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Comparison between clinical and computerized methods for assessing gingival pigmentation

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Abstract

Background and Objective: Digital computerized assessment can provide objective values for the measurement of gingival pigmentation. This study aims to compare the Commission Internationale de l'Eclairage Lab color space (CIELAB) values and the computerized intensity values (CIVs) from digital imaging with clinical evaluations using the Dummett–Gupta Oral Pigmentation Index (DOPI) for assessing gingival pigmentation in a multi-ethnic population.

Methodology: Digital photographs of 188 participants were taken using standardized parameters. The buccal gingival pigmentation was evaluated using three methods (a) a clinical evaluation by two independent assessors using the DOPI, (b) the CIELAB values using the Adobe Photoshop® software (Version 23.1.1) and (c) the CIV calculated using the ImageJ software (Version 1.53k). A hierarchical clustering analysis was used to identify colour groups that clustered together. Agreement between the clinical and digital categorization of the pigmentation was carried out using weighted kappa analysis. Agreements between CIELAB and CIV were compared using intra-class correlation coefficient.

Results: There was a statistically significant difference in the DOPI, the L*, a*, and b* coordinates, and the CIV between the different ethnic groups of the participants. Cluster analysis for the CIELAB and CIV both identified four clusters. The gingival pigmentation categorization using the L*, a*, and b* values moderately agreed with the clinical evaluation using the DOPI index while the categorization with the CIV was in slight agreement with the clinical evaluations.

Conclusion: This study identified four clusters of gingival pigmentation in 188 multi-ethnic participants. The clusters, determined by CIELAB values, align with the clinical assessment of gingival pigmentation. Digital measurements derived from clinical photographs can serve as an effective means of pigmentation measurement in dental clinics.

Keywords

Oral health, aesthetics, digital photography, melanin, teledentistry

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Introduction

The gingival colour significantly contributes to smile aesthetics. Although the typical colour of the gingiva is pink, all races and nationalities have been reported to have various degrees of gingival pigmentation.[1] This can be physiological or due to factors such as melanoplakia, smoker's melanosis, drug-induced pigmentation, or from an amalgam tattoo.[2]

Assessment of gingival pigmentation routinely relies on various clinical gingival indexes such as the Dummet–Gupta

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Oral Pigmentation Index (DOPI), the Melanin Index, and the de Krom categories.[1,3,4] However, these methods are subjective and prone to variability due to human factors. Additionally, there is low comparability among these clinical indexes, leading to overlaps among the classifications.[5] To address these limitations, more objective methods have been explored including visual assessment using colour tabs such as the Munsell Colour Charts, electronic colour measuring devices, and the quantification of the pigmentation using digital software. However, the use of colour tabs is susceptible to observer factors such as colour blindness, fatigue, light conditions and health impairments, and coverage errors of the available shade guides. Some authors have reported that no optimal gingival shade guides are currently available in the market.[6] The quantification of gingival pigmentation either using electronic colour measurement devices such as a spectrophotometer or a colorimeter was also previously reported.[7–9] However, they exhibit limited reproducibility of the colour coordinates of the gingiva and a high variability between different measurement systems.[10]

The usage of digital software to quantify gingival colour has been reported in values such as the Commission Internationale de l'Eclairage Lab color space (CIELAB) values.[11] CIELAB or CIE L*a*b* is an internationally recognized method to report colour that is recommended by the Commission Internationale de l'Éclairage and is published as a Joint ISO/CIE Standard.[12] It is a device-independent, 3D colour space that enables accurate measurement and comparison of all perceivable colours using three colour values. CIE L*a*b* colour characteristics are commonly used in dentistry to define the colour of teeth and gingiva and can simplify communication between different parties.

The colour range of the human gingiva using the CIELAB values has previously been described in different American populations (Ito et al., 2014; Ho et al., 2015), in Spanish Caucasians, Taiwanese subjects, and Danish hygienists.[8,9,13] These studies did not report on the clinical or digitally assessed gingival pigmentation level in these subjects. Only Ito et al.[7] and Ho et al.[14] recruited subjects from different ethnicities while the other studies investigated subjects from the same ethnic background. To date, the CIELAB values corresponding to the different levels of clinical gingival pigmentation have yet to be reported.

Another digital method to measure the different levels of gingival pigmentation is the computerized intensity values (CIVs). It was first described by Raghu Ramaan et al. in an Indian population.[15] The CIV employs a digital method to measure the intensity of gingival pigmentation on a grey scale with values ranging from pure white to pure black. The authors reported the CIV of the gingiva according to the different DOPI classes in the study. However, the method of measurement for the CIV and the corresponding values for each class of gingival pigmentation has yet to be investigated in another population.

This study aimed to compare the clinical assessment of gingival pigmentation with digital methods as measured using the CIELAB and CIV. It also aimed to report on the digitally assessed values corresponding to the different levels of clinical gingival pigmentation in a multi-ethnic population.

Methodology

Study design and participants

This was a prospective cross-sectional study involving participants that were recruited from among students, staff, and patients of the Faculty of Dentistry, Universiti Kebangsaan Malaysia. The study was carried out for 12 months from December 2021 until December 2022. The study was approved by the ethical committee of Universiti Kebangsaan Malaysia (UKM/PPI/111/18/JEP-2021-037) and performed according to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.

The inclusion criteria for the participants were (i) partially or fully dentate with the presence of upper anterior teeth; (ii) more than 18 years old and (iii) systemically healthy. The exclusion criteria were as follows: (i) pregnancy; (ii) lactating females; (iii) patients with gingival recession on the examined teeth; (iv) patients with extensive restorations on the upper anterior teeth; (v) smokers; (vi) patients taking any medications that can affect the periodontium; and (vii) patients with periodontal disease. Written consent was taken from all participants.

Sample size

The sample size for this study was calculated based on the primary objective of comparing the digital and clinical assessment of gingival pigmentation. Using the minimum acceptable kappa as 0.4 to indicate a fair agreement, an expected kappa to be 0.2 as based on Lee et al., significance level (α) at .05, and power of 80%, the sample size for this study was calculated to be 184 samples with 10% dropout rate.[16] The sample size calculator by Arifin (2020) was used in this study.[17]

Digital photographs

The digital photographs of the participants were taken to achieve complete photographic documentation from the upper right canine (tooth 13) to the upper left canine (tooth 23) and the adjacent gingiva. Standardized photographs were taken with a Nikon D5500 DSLR (digital single lens reflex) camera. The settings were 24 megapixels, 300 dpi horizontal and vertical resolution, with the exposure time fixed at 1/100 s, the f/stop at f/20, and the ISO speed at ISO-320. The occlusal plane was aligned to be

parallel to the floor while the midsagittal plane was perpendicular to the floor. The distance of the maxillary teeth from the lens was estimated at 14 cm depending on the inclination and position of the teeth. A standard UNC-15 (Hu-friedy) was also taken with the photographs for validation purposes. The photographs were excluded if they had poor image quality such as photographs with low resolution, images out of focus at the region of interest, images without a visible area of keratinized tissue, and unclear visualization of the probe used to set a scale for the digital measurements.

The photographs were cropped using Adobe Photoshop® software (Version 23.1.1), separately by two investigators (HY and NZ) for the anterior teeth from the upper right canine to the upper left canine to remove the hard tissues and the upper lip margin from the photographs. Only the gingival portion of the pictures was analysed.

Reference standard

Evaluations by two blinded investigators (NMNA, MR) were carried out under standardized conditions to categorize the subjects into four categories of gingival pigmentation based on the DOPI. The evaluation was done independently, using a randomized order of the photographs. Any disagreements were discussed later, and a third evaluator (SNAS) was consulted if consensus was not achieved.

Digital measurements

The digital photographs were first cropped using the Adobe Photoshop® software (Version 23.1.1) as shown in Figure 1. Measurement of the CIELAB values was done using the Adobe Photoshop® software by SNAS and NMNA. The histograms application was used to show the mean colour values for each of the Lab characteristics for the entire cropped photograph (Figure 1(a)). The CIV was also concurrently measured using the cropped images with the ImageJ (Version 1.53k) application to determine the intensity of the pigmentation (HY, ZA) (Figure 1(b)).

Statistical analysis

Data analysis was carried out using the Statistical Package for the Social Science version 28.0 software (IBM Corp., Armonk, NY). Agreement between the examiners was measured using the intra-class correlation coefficient (ICC) and kappa. The digital assessment of pigmentation using CIELAB values and CIV was analysed using cluster analysis to identify the colour groups that clustered together. The hierarchical method using Ward's method utilizing squared Euclidean distance was first employed to determine the number of clusters. The k-means algorithm clustering method was then utilized to reduce the within-group sum of squares.[18] The agreement between the clusters identified based on the L*, a*, and b* values from the CIELAB and the CIV, with the clinical assessment using the DOPI was done using the weighted Cohen's kappa test.

Results

A total of 188 periodontally healthy participants were recruited, including 52 (27.7%) males and 136 (72.3%) females. The mean age of the participants was 25.87 ± 9.14. The ethnicity of a majority of the participants was Malay (n = 125, 66.5%) followed by Indian (n = 34, 18.1%), Chinese (n = 28, 14.9%), and other races (n = 1, 0.5%). The characteristics of the subjects according to the DOPI, mean L*, a*, and b* coordinates, and mean CIV are shown in Table 1. There was no difference in pigmentation between participants of different age categories and genders.

There was a statistically significant difference in L*, a*, and b* coordinates between the different ethnic groups of the participants, $F(6, 364) = 6.228$, $p < .001$, Wilk's $\Lambda = 0.822$, partial $\eta 2 = .093$. Post-hoc Tukey test showed that the L* coordinates differed between Chinese and Indian participants ($p = 0.024$, 95% CI = 0.572, 10.085) and between Malay and Indian participants ($p = 0.010$, 95% CI = 0.877, 8.087) while the a* coordinates differed between Malay and Indian participants ($p = 0.003$, 95% CI = 0.710, 4.021). There was no difference between the different ethnicities for the b* coordinates.

There was also a significant difference between the gingival pigmentation as categorized using the CIV between the different ethnic groups, $F(2, 184) = 8.596$, $p < .001$. Post-hoc Tukey test showed that the CIV was significantly different between the Malay and Indian participants ($p < 0.001$, 95% CI = 5.328, 24.106) and between Chinese and Indian participants ($p < 0.001$, 95% CI = 7.030, 31.806). There was no difference between the Malay and Chinese participants ($p = 0.519$).

For the DOPI, the chi-squared test showed there was a significant difference between the different ethnic groups of the participants, $\chi 2\ (9, N = 187) = 53.504$, $p = <.001$.

Categorization using DOPI compared to cluster analysis using CIELAB coordinates

Cluster analysis based on the L*, a*, and b* values of the CIELAB colour space identified four clusters for the gingival pigmentation levels, with one outlier removed from the analysis. The cluster centres are shown in Table 2 below. The clinical photographs of cases corresponding to each cluster are shown in Figure 2.

Comparison between the categories of gingival pigmentation as identified by the CIELAB cluster analysis and the categories based on the DOPI clinical assessment was

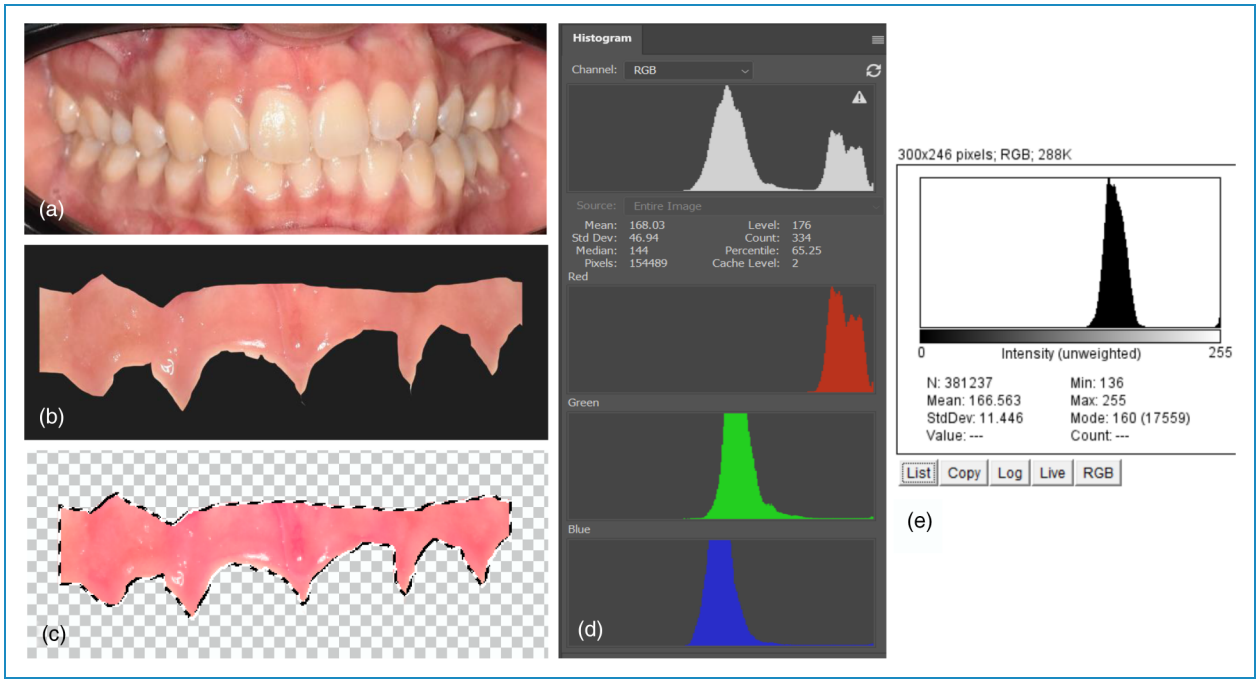

Figure 1. Measurement of the CIELAB and CIV values from the clinical photographs. (a) Original clinical photograph used for the assessments, (b) cropped photograph to remove the hard tissues from the image, (c) Selection of the gingival tissues in the photograph using the Adobe Photoshop® software, (d) measurement using the Adobe Photoshop® software histogram feature to assess the CIELAB values, measurement using the ImageJ software histogram to assess the CIV. CIELAB: Commission Internationale de l'Eclairage Lab color space. CIV: computerized intensity value.

carried out using Cohen's weighted Kappa analysis. There was moderate agreement between the two methods with $\kappa = 0.402$ (95% CI = 0.307 to 0.498), $p = <.001$.

Categorization using DOPI compared to cluster analysis using CIV

Cluster analysis based on the CIV identified four clusters with two outliers removed from the analysis. The cluster centres are shown in Table 3 below. The clinical photographs of cases corresponding to each cluster are shown in Figure 2.

Comparison between the categories of gingival pigmentation as identified by the CIV cluster analysis and the categories based on the DOPI clinical assessment was carried out using Cohen's weighted Kappa analysis. There was a slight agreement between the two methods with $\kappa = 0.193$ (95% C=, 0.138 to 0.249), $p = <.001$.

CIELAB compared to CIV

The distribution of the CIV compared to the L*, a*, and b* values is shown in the scatter plot in Figure 3. Agreement between the CIV with the L*, a*, and b* values were analysed using the ICC. The ICC estimates and their 95% confidence intervals were calculated based on single measures, consistency, two-way mixed-effects model. An ICC of 0.605 (95% CI = 0.506–0.698) was obtained for L*, 0.004 (95% CI = -0.139–0.147) for a*, and 0.075 (95% CI = -0.216–0.069) for b* indicating a moderate agreement between the CIV and the L* values and poor agreement with a* and b*.

Discussion

The current practice of clinical assessments of gingival pigmentation is a subjective method that utilizes one of the various pigmentation indexes or a commercially produced gingival shade guide. However, the threshold value for the perception of colour changes in human gingiva has been reported to be $\Delta E\ 3.1 \pm 1.5$.[19] The majority of gingival shade guides and gingiva-coloured restorative materials also exhibited significant coverage errors above the 50:50% acceptability threshold and an uneven shade distribution.[20] Digital assessments of the gingival colour using systems investigated in this study are beneficial due to their objectivity and simplicity as well as their ability to calculate colour differences with satisfactory visual perceptibility and acceptability thresholds.[7]

This study found that clinical categorization using DOPI agreed with the digital categorization based on CIELAB coordinates. Comparisons between digital dental photo assessment and clinical assessments of

Table 1. Characteristics of the participants according to mean L*, a*, and b*, the CI, and the DOPI.

	Digital assessment using CIELAB				Digital assessment using CIV		Clinical assessment using DOPI				
	N	L*	a*	b*	*p*-value	CIV	*p*-value	Score 1	Score 2	Score 3	Score 4	*p*-value
Mean	188	65.725 (8.032)	30.639 (3.710)	17.628 (4.025)	NR	166.876 (21.309)	NR	NR	NR	NR	NR	NR
Min value	188	27.632	15.560	5.965		71.926						
Max value	188	78.885	50.760	39.950		201.663						
	N (%)	L*, mean (SD)	a*, mean (SD)	b*, mean (SD)	*p*-value	CIV, mean (SD)	*p*-value	Score 0, n (%)	Score 1, n (%)	Score 2, n (%)	Score 3, n (%)	*p*-value
Gender												0.201
Male	52 (27.7)	64.672 (8.581)	30.972 (3.848)	17.420 (4.275)	0.435	163.243 (21.742)	0.990	13 (6.9)	16 (8.5)	14 (7.4)	9 (4.8)	
Female	136 (72.3)	66.127 (7.808)	30.511 (3.663)	17.707 (3.310)		168.266 (21.057)		41 (21.8)	57 (30.3)	23 (12.2)	15 (8)	
Age (years)												0.612
<30	145	65.144 (8.139)	30.970 (3.832)	17.679 (4.173)	0.068	165.404 (21.892)	0.167	40 (21.3)	57 (30.3)	27 (14.4)	21 (11.2)	
30- 59	40	67.512 (7.522)	29.364 (2.935)	17.208 (3.527)		171.176 (18.889)		12 (6.4)	15 (8.0)	10 (4.3)	3 (1.6)	
>59	3	69.988 (6.599)	31.635 (4.474)	20.746 (0.136)		180.713 (13.400)		2 (1.1)	1(0.5)	0	0	
Ethnicity[a]												<0.001
Malay	125	66.411 (6.940)	31.169 (2.943)	17.430 (3.520)	<0.001	168.853 (17.944)	<0.001	41 (21.8)	53 (28.2)	25 (13.3)	6 (3.2)	
Chinese	28	67.258 (6.550)	30.619 (3.058)	16.677 (3.969)		173.554 (18.380)		11 (5.9)	10 (5.3)	6 (3.2)	1 (0.5)	
Indian	34	61.929 (11.440)	28.803 (5.739)	19.049 (5.392)		154.135 (29.445)		2 (1.1)	9 (4.8)	6 (3.2)	17 (9.0)	
Other	1	66.076	27.309	20.717		166.088		0	1 (0.5)	0	0	

Age cut off based on Polo et al. 2018. [a]The 'other' category was removed from the analysis.
CIELAB; Commission Internationale de l'Eclairage Lab color space; CIV: computerized intensity value.

gingival pigmentation have yet to be reported. The only available reports on digital dental photo analysis were related to tooth colour matching, where the computerized method was compared to clinical shade matching on a phantom head model. The authors found the digital method to have better matching performance as well as a large variation in the observers' matching ability.[21] The digital categorization has also been compared to assessments using a reflectance spectrophotometer for tooth colour where the spectrophotometer was considered more suitable for slight colour changes.[22]

The CIV was only in slight agreement with the clinical categorization using DOPI. On the other hand, there was moderate agreement between the L* axis in the CIELAB and the CIV. This can be attributed to both measurements of the L* axis and CIV representing the white-black axis. The L* axis is a measure of 'lightness' that ranges from 0 to 100 where 0 represents pure black and 100 represents pure white (CIE, 1978) while CIV is a measure of darkness that ranges from 0 to 255 where 0 denotes pure dark and 255 denotes pure white (Raghu Raaman et al., 2015). Poor agreement between the a* and the b* coordinates with the CIV as well as the DOPI and CIV may be because the CIV does not measure colour in the red-green and yellow-blue axis. This is a limitation of the measurement of gingival pigmentation using the CIV where only the white-black axis is assessed.

Table 2. Clusters generated using the L*, a*, and b* values from the CIELAB.

Cluster	N	L*	a*	b*	Colour
A	64	73.535	29.124	15.797	
B	56	66.598	32.735	20.040	
C	48	60.708	30.471	16.551	
D	19	51.523	28.923	18.231	
Outlier	1	27.632	50.760	39.950	

*Colour tab generated using the http://colormine.org/color-converter website.
CIELAB: Commission Internationale de l'Eclairage Lab color space.

Figure 2. Clinical photographs of participants corresponding to each cluster where (a) is categorized as cluster A, (b) as cluster B, (c) as cluster C, and (d) as cluster D for both CIELAB and CIV categorizations. The generated colours based on the L*, a*, and b* are shown in the upper right corner while those based on the CIV values are shown in the lower right corner of the photographs. CIELAB: Commission Internationale de l'Eclairage Lab color space. CIV: computerized intensity value.

The difference in gingival pigmentation between different ethnicities has often been reported. This is reflected in the results of all three measurement methods in this study where significant differences were found between the different ethnic groups. This can also explain the difference in the range of the green-red (a*) values that were larger with a mean of 30.639 (Min: 15.560 to Max: 50.760) compared to those of Ito et al. with a mean of 25.9 (Min: 4.2 to Max: 38.2), a mean of 18.3 by Ho et al. and Huang et al., reporting a mean of 15.09 (Min: 7.34 to Max: 23.66).[7,8,14] In this study, the number of clusters identified for CIELAB measurements was four, which was dissimilar to Ito et al., who only identified three, and Huang et al., who identified 10 clusters.[7,8] This can be attributed to the variations in the population investigated, as well as the method for measurements of pigmentation where both Ito et al. and Huang et al. utilized a reflectance spectrometer while the present study used digital photographs and Adobe Photoshop to measure the pigmentation.

Table 3. Clusters generated using the computerized intensity values (CIVs).

Cluster	N	CIV	Colour
A	56	189.826	
B	65	170.229	
C	48	152.523	
D	17	128.826	
Outlier	2	71.926, 94.479	

*Colour tab generated using the http://colormine.org/color-converter website.

An objective and standardized digital method for assessing the colour distribution of gingiva using clinical photographs holds significant value, particularly in populations exhibiting diverse levels of gingival pigmentation from different ethnicities such as those investigated in this study. Such a digital assessment serves clinical purposes by providing precise reporting of gingival pigmentation and in research aimed at evaluating post-treatment changes in gingival pigmentation, as well as in the development of gingival shade guides for patients with pigmentation. Additionally, these data can aid in training artificial intelligence systems to accurately identify and monitor specific sites of gingiva as previously reported by Chau et al.[23]

The emergence of digital photography and its application in patient imaging for educational and research purposes signifies a new era where clinical photographs are extensively utilized.[24] This study substantiates the use of standardized digital images and Adobe Photoshop, a photo editing software, for the evaluation of gingival pigmentation. This can enhance the accuracy of gingival pigmentation evaluations, eliminate the need for electronic devices such as the spectrophotometer, and be employed in teledentistry applications as well as research applications making studies more comparable and reliable.

Limitations of this study include the limited regional sampling where one sampling centre with only three main Asian ethnicities included. Other limitations include

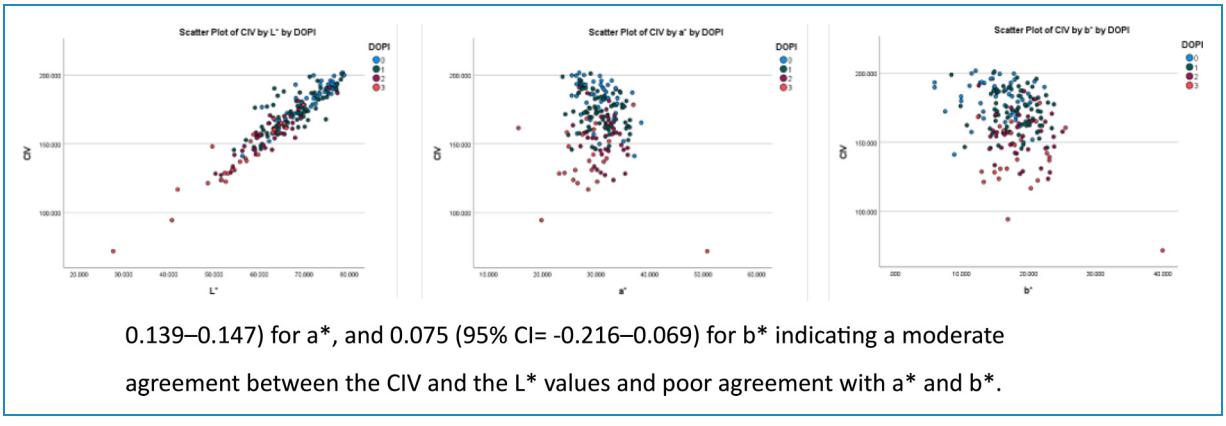

Figure 3. Scatter plot showing the distribution of the CIV compared to the L*, a*, and b* values. CIV: computerized intensity value.

average values of the pigmentation being reported rather than specific values for different sites such as the free gingiva, attached gingiva, and interdental papilla. The difference between the sites can be significant in participants with uneven distribution of gingival pigmentation. The gingival thickness was also not reported, although this can influence the perception of pigmentation.[25]

Conclusion

This study identified four clusters of gingival pigmentation in 188 multi-ethnic Asian participants. The clusters, determined by CIELAB values, align with the clinical assessment of gingival pigmentation. The range of CIELAB values was 27.632–78.885 for L*, 15.560–50.670 for a* and 5.965–39.950 for b*. Digital measurements derived from clinical photographs can serve as an effective and objective means of gingival pigmentation measurement in dental clinics.

Clinical relevance

Scientific rationale for the study

To validate two methods for computerized assessments of gingival pigmentation in a multi-ethnic population.

Principal findings

The computerized method of assessing gingival pigmentation using the CIELAB values aligns with clinical assessment methods. The CIVs are in weak agreement with the clinical assessment methods.

Practical implications

Objective assessments of gingival pigmentation using the CIELAB values can be recommended for the measurement and monitoring of gingival pigmentation in patients with varying levels of pigmentation.

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Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Contributorship: Conceptualization: NMNA and MR; analysis: HYZ, NZZ, NMNA, and SNAS; methodology: HYZ, NZZ, NMNA, and MR; project administration: NMNA; supervision: NMNA and MR; validation: SNAS; writing—original: NMNA; writing—review: MR, SNAS, HYZ, and NZZ.

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Ethical approval: The study was approved by the ethical committee of Universiti Kebangsaan Malaysia (UKM/PPI/111/18/JEP-2021-037) and performed according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

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