 2 were $4.29° \pm 11.34°$ 51.67 ± 3.42, 8.79 ± 3.13, 21.36 ± 2.38, respectively. The mean ITA and $L^*a^*b^*$ values for Cluster 3 were $34.65 \pm 4.29°$, 62.66 ± 3.08, 6.53 ± 1.79, 17.73 ± 2.39, respectively. The proposed shade guide comprised a total of 24 different shades that were categorized into three primary colors according to three distinct clusters, each of which was further broken down into eight subclusters containing various shades within each cluster. Logistic regression analysis gave an equation as follows: $Y = 12.43 + 0.186X$ (Y = Predicted skin color, X = ITA angle).

Address for correspondence: Dr. Priyanka S. Gadakh, Happy 32 Dental Clinic, 5, Dryaneshwari Apartment, Ambad Link Road, Pawan Nagar, New Nashik - 422 008, Maharashtra, India.
E-mail: dentopathfider2009@gmail.com

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Conclusions: Twenty-four facial skin shade tabs have been proposed based on ITA angle and CIELAB values. This comprehensive approach to categorize the shades will ensure a detailed and organized system for selecting and matching colors in maxillofacial prosthesis.

Keywords: Colorimetry, skin color, shade guide, maxillofacial prosthesis, Indians

INTRODUCTION

Maxillofacial prosthodontics consist of artificial replacements for intraoral and extraoral structures.[1] Ensuring precise color accuracy of human skin is a crucial step in the production of maxillofacial prosthesis.[2] Optimal esthetic results are achieved when the prosthesis seamlessly blends with the natural skin tone.[3] As a result, precise identification of the exact shade is of paramount importance.[4]

Among the diverse population around the world, Indians are recognized for their unique skin color, which ranges from light to dark due to a complex combination of factors. While numerous elements contribute to the variation in skin tone, melanin stands out as the primary pigment responsible for imparting color. Those individuals with higher levels of melanin typically exhibit a darker complexion, whereas individuals with lighter skin tones have lower melanin content, leading their skin color to be influenced more by the bluish-white connective tissue beneath the dermis and the presence of hemoglobin in the veins of the dermis.[5-7]

Wilson *et al*.[8] have documented that the average proportion of publications pertaining to skin color is relatively minimal. The number of publications done to assess the skin color ranged from 2.04% to 61.81%, with a mean value of 16.3%. Visual methods have been used in the past to estimate skin color, however, they are hindered by subjective differences.[9] Instruments for measuring skin reflectance, such as spectrophotometers and colorimeters, make use of advanced technology, however, are expensive, cumbersome, and not easily portable for regular clinical applications.[10]

Tristimulus reflectance colorimeters are advantageous, portable, and increasingly prevalent in the measurement of skin color, portraying skin color through the utilization of the Commission Internationale de l'eclairage (CIE) L*a*b* color space: L* representing brightness, +a* indicating various tones of red and green, and +b* denoting yellow and blue.[11] This system, while conforming to the CIE standards for blue, green, and red, exhibits a lack of total monochromaticity.[11-13] Recently, new colorimeters are now available such as Dermacatch and SkinColorCatch which uses the entire visible-spectrum reflectance.[13] Therefore, the primary objective of this investigation was to assess facial skin color values in the Indian population utilizing SkinColorCatch (Delfin Technologies, Kuopio, Finland) and secondary objectives were to propose a skin shade guide for maxillofacial prosthesis using cluster analysis and to propose a formula to estimate the skin shade of an individual using linear logistic regression method.

SUBJECTS AND METHODS

Study design

This observational cross-sectional study was conducted on voluntary basis in the department of prosthodontics from November 2022 to April 2023. Institutional ethical committee approval was sought before starting the study and the study was conducted in accordance with principles of Declaration of Helsinki. All the subjects were explained about the study protocol and written informed consents were obtained.

Sample size calculation

The sample size was calculated using the G Power software version 3.2.9. According to the previous study by Kaarthikeyan and Niveda,[14] the prevalence of light skin shade in Indian population was 76%, medium skin was 16%, and dark skin was 8% in a population sample of 130. Taking into consideration the confidence interval of 95% and margin of error 5%, the estimated sample size for the present study was 368.

Eligibility criteria

Three hundred and sixty-eight subjects were selected in the age range of 20–45 years based on the eligibility criteria of the study. The convenience method of sampling was adopted for the study. All the subjects of Indian origin with similar lifestyle, devoid of any skin disease, hypo- or hyperpigmentation, melanosis, burns, facial scars or deformities, skin blanching, scars or rashes on malar region, and those were willing to participate in this noninvasive method of skin color measurement were included in the study. The subjects with skin disorders, skin tanning, post radiation therapy, those who did not gave their consent, any history of drug reactions, abnormal reaction to sun, extensive exposure to sunlight in the past 4 weeks, infection or inflammation of skin, chronic daily administration of corticosteroids, immunosuppressors, and nonsteroidal anti-inflammatory agents topically, systemically or by inhalation in the month before study beginning, pregnant, and lactating females were excluded from the study. All the subjects were asked to refrain from using skin care products 24 h before the procedure, and female subjects were instructed not to wear facial makeup.

Instrument

SkinColorCatch is the visible-spectrum reflectance colorimeter is made of a diode emitting in the full visible spectrum. With traditional colorimeters erythema measurement is often affected by melanin and vice versa, however, this is not the problem with SkinColorCatch. The device also shows red, green, blue (RGB), CIE L*a*b* and L*c*h* color coordinates and calculates automatically the Individual typology angle (ITA) degree, which classifies the skin tone. The measured area covers a skin area of 0.30 cm^2. The probe sends out a white light by three white emitting diodes (LEDs) arranged circularly to uniformly illuminate the skin in a range of emitted wavelengths of 440–670 nm. Once the device is placed on skin to perform the measurement, the white LEDs illuminate the skin in an angle of 45° to minimize gloss. The light reflecting back from skin is detected with a sensitive RGB sensor and the measurement values are displayed within seconds. The measurement is not affected by ambient lighting conditions and the optical orifice of the SkinColorCatch is designed to minimize possible blanching effects caused by the contact pressure against the skin. The ITA value is believed to be a quantitative and objective value, which can be used to classify an individual's skin color as follows: Very Light > 55°> Light > 41°> Intermediate > 28°> Tan > 10°> Brown > −30°> Dark.[15]

Procedure

The skin color measurements were noted by an experienced prosthodontist (PP) with more than 5 years of experience at two areas for each subject: right and left malar region (for maxillofacial prosthesis) [Figure 1].[7,16] The malar area was chosen for skin color assessment as it typically experiences a steady and uniform level of exposure to sunlight in comparison to other facial regions. This quality makes it a dependable location for evaluating skin tone, which can provide insights into an individual's usual sun exposure and skin pigmentation response. Unlike other facial areas, the malar region is less influenced by the presence of facial hair, which could obscure skin tone and impact the accuracy of measurements. The skin on the cheeks is characterized by a more consistent thickness when compared to regions such as the forehead or nose, resulting in more dependable color assessments. In contrast, the nose and forehead exhibit higher levels of activity in sebaceous glands, which may lead to variations in skin tone readings due to increased oiliness or shine. The cheeks, however, are less susceptible to these influences. All measurements were carried out in a climatized room under controlled ambient conditions (room temperature 22°C ± 2°C and relative humidity 45% ± 5%). An acclimatization period of at least 10 min was given before the start of every measurement session.[7] The acclimatization period of 10 min before assessing skin color was given to ensure that the individual's skin color is measured under stable and consistent conditions. This period allowed the body to adapt to the environmental conditions of the assessment area, minimizing the effects of recent physical activity, temperature changes due to recent exposure to sun, heat, or cold, and other factors that can temporarily alter skin color. The controlled ambient light was provided by the use of light-blocking shades, portable room partitions, and a consistent location for measurements. For standardization of measurements, a point of intersection on ala-tragus line with the perpendicular dropped from the lateral canthus of the eye (malar region) was taken on right and left side of the face. The selected areas were cleaned with a neutral lotion and then rehydrated with application of Orasilk lotion (Fixderma, Cosmetic labs, Gurugram, India). Three measurements were taken at each anatomic location and L*, a*, and b* and ITA values were recorded for each reading. A single measurement consisting of the mean value of three readings was used for skin color determination. For each measurement session, the colorimeter was calibrated against the provided white background according to the manufacturer's instructions.

Reliability

The measurements were repeated after 2 days on randomly selected 40 subjects by the same observer who was blinded

Figure 1: Skin color measurements using skin color catch colometric device. (a) Right malar region. (b) Left malar region

to the previous readings to assess intraobserver reliability using intraclass correlation coefficient and it was found to 0.97, showing excellent agreement.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 23 (SPSS Inc., Chicago, IL, USA) software. The normality of the data was assessed using Shapiro–Wilk test and data were found to be normally distributed. To identify the skin color, the study sample was divided into three clusters according to ITA angle and CIELAB values. K-means clustering was utilized to elicit three groups with eight subgroups in each group with various traits to propose a shade guide for maxillofacial prosthesis with 24 shades. The three diverse groups were formed, each consisting of similar colors. Consequently, there were notable distinctions between the groups, whereas the colors within each group shared similarities. Once clusters were recognized, a primary color was positioned at the 3D center of the cluster. The CIELAB color space was utilized in a comprehensive analysis of the facial region data set. Logistic regression analysis was conducted to propose a formula to estimate skin shade of the individuals.

RESULTS

The study design is depicted in Figure 2. The fewer features the data have, the more likely the processing performance may increase; hence, the cluster analysis was based on two features: CIELAB, and ITA angle.[17] Table 1 shows that based on cluster analysis, 368 subjects were divided into three clusters with similar characteristic as Cluster 1 with dark skin color in 88 (23.91%) subjects, Cluster 2 with medium skin color (combination of tan and brown) in 224 (60.87%) subjects, and Cluster 3 with light skin color (intermediate) in 56 (15.22%) subjects. This division of clusters into three skin colors was according to classification by Chardon *et al*.[15] This showed a predominance of medium skin color in the study sample.

Table 2 shows that the mean ITA angle was −47.04 ± 14.77° in Cluster 1, 4.29 ± 11.34° in Cluster 2, and 34.65 ± 4.29° in Cluster 3. The mean L* values were highest in Cluster 3 (62.66 ± 3.08), and least in Cluster 1 (34.53 ± 4.31). The mean a* values were highest for Cluster 2 (8.79 ± 3.13), and least in Cluster 3 (6.53 ± 1.79). The highest b* values were recorded for Cluster 2 (21.36 ± 2.38), followed by Cluster 3 (17.73 ± 2.39) and Cluster 1 (11.42 ± 3.70).

Each cluster was further divided into eight subclusters depending on ITA angle in ascending order (D1-D8, M1-M8, and L1 to L8) [Table 3]. Cluster 1 data showed that each subgroup consisted of 11 subjects with ITA angle ranging from lowest for D1 subcluster (−57.29 ± 0.04°) to highest for D8 subcluster (−32.73 ± 3.64°). The corresponding L* and b* values increased from D1 to D8. The a* values were highest for D4 and D8, and lowest for D1 and D3. Cluster 2 consisted of 28 subjects in each subcluster (M1–M8). The ITA angle, L* and b* values increased from M1 to M8. The a* values were highest for M1 and M5, and lowest for M7 and M8. Cluster 3 consisted of 7 subjects in each subcluster from L1 to L8. The ITA angle, L* and b* values increased from L1 to L8 in subcluster 3. The a* values decreased from L1 to L8.

The skin shade guide was proposed based on clusters and subclusters having 24 shades as depicted in Figure 3. Linear regression analysis for prediction of skin color for cluster subgroups using ITA angle gave an equation as follows: Y =12.43 + 0.186X (Y = Predicted skin color, X = ITA angle). The correlation between ITA angle and cluster subgroup is as follows: $R^2 = 0.94$ ($P < 0.001$). This means that 94% of the variability of Y is explained by X and there is a very strong correlation between X and Y [Figure 4].

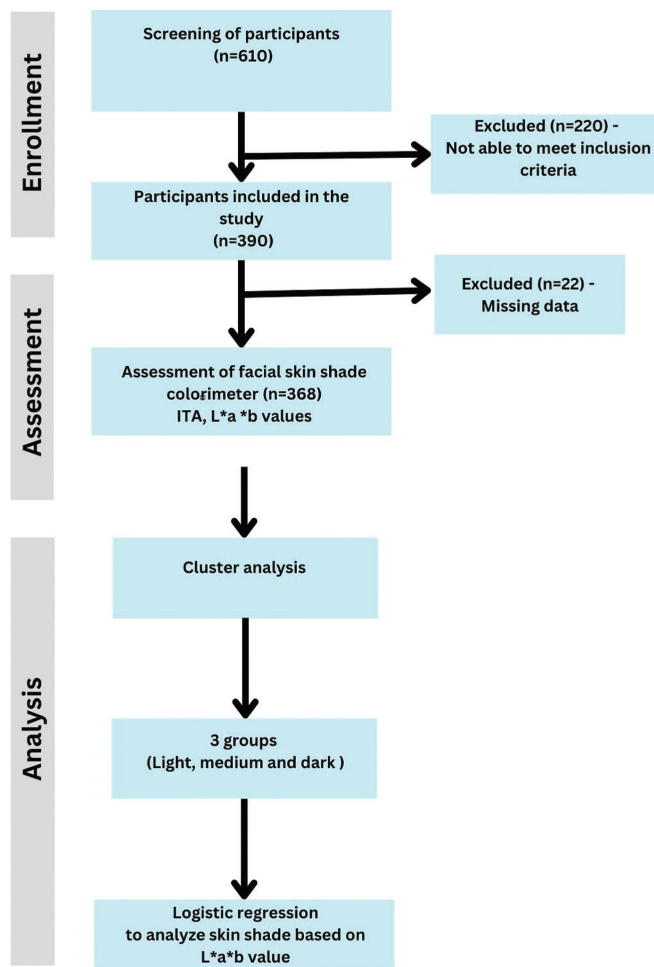

Figure 2: Study flowchart

Table 1: Demographic details of the study population in different clusters

Variables	Cluster 1 (dark)	Cluster 2 (medium)	Cluster 3 (light)	Total
Clusters, *n* (%)	88 (23.91)	224 (60.87)	56 (15.22)	368 (100)
Gender, *n* (%)				
Male	23 (6.26)	108 (29.35)	22 (5.98)	153 (41.59)
Female	65 (17.66)	116 (31.52)	34 (9.23)	215 (58.41)
Age (years)				
Male	28.34±5.31	32.12±6.25	26.56±5.12	29.00±4.34
Female	34.12±4.62	31.32±5.83	27.43±4.23	30.95±5.12
Average	31.23±3.47	31.72±4.71	26.99±5.78	29.98±5.88

Table 2: Mean and standard deviation of individual topography angle and L*a*b values in different clusters

Variables	Clusters	Sample	Mean±SD	Minimum	Maximum
ITA angle (°)	Cluster 1	88	−47.04±14.77	−57	−27
	Cluster 2	224	4.29±11.34	−22	30
	Cluster 3	56	34.65±4.29	24	43
L*	Cluster 1	88	34.53±4.31	24	41
	Cluster 2	224	51.67±4.24	42	60
	Cluster 3	56	62.66±3.08	57	69
a*	Cluster 1	88	8.55±3.23	1	15
	Cluster 2	224	8.79±3.13	2	14
	Cluster 3	56	6.53±1.79	3	9
b*	Cluster 1	88	11.42±3.70	5	17
	Cluster 2	224	21.36±3.28	12	29
	Cluster 3	56	17.73±2.39	13	22

SD: Standard deviation, ITA°: Individual typology angle

Table 3: Mean and standard deviation of individual topography angle values in clusters and subclusters

ITA°	Subclusters	Sample	Mean±SD	Minimum	Maximum
Cluster 1	D1	11	−57.289±0.038	−57.31	−57.18
	D2	11	−56.448±0.884	−57.18	−54.28
	D3	11	−54.335±0.052	−54.38	−54.28
	D4	11	−50.328±1.63	−51.28	−47.79
	D5	11	−45.379±2.11	−47.79	−41.7
	D6	11	−40.557±0.919	−41.7	−39.83
	D7	11	−39.332±1.023	−40.35	−38.07
	D8	11	−32.727±3.643	−38.07	−27.8
Cluster 2	M1	28	−13.664±5.148	−22.8	−5.2
	M2	28	−6.442±2.772	−12.1	−2.49
	M3	28	−2.586±3.028	−8.98	3.37
	M4	28	2.938±2.68	−2.86	7.77
	M5	28	7.006±1.489	5.44	10.31
	M6	28	10.318±1.148	8.13	11.77
	M7	28	14.241±1.938	10.01	19.17
	M8	28	22.526±2.709	18.43	30.1
Cluster 3	L1	7	29.557±2.79	24.97	32.49
	L2	7	32.217±1.565	30.79	35.16
	L3	7	34.369±2.869	29.23	38.07
	L4	7	34.28±1.939	31.24	36.91
	L5	7	35.05±2.431	32.05	38.81
	L6	7	33.863±1.145	32.77	35.96
	L7	7	36.716±2.269	33.98	39.38
	L8	7	41.217±1.796	38.37	43.66

SD: Standard deviation, ITA°: Individual typology angle

DISCUSSION

Ensuring precise color accuracy of human skin is a crucial step in the production of maxillofacial prosthesis. The variation in skin pigmentation among different ethnicities stands out as a significant factor in distinguishing racial characteristics.[6,18] Therefore, it is important to use customized shade guide for the patients of specific ethnic and racial origin such as in Indian population.

Therefore, in this study, skin color quantification was performed using a color space values such as ITA angle and CIELAB in Indian population by clustering and proposing a skin shade guide consisting of 24 colors. In the present study, SkinColorCatch instrument was used for skin color estimation which is a colorimeter device that uses the entire visible-spectrum reflectance. It is based on the same principle which was used by Dermacatch. In a study by Baquié and Kasraee[13] concluded that Dermacatch could record skin color of the individuals with high specificity and reproducibility, compared to narrow-band reflectance colorimetry. The findings of the present study revealed excellent reproducibility of measurements by SkinColorCatch, which was in accordance with the findings of Baquié and Kasraee.[13]

The cluster analysis revealed that most of the Indians have tan and brown skin color which has been grouped as medium skin shade in our study. This could be due to the fact that the present study was conducted in Maharashtra, and therefore, consisted of mainly Maharashtrian population. This finding could not be supported by previous study as to the best of our knowledge, no study has been conducted to assess the skin color in Maharashtrian population. However, this finding was in agreement with previous study by Hourblin *et al*.[19] and Jaswal[20] The spectrum of skin tones examined in our research varied from pale brown to deep brown. This diversity may be attributed to the elevated levels of eumelanin found in Indian skin tones, a pigment responsible for brown and black hues.[21]

According to the present study, mean ITA and L*a*b* values were in agreement with the findings of Del Bino and Bernerd[22] who determined L*a*b* values in 3500 individuals using spectrophotometer. They classified the skin color of the individuals based on their ITA angle as given by Chardon *et al*.[15] The ITA and L*a*b* values pertaining to the light skin shade observed in our research align closely with the intermediate skin shade identified in the previous study, while conversely, the values associated with the medium skin shade in our investigation correspond to the tan and brown skin shades outlined in the previous study.[22]

Our research findings unveiled a robust association between the ITA angle and the skin color of the subjects, which was subsequently employed in a logistic regression model for

S.no	Shade No	Color
1	D1	
2	D2	
3	D3	
4	D4	
5	D5	
6	D6	
7	D7	
8	D8	
9	M1	
10	M2	
11	M3	
12	M4	
13	M5	
14	M6	
15	M7	
16	M8	
17	L1	
18	L2	
19	L3	
20	L4	
21	L5	
22	L6	
23	L7	
24	L8	

Figure 3: Proposed shade guide

the purpose of predicting the skin color of the individuals. However, this formula has its own limitations and should be addressed carefully before its clinical application. The ITA serves as a valuable instrument in forecasting the associated clinical impacts of exposure to ultraviolet radiation (UVR) and plays a crucial role in objectively assessing the risks and effects of UVR exposure on different skin types, aiding in the prediction and management of related clinical conditions.[22] The L* and b* parameters play a crucial role in calculating the associated ITA values. It was observed in our study that within the cluster subgroups, there was a direct correlation between the increase in ITA values and the corresponding rise in L* and b* values. This relationship indicates that as the ITA values increase, the skin tends to appear lighter in tone due to the higher L* and b* values. The present study proposed a skin shade guide of 24 colors. Anitha *et al*. fabricated an intrinsic silicon shade guide for Indian population with 15 colors based on visual assessment method and found less to fair agreement.[23] Guttal *et al*. used ten powder pigments to fabricate the silicone samples for subjects with light, medium, and dark complexions and found good reliability for dark skin tone. Visual assessment method was used for evaluation.[24] Wee *et al*. proposed a shade guide by forming five clusters and five shades using spectroradiometer.[25] Therefore, to the best of our knowledge, none of the study has proposed or given customized shade guide for Indian population consisting of 24 varying shades of light, medium, and dark skin tone.

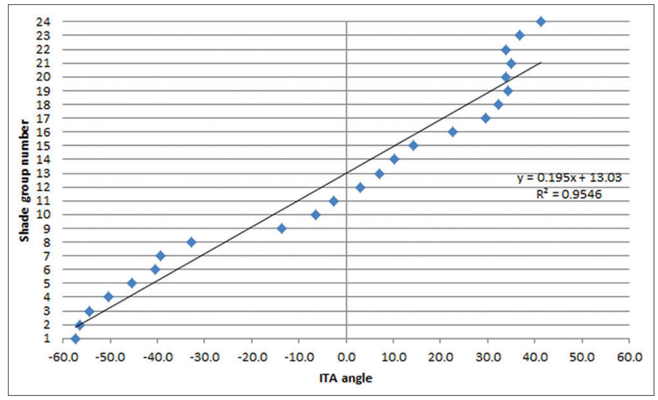

Figure 4: Regression analysis for different skin shade subgroups and individual topography angle (X axis-ITA angle value, Y axis-cluster subgroups from 1 to 24). ITA: Individual topography angle

Skin color is determined by a variety of factors including the type of melanin present, exposure to ultraviolet light, genetic makeup, the composition of melanosomes, and other pigments found in the skin. The perception of skin color is influenced in part by the presence of different combinations of four chromophores: carotenoids, melanin, oxyhemoglobin, and hemoglobin. This complex mixture of chromophores leads to variations in the way light is reflected and absorbed by the skin, resulting in a diverse range of skin tones. For instance, the combination of oxyhemoglobin and hemoglobin produces a pink hue in white skin, whereas the interplay between melanin and carotenes results in a yellow–orange tint in brown skin. Melanocytes, which are specialized skin cells responsible for producing the pigment melanin, play a crucial role in determining skin color. Within melanocytes, melanosomes are organelles that are involved in the synthesis, storage, and transfer of melanin pigment. Changes in skin color across different populations are primarily due to alterations in the size, distribution, and abundance of keratinocytes and melanocytes, rather than variations in the number of melanocytes present. In individuals with light skin tones, melanosomes are smaller and tend to be grouped together in secondary lysosomes, whereas those with darker skin tones have larger melanosomes that are dispersed individually within lysosomes.[6,26]

Mukherjee *et al.,* conducted a study to investigate the frequencies of alleles in single nucleotide polymorphisms within four genes associated with pigmentation: SLC45A2, SLC24A5, MC1R, and TYRP1. The findings of this study shed light on the complex genetic mechanisms contributing to the diverse skin pigmentation observed in different Indian subpopulations.[27]

In 1975, Fitzpatrick put forward a classification system where self-assessment of skin tone was done which has been identified as less precise compared to evaluations conducted by experienced dermatologists. This method has been observed to frequently overlook the vast majority of individuals of Black descent who engage in self-assessment.[28,29] Therefore, objective classification as given by Chardon *et al*.[15] based on ITA angle is considered more valid and useful.

Limitations

Many of the factors which could affect skin color could not be controlled in the present study. The other constraints included the limited sample size and localized regional representation of the population, which may affect the generalizability of the findings. Moreover, the measurement of color in a specific area of a craniofacial structure (malar area in our study) may not accurately reflect the overall color of the entire structure due to potential variations among participants. Moreover, only two parameters were used in the present study. Therefore, a significantly increased sample size is required to accurately determine the fundamental skin color based on other parameters such as hue, chroma, RGB values, melanin, and erythema index. The proposed shade guide in our study predominantly light to dark brown shades with absence of yellow tones. This could have been due to overrepresentation of south Indian population in our sample. Indian skin generally has higher melanin content, which produces brown hues. Melanin is responsible for the pigmentation of the skin, and higher levels result in darker shades. The brown tones more accurately reflect the variations in melanin levels within this demographic. While some individuals may have skin with yellow undertones, these are less prominent and less common compared to brown tones in the Indian context. The guide is designed to cater to the majority, ensuring practical utility. However, further studies should be conducted on diverse population of different ethnicity to ensure generalizability of the results.

Clinical implications

The utilization of the recommended facial shade guide will provide clinicians with the ability to commence the silicone mixing process through the careful selection of a preblended silicone color, thus streamlining the initial stages of prosthesis fabrication. This approach is anticipated to significantly diminish the duration required for fine-tuning the silicone mixing procedure, consequently enhancing the overall efficiency of the prosthetic creation process. The color formula proposed in the study can be tested in the large sample for validity and then could be used in the mobile application for skin color determination. The actual shade guide manufactured on basis of proposed shade guide needs to undergo extensive validation and testing on diverse population to ensure broader applicability.

CONCLUSION

The present study identified three clusters in the study sample of light (L1–L8), medium (M1–M8), and dark skin tone (D1 to D8). L* and b* values increased from D1 to D8. The a* values were highest for D4 and D8, and lowest for D1 and D3. The ITA angle, L* and b* values increased from M1 to M8 and L1 to L8. The a* values were highest for M1 and M5, and lowest for M7 and M8. The a* values decreased from L1 to L8. 24 facial skin shade tabs have been proposed based on ITA angle and CIELAB values. Utilizing the recommended facial shade guide could significantly improve the accuracy of matching silicone facial prostheses to human skin tones, thereby enhancing the overall quality and realism of the prosthetic results. A linear regression analysis was conducted to predict skin color, revealing a positive relationship between the ITA angle and the predicted skin color.

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Conflicts of interest

There are no conflicts of interest.

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