Research Techniques Made Simple: Cutaneous Colorimetry: A Reliable Technique for Objective Skin Color Measurement

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Skin color evaluation contributes to assessment of an individual's cutaneous phenotype. Skin color changes provide important clues to disease progression or treatment response. Skin color is also a predictor of skin cancer risk. Melanin pigment, blood flow, skin thickness, and photoaging contribute to skin color. Melanin, hemoglobin, bilirubin, and carotene are the primary chromophores of skin color. Their concentrations vary depending on the individual's phenotype, anatomic location, external insults of chemical irritants and UVR, and physiological changes. The evaluation and perception of skin color are often subjective. Objective quantification of skin color can be achieved with colorimetric devices such as tristimulus colorimeters. These devices compute the intensity of light reflected from skin and correlate with pigmentation and erythema. Cutaneous color and color changes can be quantified under color organization systems, such as the CIELAB color space, which is standardized by the Commission Internationale de l'Eclairage (CIE). The CIELAB expresses color's lightness, red/green intensity, and yellow/blue intensity, as L*, a*, and b* values, respectively. Additionally, skin color's full spectral characteristics and cutaneous physiology can be measured with spectrophotometers. This article outlines basic principles of the CIELAB color system and how to optimally use colorimetric devices as a skin research tool.

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Description: This article, designed for dermatologists, residents, fellows, and related healthcare providers, seeks to reduce the growing divide between dermatology clinical practice and the basic science/current research methodologies on which many diagnostic and therapeutic advances are built.

Objectives: At the conclusion of this activity, learners should be better able to:

- Recognize the newest techniques in biomedical research.
- Describe how these techniques can be utilized and their limitations.
- Describe the potential impact of these techniques.

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Abbreviations: CIE, Commission Internationale de l'Eclairage; FST, Fitzpatrick Skin Type; ITA°, Individual Typology Angle

SUMMARY POINTS

What colorimeters and spectrophotometers do:

- A colorimeter quantifies the appearance of a color and a spectrophotometer measures the spectral characteristics of the color.
- Colorimeters and spectrophotometers allow researchers and clinicians to objectively and quantitatively measure skin color without the bias associated with subjective clinical scoring.
- Measurements using these instruments provide a unifying language for both researchers and physicians regarding skin color.

Limitations:

The same settings, such as illuminant, standard observer, colorimetric system, specular component, and measurement geometry must be used to be able to compare values obtained with different colorimetric instruments. These geometrical configurations should therefore be specified in the literature and in each report on skin color.

INTRODUCTION

Consistent and reproducible skin color evaluation is useful for dermatology. Researchers and physicians must often describe skin color in assessments of pharmacologic interventions, environmental exposures, and physiologic changes. Cutaneous parameters like pigmentation can contribute to skin cancer risk. Furthermore, the minimal erythema dose response of skin to UV light exposure is used in establishing a care plan in phototherapy (Del Bino and Bernerd, 2013; Diffey, 2004; Youn et al., 2003).

To date, the Fitzpatrick Skin Type (FST) scale is widely used for skin type classification, which includes the parameter of color. The FST scale was developed in 1975 to categorize the skin type of Caucasians based on self-reported erythema sensitivity and ability to tan (Fitzpatrick, 1988). Phototypes I–IV classify skin types in decreasing sensitivity to UV light and increasing tanning ability, from "always burn, never tan" to "never burn, always tan". Later, brown and dark-skinned individuals were classified into categories V and VI, respectively based on their constitutive pigmentation or ethnic origin, rather than responsiveness to sun exposure. Although the FST provides a general basis for skin phototyping, its means of classification is limited because of subjectivity and observer and recall bias. Individuals of skin of color have variable skin pigmentation, and terms of sunburn and tanning sensitivity, such as "burns minimally to rarely" and "tans deeply", can be unrelatable and even culturally insensitive (Eilers et al., 2013; Pichon et al., 2010). Skewed self-reporting and subjective assessment can result in inaccurate skin phototyping and underestimation of risk of developing skin cancer.

Alternatively, an objective, quantitative, and observer-independent evaluation method of skin color assessment can be achieved with noninvasive devices called colorimeters and spectrophotometers. Such colorimetric devices can quantify the skin color, erythema, and tanning in various skin types. The devices have also been used for evaluation of vitiligo and psoriasis lesions, efficacy assessments of pharmacological compounds, and redefining skin phototyping methods. Their application extends into other fields of medicine and research, including forensic analysis of bruises, evaluation of chemotherapy-related erythema in oncology, and color matching of donor skin flap in facial surgeries for aesthetic medicine.

Colorimeters were developed under the standardization of the Commission Internationale de l'Eclairage (CIE), an international authority on light and color, as an objective color quantification tool that represents human color vision. The spectrophotometer analyzes the entire spectral characteristics of a color.

In this article, we aim to outline the general operating principle of colorimetry, usage recommendations, and applications of colorimetric devices.

HUMAN PERCEPTION OF COLOR

The fundamental operating principle of colorimetry is the human color vision. Visualization of color is the result of stimulation of photoreceptor cells in the eyes and interpretation of the visual signals by the brain. Color perception can be explained by two fundamental theories, the trichromatic color theory and the opponent-process theory (Bloj and Hedrich, 2012). The trichromatic theory explains that normal color perception is determined by the interplay of signal from the three types of color-sensitive photoreceptors, or trichromatic cone cells, each with different spectral sensitivity peaks and ranges within the visual spectrum (Ohta and Robertson, 2006). They are short, medium, and long, which are most sensitive to the colors blue, green, and red, respectively. The opponent-process theory outlines certain pairs of colors (red and green, blue and yellow, and black and white) that are antagonistic to each other (Ohta and Robertson, 2006). For example, when red wavelength stimulates the photoreceptors, it simultaneously causes inhibition of green color vision. Removal of the inhibitory signal allows the green signal to reach the brain. This explains the phenomenon of seeing a green afterimage of a red figure and the absence of greenish-red color. Similar to the brain's interpretation of the signal from the photoreceptors in human color vision, the colorimeter device analyzes the intensity of the reflected wavelength to deduce the color it is seeing.

CIE: A SYSTEMATIC APPROACH TO COLOR

One of the earliest methods to standardize color is the Munsell color system (Ohta and Robertson, 2006). It separates hue, value, and chroma into independent dimensions. For a given colored substance, hue refers to absorbance or reflection of specific wavelengths of light, value refers to the intrinsic luminosity, and chroma refers to the saturation.

For color to be interpreted, there must be an object, a light source, and an observer. In 1931, the CIE initiated several standardized color ordering systems based on objectively specifying the light source, the observer, and the relationship among colors, or color matching. The Standard Illuminant

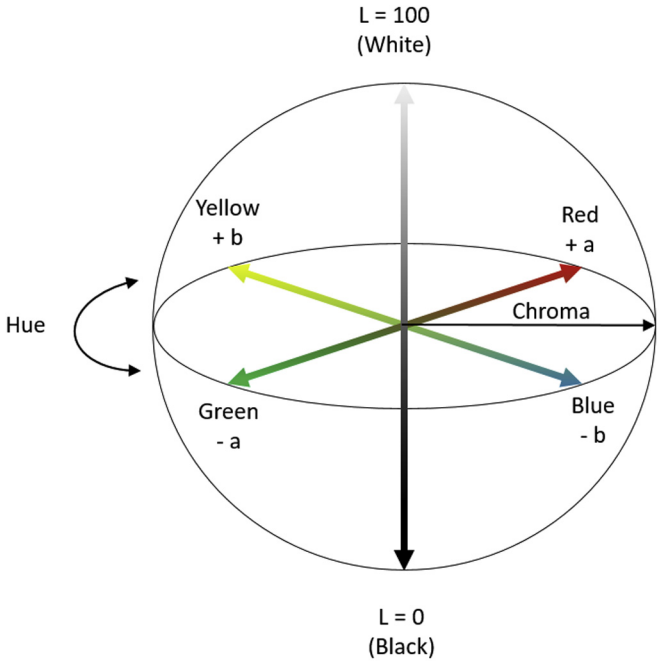

Figure 1. The CIELAB color space diagram. The CIELAB, or CIE L* a* b*, color system represents quantitative relationship of colors on three axes: L* value indicates lightness, and a* and b* are chromaticity coordinates. On the color space diagram, L* is represented on a vertical axis with values from 0 (black) to 100 (white). The a* value indicates red-green component of a color, where +a* (positive) and −a* (negative) indicate red and green values, respectively. The yellow and blue components are represented on the b* axis as +b* (positive) and −b* (negative) values, respectively. At the center of the plane is neutral or achromatic. The distance from the central axis represents the chroma (C*), or saturation of the color. The angle on the chromaticity axes represents the hue (h°). The L*, a*, and b* values can be transcribed to dermatological parameters. The L* value correlates with the level of pigmentation of the skin. The a* value correlates with erythema. The b* value correlates with pigmentation and tanning. CIE, Commission Internationale de l'Eclairage.

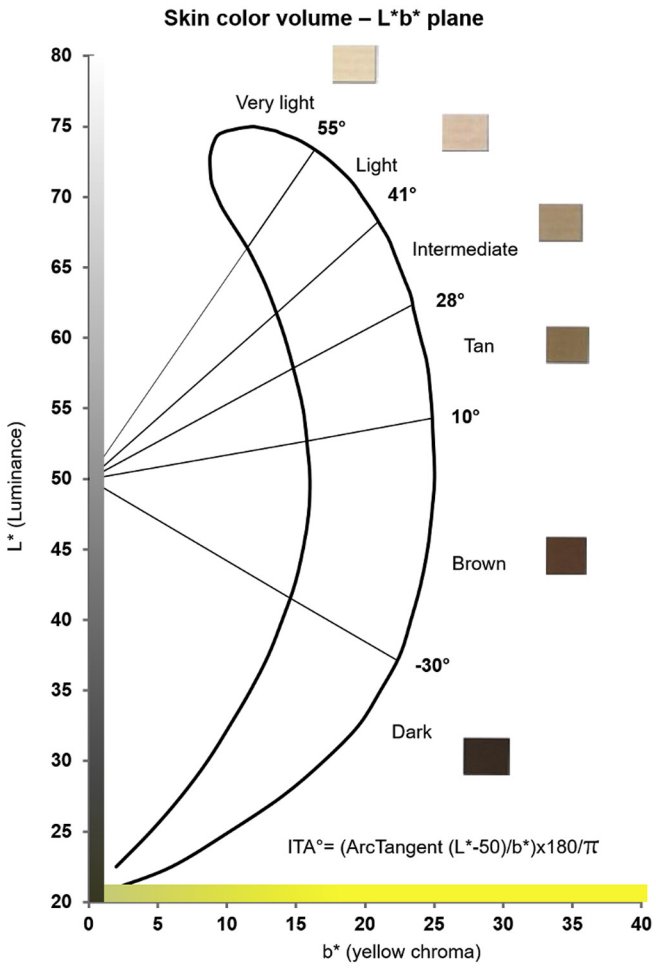

Figure 2. Skin color volume. Skin color volume allows for objective quantification and classification of skin color into six groups: very light, light, intermediate, tan, brown, and dark (Chardon et al., 1991; Del Bino et al., 2015). The skin color volume aligns the colorimetric 1976 CIE L*a*b* parameters with the ITA° value. The L* (luminance) value of the skin color is represented on the vertical axis and the b* (yellow-blue) component is on the horizontal axis. The ITA° of the corresponding skin color can be obtained from the L* and b* values according to the formula. The color swatches are representative average skin colors for each color group that match the L'Oréal Skin Color Chart (De Rigal et al., 2007). CIE, Commission Internationale de l'Eclairage; ITA°, individual typology angle.

D65 and C are commonly used settings for light source, and they correspond to average midday light with a clear sky in Western Europe, with and without UV wavelength, respectively (Fullerton et al., 1996). The observer parameters were standardized as mathematical functions, called 2° and 10° Standard Observers. The functions were derived from experiments in which observers color-match the target color by mixing varying intensities of the monochromatic lights (Randall and Charlotte, 1997; Weatherall and Coombs, 1992). The 2° Standard Observer represents the average human eye's spectral sensitivity if viewing colors at an arm-length distance and from a small field of view; it is typically used with colorimeters. The 10° Standard Observer represents visual assessment from a larger field of view and provides better correlation to human color vision. It is typically used with spectrophotometers (Ohta and Robertson, 2006).

Color quantification can be performed and represented under a multitude of color spaces and systems, each with their own application. The CIE (1931) RGB (Red, Green, Blue) and XYZ color systems described components of a color in relation to the standardized reference wavelengths of monochromatic red, green, and blue lights. This property is expressed in three, or tristimulus, values. The 1976 CIELAB color space is currently the most widely-used space. The system operates under the premise of opponent-process theory.

The CIELAB and cutaneous colorimetry

The 1976 CIELAB measurements are found to correlate to skin color and related parameters, such as erythema (Brainard and Stockman, 2010; Del Bino and Bernerd, 2013; Everett et al., 2012). The CIELAB, or CIE L* a* b*, system is a three-dimensional color-space consisting of three axes (Figure 1). The L* axis is a gray scale with values from 0 (black) to 100 (white). The L* value correlates with the level of pigmentation of an individual. The a* is the red/ green axis; positive and negative a* describe red and green values, respectively, which correlate with erythema. The b* is the yellow/ blue axis; positive and negative b* describe yellow and blue values, respectively, and correlate with pigmentation and tanning. The CIELAB units included the asterisk (*) to

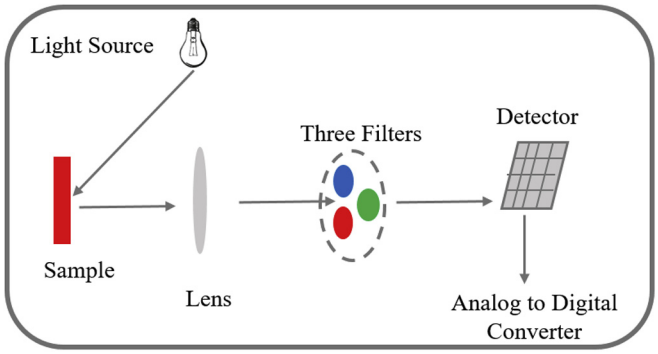

Figure 3. Operating principle of colorimeter. The components of a colorimeter generally include an illuminant, lens, filters, and a computer analyzer. The illuminant, demonstrated by the light source, emits certain wavelengths onto a sample. The sample absorbs the wavelengths and reflects the light. The reflected light that is captured by the colorimeter is filtered through the trichromatic filter of red, green, and blue chroma. Downstream processing of the data is performed under a set of parameters, such as observer color matching function and illuminant spectral setting, that is personalized by the user.

differentiate the CIELAB system from the units of other color systems. Chroma (C*) and hue (h*) can be extracted from the a* and b* values as:

$$C^* = \left((a^*)^2 + (b^*)^2\right)^{\frac{1}{2}}$$

$$h^\circ = \arctan\frac{b*}{a*}$$

The composite color difference is denoted by ΔE^*_{ab}, which accounts for the changes of L*, a*, and b* components, which can be calculated using the equation:

$$\Delta E^*_{ab} = \left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right)^{\frac{1}{2}}$$

ΔE* value greater than one indicates color difference observable by the human eye (Fullerton et al., 1996).

The Individual Typology Angle (ITA°), which is defined as:

$$ITA^o = \arctan\left(\frac{L^* - 50}{b^*}\right) * \frac{180}{\pi}$$

is an objective classification of skin color in dermatological and cosmetic research. Using ITA°, skin color can be classified into one of the following categories: Very light >55°; Light 55°−41°; Intermediate 41°−28°; Tan 28°−10°; Brown 10° to −30°; and Dark < −30° (Figure 2) (Chardon et al., 1991; Del Bino and Bernerd, 2013). The ITA° correlates with total melanin content, as well as the eumelanin and pheomelanin content (Del Bino et al., 2015). This objective classification of skin color can overcome the lack of reliability of self-reporting and subjective assessment of the FST (Del Bino and Bernerd, 2013).

Melanin, hemoglobin, bilirubin, and carotene are the primary chromophores of skin color. The melanin content and distribution in the epidermis yield the appearance of light-pigmented and dark-pigmented skin, which correlate with L* and ITA° in value. Individuals of lighter skin pigmentation have a higher L* value and higher ITA° than darker pigmented individuals (Andreassi and Flori, 1995; Del Bino and Bernerd, 2013). The content and saturation of hemoglobin of the superficial vasculature in the dermis impact the reddish appearance of the skin. Dermal thickness, melanin content, and photoaging also affect the a* and b* values of the skin. Sun-exposed and pigmented skin was shown to present with lower L* values than sun-protected and less pigmented skin (Alaluf et al., 2002; Chien et al., 2016). Additionally, cutaneous erythema was shown to be correlated with sun-exposure and was more observable in lighter pigmented skin of Caucasian participants when compared with African-American participants (Chien et al., 2016).

Using the tristimulus colorimeter

Objective color quantification can be obtained with colorimetric devices, such as a tristimulus colorimeter and spectrophotometer. Figure 3 illustrates the essential components of a colorimeter, which include an illuminant, colored filters

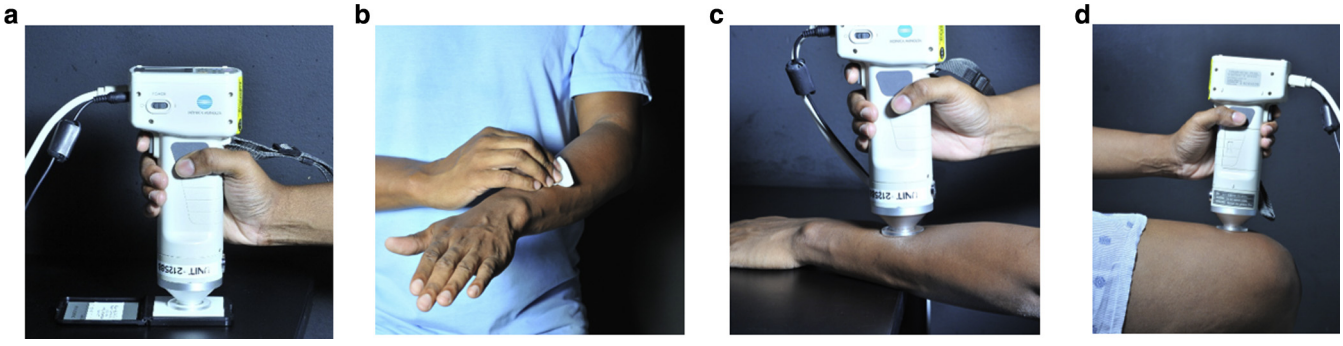

Figure 4. Usage recommendation for colorimeter. (**a**) Before using the colorimeter, calibrate the device with a standard calibration tile provided by the manufacturer. To prepare the subject for accurate and reproducible measurements, allow the subject to equilibrate by resting for an appropriate amount of time, or a minimum of 15 minutes, before measurement. (**b**) If appropriate, clean the skin with a mild cleaning agent. (**c, d**) Position the area of interest on a support, such as having the arm rested on a table or supporting the leg, to minimize orthostatic effects. To acquire measurements, hold the device perpendicular to the skin surface with the tip pressed against the skin with moderate pressure. Obtain at least three measurements to minimize data variation. The colorimetric device used in these figures is the Konica Minolta CR-400 chromameter. The chromameter can be used as a stand-alone device or linked to a computer.

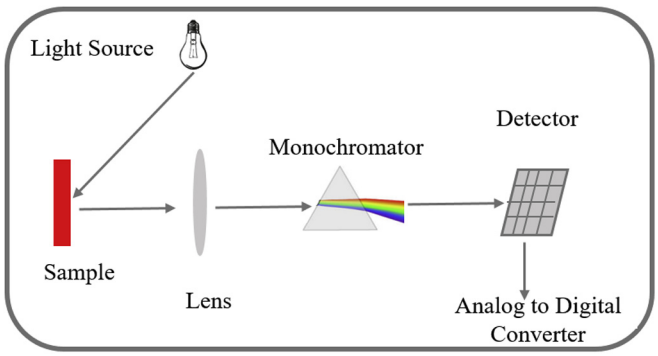

Figure 5. Operating principle of spectrophotometer. The general operating principle of the spectrophotometer is similar to that of the colorimeter. The device emits wavelengths onto a sample. The reflected light is captured by the device, and wavelengths between 360–700 nm are processed by the multiple spectral sensors. Downstream processing analyzes the spectral characteristics of the reflected light, and therefore, the sample color.

that replicate the spectral sensitivity of cones in the human eye, and a processor to adjust for the Standard Observer. The Chromameter CR series (Konica Minolta, Tokyo, Japan) (Figure 4) is commonly used. Other tristimulus colorimetric instruments include Antera 3D (Miravex Limited, Dublin, Ireland) and Colorimeter CL400 (Courage-Khazaka, Cologne, Germany).

Care must be taken during measurements as these devices are sensitive to environmental changes. The instrument must be calibrated with a white standard before use. Measurements should be obtained in an adequately lit, windowless room with ambient temperature (19–25 °C) (Fullerton et al., 1996; Healy et al., 2009). To minimize the effect of orthostatic position and physical activity on measurements, the subject should be allowed to equilibrate by resting for a sufficient period or a minimum of 15 minutes before measurements. Readings should be obtained with the device directed perpendicular to the site, with the device head pressed against the skin with only moderate pressure. Values should be obtained from the average of repeated measurements to minimize random errors. A minimum of three repeated measurements is recommended and skin should be allowed to equilibrate between sets of measurement. Reproducibility of the data can be preserved by adopting a protocol of measurement. If possible, wounds, scarred skin, regions of dense hair growth, tattoos, and uneven pigmentation, such as nevi or acne vulgaris, should be avoided in measuring constitutive skin color.

SPECTROPHOTOMETER: ALTERNATIVE COLOR QUANTIFICATION DEVICE

The spectrophotometer is another colorimetric device (Figure 5). In addition to extrapolating the tristimulus values of a sample, the spectrophotometer measures the complete spectral composition of light between 360 and 700 nm. Spectrophotometers are equipped with the spectral power distributions of a wide range of illuminants and thus can display color differences not noticeable to the naked eye using one of the standard illuminants. Spectrophotometers can also display output values based on a wide variety of color spaces. The instrument must be calibrated with the accompanying dual calibration of black and white references after turning on the device. One must consider the various factors that may affect measurements and adhere to the colorimeter usage guidelines, such as minimizing the impact of the subject's physiological activity on measurements, reducing deviation by obtaining the average of multiple readings, and creating a standardized protocol for consistent measurements (Fullerton et al., 1996). Spectrophotometric instruments confer a high degree of accuracy and can measure absolute colors. As the cost of spectrophotometric instruments decreases and their portability improves, the spectrophotometer is now increasingly more applicable in clinical practice. Commonly used spectrophotometers are

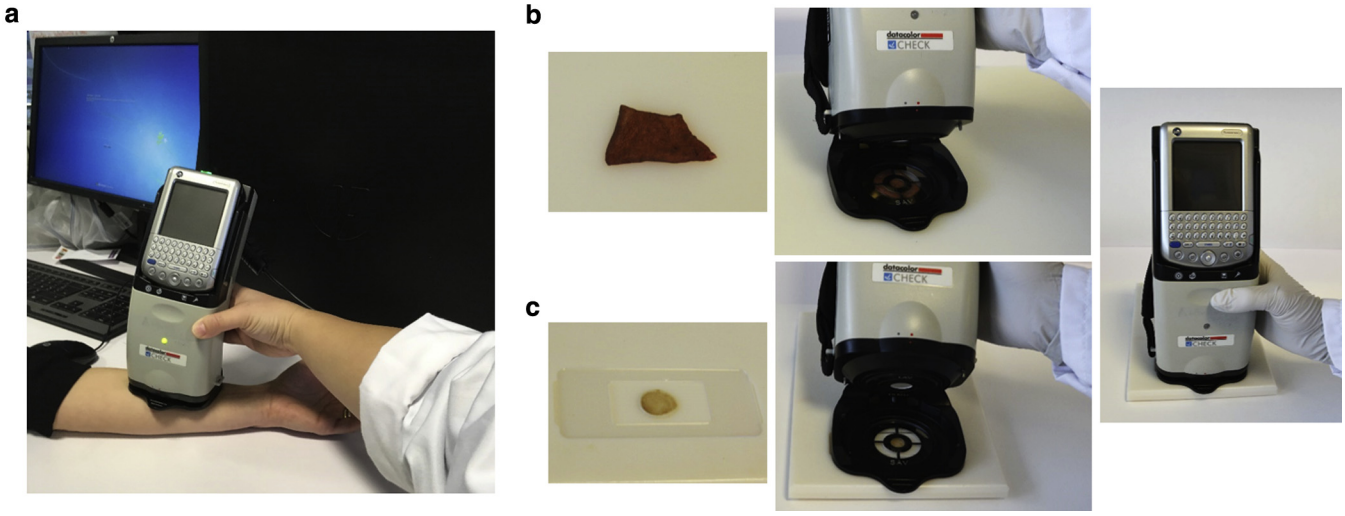

Figure 6. Usage recommendation for spectrophotometer. (**a**) The spectrophotometer is pressed with moderate pressure perpendicular to the skin surface. Similar set-up and measurement requirements discussed for the colorimeter are applied to the spectrophotometer, including calibration with reference color, obtainment of measurements in a suitable environment, and maintaining the same settings to produce accurate and objective measurements. (**b**) Spectrophotometer can be used to measure ex vivo skin or (**c**) in vitro reconstructed skin. The stapler foot of the spectrophotometer can be opened to correctly position the device onto the sample or skin area. The device demonstrated in this picture is the Check Spectrophotometer (Datacolor).

Table 1. Colorimeter and Spectrophotometer Applications Found in the Literature

Articles	Condition Studied	Device	Population
Weatherall and Coombs, 1992	Skin color measurement	Spectrophotometer	Europeans, Chinese, Indian, Polynesian, and mixed origin
Del Bino and Bernerd, 2013	Skin color measurement, ITA, UVR responses in ex vivo skin	Spectrophotometer	African descent, Asian, Caucasian, and Hispanic; adults (US, France, Russia, Brazil, China, Japan, India, Thailand)
Alaluf et al., 2002	Epidermal melanin impact on human skin color	Chromameter	European, Chinese, Mexican, Indian, and Black (South Africa)
Chardon et al., 1991	Skin color measurement, ITA, and tanning	Spectrophotometer	Caucasian (France)
Chien et al., 2016	Pigmentation in aging	Chromameter	Caucasian, African-American (USA)
Wright et al., 2015b	Skin color measurement, ITA, and erythema sensitivity	Colorimeter	Black, Indian or Asian, White, mixed origin (South Africa)
Park et al., 2002	Skin color measurement, ITA, skin color changes after UVB and UVA	Spectrophotometer	Asian (Korea)
Wright et al., 2015a	Skin color measurement and ITA	Spectrophotometer Munsell color chart	Children (New Zealand)
Everett et al., 2012	Skin color measurement	Spectrophotometer	Asian, Black or African-American, White, Biracial (USA) Asian, Black or African-American, White, mixed origin (USA)
Nam et al., 2015	Skin brightness measurement	Spectrophotometer	Asian, adults (Korea)
Xiao et al., 2017	Variation in skin color measurement	Spectrophotometer	Caucasian, Chinese, Kurdish, Thai (United Kingdom)
Clarys et al., 2000	Skin color measurement	Chromameter, DermaSpectrometer, Mexameter	Adults (Belgium)
Stamatas et al., 2008	In vivo skin erythema and pigmentation	Spectrophotometer	African-American, Asian, Hispanic or Latino, Hawaiians or other Pacific Islanders, White
Eilers et al., 2013	Evaluating the accuracy of self-report and dermatologist-determined FST	Spectrophotometer	Non-Hispanic white, Hispanic or Latino, black, or Asian or Pacific Islander (USA)
Cust et al., 2015	Skin pigmentation and nevus phenotype measurement	Spectrophotometer	Adults (Australia)
Perkins et al., 2011	Acne	Chromameter	African-American, Asian, Caucasian, Hispanic, and Indian (USA)
Scafide et al., 2013	Changes in bruise	Chromameter	Adults
Mimasaka et al., 2010	Bruise patterns and changes	Spectrophotometer	Pediatrics (Japan)
Al-Zobidi et al., 2015	Periocular skin hyperpigmentation measurement related to prostaglandin analogue use	Chromameter	Pediatrics with glaucoma (USA)
Choi et al., 2009	Determine parameters of cutaneous narrow-band UVB phototherapy for psoriasis and vitiligo	Spectrophotometer	Asian FST III–IV (Korea)
Kim et al., 2012	Psoriasis severity evaluation	Chromameter	Asian (Korea)
Oliveira et al., 2005	Scar formation after burn measurement	Dermaspectrometer and Chromameter	Skin type I–VI (USA)
Draaijers et al., 2004	Reliability of observer's assessment of scar color compared object measurements	Dermaspectrometer and Chromameter	(Netherlands)
van der Wal et al., 2013	Scar tissue	Mexameter, Colorimeter, and the DSM II ColorMeter	Pediatric and adult patients with scar (Netherlands)
Pershing et al., 1995	Psoriatic and nonlesional skin measurement	Chromameter	Adults (USA)
Ahmad Fadzil et al., 2009	Psoriasis erythema for PASI scoring	Chromameter, DermaSpectrometer	Low to highly pigmented skin adults with psoriasis (Malaysia)
Devpura et al., 2011	Acanthosis nigricans	Chromameter and spectrophotometer	Adults (USA)
Healy et al., 2009	Erythema response quantification and evaluation of protectors such as sulforaphane	Chromameter	Caucasian FST I–III, (USA)
Kimbrough-Green et al., 1994	Evaluation of efficacy of tretinoin therapy for melasma	Chromameter	African-American adults (USA)
Huixia et al., 2012	Skin tone, pigmentation measurements, ITA, and changes induced by whitening products	Chromasphere	Asian (China)

(*continued*)

Table 1. Continued

Articles	Condition Studied	Device	Population
Hurley et al., 2002	Assessment of efficacy of 4% hydroquinone cream versus 4% hydroquinone cream combined with glycolic acid peels as treatment for melasma	Mexameter	Hispanics of FST IV–V (USA)
Draelos and Raymond, 2018	Efficacy of a ceramide-based cream in atopic dermatitis and other xerotic or pruritic dermatoses	Colorimeter	African-American and Caucasian (USA)
De Rigal et al., 2007	Evaluation of efficacy of skin care products	Chromasphere	African, Asian, Caucasian; adults (France)
Maroñas et al., 2014	Development of a forensic skin color predictive test centered on the most strongly associated single nucleotide polymorphisms	Colorimeter and spectrophotometer	Skin color of various ethnicity
Paravina et al., 2009	Determine perceptibility and acceptability thresholds for color differences in maxillofacial elastomer	Spectrophotometer	Light-colored specimens (mimicking White, Asian, and Hispanics) and darker-colored specimens (mimicking African-American skin) (USA)
Ngo et al., 2006	Determine the optimal color match of free flap donor sites to facial tissue transplant	Chromameter	African-American, Caucasian, Asian (Canada)
Partl et al., 2017	Radiation-induced dermatitis	Spectrophotometer	Caucasian, adults (Austria)
Hayashi et al., 2018	Vitiligo and leukoderma severity	Spectrophotometer	Asian (Japan)

Abbreviations: FST, Fitzpatrick skin type; ITA, individual typology angle; PASI, psoriasis area severity index.

CM508i or CM 2002 (Minolta, Osaka, Japan) and Check and Mercury (Datacolor, Monteuil, France) (Figure 6). Other devices include the Chromasphere (Chromasphere, Paris, France), a diffuse daylight lightning device coupled to a spectroradiometer that can be used to evaluate skin color even on uneven surfaces such as the forehead and cheek (Baras and Caisey, 2016).

Narrow-band reflectance spectrophotometers such as Mexameter (Courage-Khazaka) and dermatospectrometer (Cortex Technology, Hadsund, Denmark) use red and green light-emitting diodes and do not measure chromatic values but can be used to measure erythema and melanin indices (Clarys et al., 2000). DSM II ColorMeter (Cortex Technology) is a handheld device that can assess skin in both narrow-band spectrophotometry and tristimulus colorimetric measurements (van der Wal et al., 2013).

COLORIMETRY AND DERMATOLOGY

Colorimetric devices have many clinical applications (Table 1) through the quantification of skin color via L* a* b* and ITA° values (Table 2). In regards to skin color assessment, the colorimeter and spectrophotometer can be used to evaluate the skin type of subjects of various geographic origins (Del Bino and Bernerd, 2013; Eilers et al., 2013; Seitz and Whitmore, 1988). In addition, the colorimetric devices are more reliable than subjective visual grading in assessment of cutaneous color changes. They enable greater accuracy in the determination of the minimal erythema dose (Heckman et al., 2013; Seitz and Whitmore, 1988). They can detect erythematous and tanning responses of the skin that are below visual threshold and even in the presence of heavy pigmentation (Seitz and Whitmore, 1988; Stamatas et al., 2008). Colorimeters have also been used to assess bruises, scarring, and efficacy of treatment in atopic dermatitis and melasma in darker-skinned patients (Draelos and Raymond, 2018; Kimbrough-Green et al., 1994; Oliveira et al., 2005; Scafide et al., 2013).

In clinical care, these noninvasive devices can provide easy and accurate methods of characterizing lesional from nonlesional skin in patients with psoriasis, vitiligo, or acanthosis nigricans (Choi et al., 2009; Devpura et al., 2011; Pershing et al., 1995). Additionally, current translational and basic science research uses them to evaluate efficacy of pharmacological compounds and pigmentation changes from skin lightening products (Healy et al., 2009; Kimbrough-Green et al., 1994; Nam et al., 2015). Moreover, colorimetric devices have been useful in the field of forensic

Table 2. Examples of Mean L*, a*, and b* Values for the Six Groups of Skin Color

		Mean values ± SEM		
Skin color type	ITA°	L*	a*	b*
Very light	>55	74.5 ± 1.5	3.7 ± 0.5	14.5 ± 0.7
Light	55–41	68.8 ± 0.5	7.0 ± 0.6	17.4 ± 0.5
Intermediate	41–28	63.3 ± 0.4	7.4 ± 0.5	18.7 ± 0.5
Tan	28–10	57.5 ± 0.3	10.1 ± 6.0	20.2 ± 0.5
Brown	10 to −30	47.0 ± 0.9	10.4 ± 0.5	18.3 ± 0.6
Dark	< −30	35.5 ± 0.7	8.8 ± 0.4	11.6 ± 0.6

Abbreviations: CIE, Commission Internationale de l'Eclairage; ITA°, individual typology angle; SCI, specular component included; SEM, standard error of the mean.

CIE L*, a*, and b* values were measured for 135 photoprotected skin samples with variable pigmentation. The L*, a*, and b* values were classified into six skin color groups according to their ITA°. L*a*b* parameters were measured with a spectrophotometer (Datacolor Check) using D65, 10°, SCI, d/8° (Del Bino and Bernerd, 2013, and personal communication).

science in characterizing patterns and extent of cutaneous bruises and profiling skin pigmentation of unidentified body parts, color matching of donor skin flap in facial surgeries, and assessment of radiation-induced dermatitis in breast cancer patients (Maroñas et al., 2014; Mimasaka et al., 2010; Ngo et al., 2006; Partl et al., 2017; Scafide et al., 2013).

Advantages and limitations of colorimetry

Colorimeters and spectrophotometers provide objective and reproducible measurements of the skin and minimize biases and inaccurate reporting that arise in using FST classification. Colorimeters can also better detect cutaneous color changes in dark-pigmented skin that are overlooked by visual assessment (Ahmad Fadzil et al., 2009; Chien et al., 2016; Scafide et al., 2013). This is especially important in the dermatologic care of darker-skin patients as certain conditions, such as skin tumors and inflammation, can present atypically or at an advanced stage on diagnosis (Bradford, 2009; Mei-Yen and Tay, 2017).

Though tristimulus colorimeters and spectrophotometers have broad applications, tristimulus colorimetric devices are limited in their ability to differentiate metameric colors, which are colors with identical perceived appearance but different spectral features. In addition, basic set-up requirements must be fulfilled to be able to compare values obtained with different colorimetric and spectrophotometric instruments. Adjustments include illuminants, standard observer, measurement system, specular component, and measuring geometry. Authors using these devices in their studies should be encouraged to communicate the specifications used.

SUMMARY

Colorimetry is a valuable standardized tool used for skin color measurement. The CIELAB or CIE L* a* b* is the most commonly used color space system. In the setting of dermatology, L* measures skin pigmentation, a* measures erythema, and b* measures tanning ability. L* and b* parameters can be used for constitutive pigmentation classification according to the ITA°. Because of their portability and standardization, colorimeters and spectrophotometers will continue to be critical tools in clinical and research. Furthermore, their ability to assess constitutive pigmentation and adaptability across skin types will provide additional valuable information regarding the increasingly diverse patients seen in dermatology clinics.

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CONFLICT OF INTEREST

Sandra Del Bino is a full time employee of a L'Oréal, which played no role in this study.

AUTHOR CONTRIBUTIONS

Conceptualization: BCKL, EBD, JLF, SDB; Investigation: BCKL; Supervision: JLF, SDB; Validation: ALC, SDB; Visualization: BCKL; Writing - Original Draft Preparation: BCKL; Writing - Review and Editing: BCKL, EBD, JLF, ALC, SDB

MULTIPLE CHOICE QUESTIONS

1. The cones in human eyes have high sensitivity at three light wavelengths. What are the corresponding colors of the wavelengths?
   A. Red, orange, Blue
   B. Yellow, magenta, cyan
   C. Red, blue, green
   D. White, blue, red

2. What does each of the L*a*b* values represent in skin measurement?
   A. L* = skin darkness/lightness; a* = jaundice; b* = cyanosis
   B. L* = skin darkness/lightness; a* = erythema; b* = tanning
   C. L* = skin color, a* = UV exposure, b* = non-UV exposure
   D. L* = cutaneous blood flow, a* = pinkness of skin, b* = skin damage

3. Which of the following Illuminant is commonly used in colorimeters and spectrophotometers?
   A. Standard Illuminant D65, which corresponds to clear sky in Western Europe without the ultraviolet wavelengths
   B. Standard Illuminant D65, which corresponds to average midday light in Western Europe with the ultraviolet wavelengths
   C. Standard Illuminant corresponding to incandescent light
   D. Standard Illuminant corresponding to windowless room

4. Which of the following pertains to individual typology angle (ITA)?
   A. It classifies skin colors into six groups, from very light to dark skin.
   B. ITA can be calculated from the L* and b* values and can be constructed from the skin color volume.
   C. The intersecting axis represents the color attributes, such as hue and luminance.
   D. Both A and B are correct.

5. What is one limitation of the colorimeter?
   A. It emits white light.
   B. It is inferior to the spectrophotometer in every aspect.
   C. It provides easier color visualization and communication.
   D. It does not measure the color's spectral characteristics.

SUPPLEMENTARY MATERIAL

Supplementary material is linked to this paper. Teaching slides are available as supplementary material.

REFERENCES

Ahmad Fadzil MH, Ihtatho D, Mohd Affandi A, Hussein SH. Objective assessment of psoriasis erythema for PASI scoring. J Med Eng Technol 2009;33:516–24.

Alaluf S, Atkins D, Barrett K, Blount M, Carter N, Heath A. The impact of epidermal melanin on objective measurements of human skin colour. Pigment Cell Res 2002;15:119–26.

Al-Zobidi M, Khandekar R, Craven ER, Hanafi S, Edward DP. Periocular skin hyperpigmentation in children treated with prostaglandin analogues. J AAPOS 2015;19:49–53.

Andreassi L, Flori L. Practical applications of cutaneous colorimetry. Clin Dermatol 1995;13:369–73.

Baras D, Caisey L. Skin and lip typology. In: Kelly AP, Taylor SC, Lim HW, Serrano AMA, editors. Taylor and Kelly's dermatology for Skin of Color, 2e. 2nd ed. New York, NY: McGraw-Hill Education; 2016. p. 557–64.

Bloj M, Hedrich M. Color perception. In: Chen J, Cranton W, Fihn M, editors. Handbook of Visual Display Technology. Berlin, Germany: Springer; 2012. p. 171–8.

Bradford PT. Skin cancer in skin of color. Dermatol Nurs 2009;21:170–7 [quiz 178].

Brainard DH, Stockman A. Colorimetry. In the OSA handbook of optics. 3rd ed. New York: McGraw-Hill; 2010.

Chardon A, Cretois I, Hourseau C. Skin colour typology and suntanning pathways. Int J Cosmet Sci 1991;13:191–208.

Chien AL, Suh J, Cesar SSA, Fischer AH, Cheng N, Poon F, et al. Pigmentation in African American skin decreases with skin aging. J Am Acad Dermatol 2016;75:782–7.

Choi KW, Kim KH, Kim YH. Comparative study of the gross interpretation of phototesting and objective measurement with using a spectrophotometer for patients with psoriasis and vitiligo treated with narrow-band UVB. Ann Dermatol 2009;21:136–41.

Clarys P, Alewaeters K, Lambrecht R, Barel AO. Skin color measurements: comparison between three instruments: the Chromameter®, the DermaSpectrometer® and the Mexameter®. Skin Res Technol 2000;6: 230–8.

Cust AE, Pickles KM, Goumas C, Vu T, Schmid H, Nagore E, et al. Accuracy of self-reported nevus and pigmentation phenotype compared with clinical assessment in a population-based study of young Australian adults. Cancer Epidemiol Biomarkers Prev 2015;24:736–43.

De Rigal J, Abella ML, Giron F, Caisey L, Lefebvre MA. Development and validation of a new Skin Color Chart®. Skin Res Technol 2007;13:101–9.

Del Bino S, Bernerd F. Variations in skin colour and the biological consequences of ultraviolet radiation exposure. Br J Dermatol 2013;169(Suppl. 3):33–40.

Del Bino S, Ito S, Sok J, Nakanishi Y, Bastien P, Wakamatsu K, et al. Chemical analysis of constitutive pigmentation of human epidermis reveals constant eumelanin to pheomelanin ratio. Pigment Cell Melanoma Res 2015;28:707–17.

Devpura S, Pattamadilok B, Syed ZU, Vemulapalli P, Henderson M, Rehse SJ, et al. Critical comparison of diffuse reflectance spectroscopy and colorimetry as dermatological diagnostic tools for acanthosis nigricans: a chemometric approach. Biomed Opt Express 2011;2:1664–73.

Diffey BL. Towards optimal regimens for the UVB phototherapy of psoriasis: a mathematical model. Acta Derm Venereol 2004;84:259–64.

Draaijers LJ, Tempelman FRH, Botman YAM, Kreis RW, Middelkoop E, van Zuijlen PPM. Colour evaluation in scars: tristimulus colorimeter, narrow-band simple reflectance meter or subjective evaluation? Burns 2004;30: 103–7.

Draelos ZD, Raymond I. The Efficacy of a ceramide-based Cream in Mild-to-moderate Atopic Dermatitis. J Clin Aesthet Dermatol 2018;11:30–2.

Eilers S, Bach DQ, Gaber R, Blatt H, Guevara Y, Nitsche K, et al. Accuracy of self-report in assessing Fitzpatrick skin phototypes I through VI. JAMA Dermatol 2013;149:1289–94.

Everett JS, Budescu M, Sommers MS. Making sense of skin color in clinical care. Clin Nurs Res 2012;21:495–516.

Fitzpatrick TB. The validity and practicality of sun-reactive skin Types I Through VI. Arch Dermatol 1988;124:869–71.

Fullerton A, Fischer T, Lahti A, Wilhelm KP, Takiwaki H, Serup J. Guidelines for measurement skin colour and erythema A report from the Standardization Group of the European Society of Contact Dermatitis. Contact Dermatitis 1996;35:1–10.

Hayashi M, Okamura K, Araki Y, Suzuki M, Tanaka T, Abe Y, et al. Spectrophotometer is useful for assessing vitiligo and chemical leukoderma severity by quantifying color difference with surrounding normally pigmented skin. Skin Res Technol 2018;24:175–9.

Healy ZR, Dinkova-Kostova AT, Wehage SL, Thompson RE, Fahey JW, Talalay P. Precise determination of the erythema response of human skin to ultraviolet radiation and quantification of effects of protectors. Photodermatol Photoimmunol Photomed 2009;25:45–50.

Heckman CJ, Chandler R, Kloss JD, Benson A, Rooney D, Munshi T, et al. Minimal erythema dose (MED) testing. J Vis Exp 2013;75:e50175.

Huixia Q, Xiaohui L, Chengda Y, Yanlu Z, Senee J, Laurent A, et al. Instrumental and clinical studies of the facial skin tone and pigmentation of Shanghaiese women. Changes induced by age and a cosmetic whitening product. Int J Cosmet Sci 2012;34:49–54.

Hurley ME, Guevara IL, Gonzales RM, Pandya AG. Efficacy of glycolic acid peels in the treatment of melasma. Arch Dermatol 2002;138:1578–82.

Kim JH, Kim BY, Choi JW, Kim SO, Lee HS, Park KC, et al. The objective evaluation of the severity of psoriatic scales with desquamation collecting tapes and image analysis. Skin Res Technol 2012;18:143–50.

Kimbrough-Green CK, Griffiths CEM, Finkel LJ, Hamilton TA, Bulengo-Ransby SM, Ellis CN, et al. Topical retinoic acid (tretinoin) for melasma in black patients: A vehicle-controlled clinical trial. Arch Dermatol 1994;130:727–33.

Maroñas O, Phillips C, Söchtig J, Gomez-Tato A, Cruz R, Alvarez-Dios J, et al. Development of a forensic skin colour predictive test. Forensic Sci Int Genet 2014;13:34–44.

Mei-Yen YA, Tay YK. Atopic dermatitis: racial and ethnic differences. Dermatologic Clin 2017;353:395–402.

Mimasaka S, Ohtani M, Kuroda N, Tsunenari S. Spectrophotometric evaluation of the age of bruises in children: measuring changes in bruise color as an indicator of child physical abuse. Tohoku J Exp Med 2010;220:171–5.

Nam GW, Baek JH, Koh JS, Hwang JK. The seasonal variation in skin hydration, sebum, scaliness, brightness and elasticity in Korean females. Skin Res Technol 2015;21:1–8.

Ngo K, Goldstein D, Neligan P, Gilbert R. Colorimetric evaluation of facial skin and free flap donor sites in various ethnic populations. J Otolaryngol 2006;35:249–54.

Ohta N, Robertson A. Colorimetry: fundamentals and applications. Chichester, United Kingdom: John Wiley & Sons; 2006.

Oliveira GV, Chinkes D, Mitchell C, Oliveras G, Hawkins HK, Herndon DN. Objective assessment of burn scar vascularity, erythema, pliability, thickness, and planimetry. Dermatol Surg 2005;31:48–58.

Paravina RD, Majkic G, Del Mar Perez M, Kiat-amnuay S. Color difference thresholds of maxillofacial skin replications. J Prosthodont 2009;18: 618–25.

Park SB, Huh CH, Choe YB, Youn JI. Time course of ultraviolet-induced skin reactions evaluated by two different reflectance spectrophotometers: DermaSpectrophotometer® and Minolta spectrophotometer CM-2002®. Photodermatol Photoimmunol Photomed 2002;18:23–8.

Partl R, Jonko B, Schnidar S, Schöllhammer M, Bauer M, Singh S, et al. 128 SHADES of RED: objective remote assessment of radiation dermatitis by augmented digital skin imaging. Stud Health Technol Inform 2017;236: 363–74.

Perkins AC, Cheng CE, Hillebrand GG, Miyamoto K, Kimball AB. Comparison of the epidemiology of acne vulgaris among Caucasian, Asian, Continental Indian and African American women. J Eur Acad Dermatol Venereol 2011;25:1054–60.

Pershing LK, Bakhtian S, Wright ED, Rallis TM. Differentiation of involved and uninvolved psoriatic skin from healthy skin using noninvasive visual, colorimeter and evaporimeter methods. Skin Res Technol 1995;1:140–4.

Pichon LC, Landrine H, Corral I, Hao Y, Mayer JA, Hoerster KD. Measuring skin cancer risk in African Americans: is the Fitzpatrick Skin Type Classification Scale culturally sensitive? Ethn Dis 2010;20:174–9.

Randall D, Charlotte N. Instruments for the measurement of color. Color technology in the textile industry. 2nd ed. AATCC; 1997. p. 9–17.

Scafide KR, Sheridan DJ, Campbell J, DeLeon VB, Hayat MJ. Evaluating change in bruise colorimetry and the effect of subject characteristics over time. Forensic Sci Med Pathol 2013;9:367–76.

Seitz JC, Whitmore CG. Measurement of erythema and tanning responses in human skin using a tri-stimulus colorimeter. Dermatologica 1988;177: 70–5.

Stamatas GN, Zmudzka BZ, Kollias N, Beer JZ. In vivo measurement of skin erythema and pigmentation: new means of implementation of diffuse reflectance spectroscopy with a commercial instrument. Br J Dermatol 2008;159:683–90.

van der Wal M, Bloemen M, Verhaegen P, Tuinebreijer W, de Vet H, van Zuijlen P, et al. Objective color measurements: clinimetric performance of three devices on normal skin and scar tissue. J Burn Care Res 2013;34: e187–94.

Weatherall IL, Coombs BD. Skin color measurements in terms of CIELAB color space values. J Invest Dermatol 1992;99:468–73.

Wright CY, Reeder AI, Gray AR, Hammond VA. Comparison of Munsell((R)) color chart assessments with primary schoolchildren's self-reported skin color. Skin research and technology. Skin Res Technol 2015a;21:459–65.

Wright CY, Wilkes M, du Plessis JL, Reeder AI. Self-reported skin colour and erythemal sensitivity vs. objectively measured constitutive skin colour in an African population with predominantly dark skin. Photodermatol Photoimmunol Photomed 2015b;31:315–24.

Xiao K, Yates JM, Zardawi F, Sueeprasan S, Liao N, Gill L, et al. Characterising the variations in ethnic skin colours: a new calibrated data base for human skin. Skin Res Technol 2017;23:21–9.

Youn JI, Park JY, Jo SJ, Rim JH, Choe YB. Assessment of the usefulness of skin phototype and skin color as the parameter of cutaneous narrow band UVB sensitivity in psoriasis patients. Photodermatol Photoimmunol Photomed 2003;19:261–4.

DETAILED ANSWERS

1. **The cones in human eyes have high sensitivity at three light wavelengths. What are the corresponding colors of the wavelengths?**

Answer: C. Red, blue, green

The short, medium, and long cones have selective sensitivity to light wavelengths that correlate with blue (450 nm), green (550 nm), and red (610 nm), respectively.

2. **What does each of the L*a*b* values represent in skin measurement?**

Answer: B. L* = skin darkness/lightness; a* = erythema; b* = tanning

The L* values determine the lightness and darkness of a color and correlate well with the lightness and darkness of skin color. The a* value measures cutaneous erythema and is impacted by melanin composition and cutaneous blood flow. The b* value reveals the individual's constitutional pigmentation and ability to tan, specifically, the change in carotenoids, melanin synthesis, and oxidation after UV exposure.

3. **Which of the following illuminants is commonly used in colorimeters and spectrophotometers?**

Answer: B. Standard Illuminant D65, which corresponds to average midday light in Western Europe with the ultraviolet wavelengths

The Standard Illuminant D65 corresponds to average midday light from a clear sky in Western Europe. This illuminant setting also includes ultraviolet wavelengths. The same standard illuminant must be used to compare values obtained with different colorimetric instruments.

4. **Which of the following pertains to individual typology angle (ITA)?**

Answer: D. Both A and B are correct.

The ITA is defined as

$$ITA^{\circ} = \left[\frac{\arctan(L^* - 50)}{b^*}\right] \times \frac{180}{3.14159}.$$

ITA allows reliable categorization of skin color of ethnic groups from different geographical areas.

5. **What is one limitation of the colorimeter?**

Answer: D. It does not measure the color's spectral characteristics.

The colorimeter measures color with consideration of an average person's color perception, rather than the color's unique properties. Similar to color perception, the color measurements acquired by colorimeters can be altered by environmental conditions, such as the lighting. Spectral characteristics, captured by a spectrophotometer, are innate to the color and therefore are not easily modified by the external environment.