ORIGINAL RESEARCH ARTICLE

Digital dermoscopy to determine skin melanin index as an objective indicator of skin pigmentation

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Abstract: Clinical assessment of skin photosensitivity is subjectively determined by erythema and tanning responses to sunlight recalled by the subject, alternatively known as Fitzpatrick Skin Phototype (SPT). Responses may be unreliable due to recall bias, subjective bias by clinicians and subjects, and lack of cultural sensitivity of the questions. Analysis of red-green-blue (RGB) color spacing of digital images may provide an objective determination of SPT. This paper presents the studies to assess the melanin index (MI), as determined by RGB images obtained by both standard digital camera as well as by videodermoscope, and to correlate the MI with SPT based upon subjects' verbal responses to standardized questions administered by a dermatologist.

A sample of subjects representing all SPTs I–VI was selected. Both the digital camera and videodermoscope were calibrated at standard illumination, light source and white balance. Images of constitutive skin of the upper ventral arm were taken of each subject using both instruments. The studies showed that 58 subjects (20 M, 38 F) were enrolled in the study (mean age: 47 yrs; range: 20–89), stratified to skin phototype I–VI. MI obtained by using both digital camera and videodermoscope increased significantly as the SPT increased ($p = 0.004$ and $p < 0.0001$, respectively) and positively correlated with dermatologist-assessed SPT (Spearman correlation, r = 0.48 and r = 0.84, respectively). Digital imaging can quantify melanin content in order to quantitatively approximate skin pigmentation in all skin phototypes including Type VI skin. This methodology holds promise as a simple, non-invasive, rapid and objective approach to reliably determine skin phototype and, with further investigation, may prove to be both practical and useful in the prediction of skin cancer risk.

Keywords: Melanin Index; Fitzpatrick Skin Phototype; digital imaging

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Introduction

For several decades, clinical assessment of photosensitivity has been based on the SPT[1]. As originally designed, the standardized questions about the ease of burning and tanning reactions to the first sun exposure in the summer were administered by trained personnel, especially those in dermatology, and the clinicians determined the SPT-based on the patient's responses[1]. Over the years, the standardized questions were used in written surveys. By relying on patient's memory of sun burning and tanning, recall bias may be introduced. Furthermore, clinicians have evolved to visually assess the SPT without asking the patient to recall their skin reaction to ultraviolet light (UVL). Subjective assessment of SPT by clinicians was heavily influenced by patients' hair and eye color[2]. Since SPT was correlated with susceptibility to developing skin cancer, errors in determining the subject's SPT contribute to misunderstanding of their susceptibility to skin cancer and need for sun protection.

Various *in vitro* and *in vivo* methods to quantify skin pigmentation have been proposed and evaluated to avoid subjective bias in SPT but none have successfully differentiated all six phototypes[2]. Over the last decade, non-invasive instrumentation has been utilized to assess pigmentation *in vivo* including spectrophotometry[3], colorimetry[4], skin color scale chart[5], fiber optic sensor[6] and digital imaging with RGB color space analysis[7,8]. While several studies reported the use of colorimetry[4,9] and spectrophotometry[10] to assess SPT, Pershing *et al.* used spectrophotometry to objectively determine all six SPTs using only constitutive skin color independent of UVL-induced erythema[2]. The "gold standard" method of assessing skin pigmentation is spectrophotometry; however, it is difficult to perform spectrophotometry under clinical conditions.

Although skin pigmentation is not the only factor that plays a role in protection against sunburn[11], it remains an important risk factor for skin cancer development. It has been reported that the low incidence of cutaneous malignancies in darker skinned groups is primarily a result of photoprotection contributed by increased epidermal melanin, which provides an inherent sun protection factor (SPF) of up to 13.4 in African American individuals[12]. Thus, a clinically feasible and objective assessment of skin pigmentation remains an unmet need[4].

The aim of this study was to assess SPT utilizing MI as determined by RGB images obtained both by digital camera and high resolution, high magnification videodermoscope.

Materials and methods

This single-center observational study assessed MI obtained from RGB digital images in adult male and female subjects with Fitzpatrick Skin Phototypes I–VI[13]. A sample of subjects, representing all SPTs and attended Northwestern University's Department of Dermatology, participated in the study. The sample consisted of subjects attending our large urban academic center (Chicago) during study enrollment. However, data on previous lifestyle and/or prior living in other geographic regions of the US and/or the world are unknown, and are therefore a limitation to this study and to the utility of SPT designations in general. The study was approved by the Northwestern University Institutional Review Board, and all participants provided written informed consent prior to participation.

Exclusion criteria were history of vitiligo, use of self-tanning products or tanning accelerators in the six weeks prior to enrollment, and recent history of prolonged sun exposure or indoor tanning. Inclusion criteria were being between age 18 to 70, and able to read in English. A dermatologist administered the following questions: a) If after several months of not being in the sun, you stayed outdoors for about one hour at noon for the first time in the summer without sunscreen, what would happen to your skin?–Always sunburn, u ually burn, burn minimally, burn rarely, or never sunburn; b) Over the next seven days, would you develop a tan? –Never tan, tan lightly, tan moderately, or tan deeply. SPTs are assigned based upon the subjects' responses (**Table 1**). Subjects also self-reported age, gender, and ethnic background by completing an anonymous written survey.

Table 1. Fitzpatrick Skin Phototype Scale[1]

Fitzpatrick Skin Phototype	Skin Reactions to Sunlight during the First Summer Exposure
I (*N* = 10)	Always burns, never tan (painful burn at 24 hrs and no tan at 7 days)
II (*N* = 13)	Burn easy, then develop light tan (painful burn at 24 hrs and a light tan at 7 days)
III (*N* = 8)	Burn moderately, then develop light tan (slightly tender burn at 24 hrs and moderate tan at 7 days)
IV (*N* = 10)	Burn minimally/rarely, then develop moderate tan (no burn at 24 hrs and a good tan at 7 days)
V (*N* = 10)	No burns, always develops dark tan
VI (*N* = 7)	No burns, no noticeable change in appearance

Assessment of Melanin Index

Two digital systems were used to capture images for analysis: a high resolution digital camera (Nikon D80®, Nikon Inc., USA) and a videodermoscopy system (Kit EasyScan Pico®, Business Enterprise, Trapani, Italy). In order to minimize measurement bias and to ensure standardization of all parameters (distance, focus, source light and white balance), digital camera images were taken with a fixed light source at the same distance for all subjects. The camera was placed in manual mode, and white balance was established for each subject using Standard Kodak Color Palette®. The videodermoscope utilized a fixed light intensity, fixed white balance, as well as fixed brightness and contrast to avoid re-calibration before each subject. Prior to videodermoscopy, antiseptic gel was applied to ensure smooth contact with the skin and to minimize stratum corneum light scattering. Images of the upper ventral arm (constitutive skin), 5 cm above the head of the humerus, were taken. These measurements were assessed for validity against the SPT determined by the dermatologist without adjustment for hair, eye color and presence of freckles.

Images taken with both instruments were stored electronically and processed by ImageJ software[14]. To obtain mean MI values, the formula (1) was used to measure melanin based on reflectance values of the red channel in the RGB image. This formula is equivalent to that used for narrow band spectrophotometers[8,15].

(1) $A_{r,g,b} = 100 \times \text{Log}_{10}(1/R_{r,g,b})$; where A, according to the model of Dawson *et al.*[16], is the absorbance of the skin and R is the reflectance.

If it is assumed that MI can be obtained from the absorbance of the red channel (A_r), then:

(2) $MI = A_r = 100 \times \text{Log}_{10}(1/R_r)$.

Reflectance of the skin is obtained from the ratio between the mean brightness value of the region of interest (ROI) and the white standard in the same ROI, hence:

(3) $R_r = S_r/W_r$

The final formula becomes:

(4) $MI = 100 \times \text{Log}_{10}(1/S_r/W_r) = 100 \times (\text{Log}_{10}1 - \text{Log}_{10}S_r/W_r) = 100 \times (-\text{Log}_{10}S_r/W_r)$.

In order to satisfy the final formula above and to make automated measurements, two of the authors (Di Loro S and Nardone B) created an ImageJ Java plugin where S is the mean brightness of skin in ROI and W is the known (previously measured) mean white brightness in the color palette in the same ROI.

Statistical analysis

Median MI obtained using both digital camera and videodermoscope were compared across SPT categories using the Kruskal-Wallis test. MI was also correlated with SPT using a Spearman correlation coefficient. A p value < 0.05 was considered statistically significant.

Results

Fifty-eight subjects (20 M, 38 F) were enrolled in the study (mean age: 47 yrs; range: 20–89 yrs), with skin types I–VI (I = 10; II = 13; III = 8; IV = 10; V = 10; VI = 7), and various races (36 White, 19 Black, 3 Asian).

MI obtained by both digital camera and videodermoscope increased significantly as the SPT increased (Kruskas-Wallis test, $p = 0.0044$ and $p < 0.0001$, respectively). The MI obtained by the videodermoscope demonstrated a progressive gradient from Fitzpatrick skin type I through VI (**Table 2**). Of note, MI obtained by the digital camera showed an overlap among FSTs III and IV. MI did not correlate with the gender or age of the subject. Also, a statistically positive correlation with the assessed Fitzpatrick SPT was found for both digital camera and videodermoscope (Spearman correlation, r = 0.48 and $p = 0.0001$, r = 0.84 and $p < 0.0001$, respectively).

Patient self-reported burn susceptibility significantly decreased as MI obtained by videodermoscope increased (Kruskal-Wallis test, $p < 0.0001$). No statistical difference was found between MI obtained by videodermoscope and self-reported ability to tan (Kruskal-Wallis test, $p = 0.21$).

Table 2. Melanin Index Obtained From the Digital Camera and Videodermoscope

Fitzpatrick Skin Phototype*	Digital Camera[1]	Videodermoscope[2]
	MI Median (1st, 3rd quartile)	MI Median (1st, 3rd quartile)
I (*N* = 10)	8.80 (6.20, 11.00)	1.85 (0.80, 2.30)
II (*N* = 13)	9.20 (6.40, 11.00)	2.50 (1.80, 3.60)
III (*N* = 8)	10.55 (6.90, 12.85)	3.15 (1.70, 4.25)
IV (*N* = 10)	10.95 (7.70, 13.00)	6.30 (3.00, 12.80)
V (*N* = 10)	12.20 (7.20, 14.50)	33.35 (15.00, 38.00)
VI (*N* = 7)	14.70 (14.20, 20.10)	41.20 (27.30, 45.50)
Kruskal-Wallis test	$p = 0.0044$	$p < 0.0001$

* Determined by dermatologist's (JKR) assessment
[1]Positive Correlation with SPT for Digital Camera (r = 0.48, $p = 0.0001$)
[2]Positive Correlation with SPT for Videodermoscope (r = 0.84, $p < 0.0001$)
Abbreviations: MI = Melanin Index

Discussion

This study demonstrated that MI as determined from RGB images, in concert with high resolution digital photography or high resolution videodermoscopy, is an objective measure of skin pigmentation among all skin types. Moreover, the positive correlation with Fitzpatrick SPT suggests that this method for objective determination of MI provides a quantifiable assessment that may be useful to predict skin cancer risk in people of all skin types.

Over the last three decades, the Fitzpatrick SPT evolved from its original purpose of determining the amount of ultraviolet light (UVL) for treatment of New England psoriasis patients to become an assessment tool for skin cancer risk[17–19]. As part of this evolution, the original four skin types (I–IV), which assessed sun reactivity with standardized questions about the ease of sun burning and tanning reactions to the first exposure in the summer, were modified by adding SPT V and VI to include those with brown and black skin[1]. Our research demonstrated that the modifications to include people with skin of color were neither culturally sensitive nor accurate, as people of color were unable to respond to the questions of sunburn and tanning[20-22]. People with deep pigmentation of the skin did not report turning red or pink but rather experienced "irritation" after sun exposure[20-22]. Another limitation of the six Roman numeral Fitzpatrick SPT integers was the reliance upon a history of sunburn after the first exposure of summer. For those who reside in regions that have sun exposure all year (e.g. Arizona, Florida, California), the sunburning and tanning questions after the first exposure of summer was irrelevant. Lastly, in the 1990s, people began to apply sunscreens to prevent sunburns; thus, those with sun-sensitive skin may never have experienced sunburn and thus were unable to answer the question about ease of burning.

The heterogeneity of those with multi-ethnic backgrounds makes it difficult to assess susceptibility to skin cancer on the basis of skin color, which is predominantly determined by pigments such as hemoglobin, melanin, bilirubin and carotene[23,24,4]. There has been a tendency to group people of similar ethnic group into a single category of SPT, which introduces potential bias into the subjective assessment of SPT by investigators[25-27]. The limitations of Fitzpatrick SPT, especially in people with darker skin[28,29], include recall bias, subjective bias by clinicians and subjects, lack of cultural sensitivity of the questions, and adherence to sun protection recommendations, resulting in children not having experienced prior sunburns. Although skin pigmentation is not the only factor that plays a role in protection against sunburn[11], it

remains an important risk factor for skin cancer development. It has been reported that the low incidence of cutaneous malignancies in darker skinned groups is primarily a result of photoprotection provided by increased epidermal melanin, which provides an inherent sun protection factor (SPF) of up to 13.4 in African American individuals[12]. Nonetheless, the Fitzpatrick SPTs are traditionally associated with skin cancer risk as follows: I, II - high risk; III, IV-moderate risk; and V, VI-very low risk of skin cancer development.

To date, reflectance methods such as spectrophotometry are considered the "gold standard" to determine melanin and hemoglobin content in the skin. Even if such instrumentation resulted in relatively non-confounded measures of melanin content, these instruments are expensive and require highly trained users, frequent calibration, as well as standard ambient room temperatures[30,2]. Such features make it clinically difficult to conduct melanin measurements, especially in pediatrics where prediction of those at risk may enhance sun protection[31]. Our findings are in part consistent with a recent study where a strong correlation between MI and individual typology angle (ITA) values were found, suggesting that either of these methods can be used to assess skin pigmentation depending on the relevance of the measurement outcome of the intended study. Determining skin type is necessary for understanding personal risk of sunburn and, by extension, personal risk of skin cancer[32].

Videodermoscopy is widely applicable, non-invasive, portable and relatively inexpensive. Since dermoscopy is familiar to clinicians, novel technology utilizing videodermascope that allows assessment of SPT is likely to be readily adaptable to practice. While it is difficult to achieve standardization for distance, brightness and identical pose with a digital camera, imaging with videodermoscopy involves a non-invasive, easy-to-use, portable device that provides a high resolution digital image with rapid and easy calibration essential to ensuring color reproducibility. Videodermoscope also provides objective and reproducible measurements to determine MI and to efficiently predict skin response to sunlight. Importantly, under clinical conditions, MI measurements are actually more consistent with a videodermoscope than with a digital camera.

Conclusion

Although these findings warrant further investigation in a larger and more racially diverse subject population in order to validate this methodology, the data suggest that quantification of pigmentation in a digital image holds

promise as a simple, non-invasive, practical and objective approach to more reliably document skin phototypes, particularly for those who are at high risk of developing skin cancer. Software and hardware, with standardization, may undergo development and be adaptable for quantification of change in pigment associated with biological processes such as stimulation of melanogenesis by hormones and UVL.

Conflict of interest

The author declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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