Objective Measurement Device for Melanin Optical Density: Dosimetry for Laser and IPLs in Aesthetic Treatments

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Objective: A methodology and device (Skintel™ Melanin Reader, Palomar Medical Technologies, Inc. Burlington, MA) are described that provide an analytical measurement of cutaneous melanin for laser and IPL dosimetry in aesthetic treatments.

Background: Intense pulsed light (IPL) and laser treatment parameters should be high enough to sufficiently damage target lesions while minimizing collateral damage to surrounding tissue. Fitzpatrick Skin Typing, a common assessment tool for these treatments, does not directly account for the density of melanin, a highly absorbing chromophore typically located in the epidermis. Quantification of skin melanin levels requires accurate accounting of optical scattering in the skin, the influence of environmental factors and measurement artifacts, as well as the interference of other cutaneous chromophores. The Skintel Melanin Reader measures skin diffuse reflectance at three discrete wavelengths to estimate a Melanin Index value, a normalized parameter for epidermal melanin content, using an algorithm based on validated Monte Carlo simulations.

Conclusions: Measurements were performed across a population of individuals with diverse skin color; the results exhibited a trend consistent with skin type and visual color appearance. The measurement procedure is simple and robust with excellent precision and minimizes the effect of competing chromophores such as hemoglobin.

Introduction

Laser and intense pulsed light (IPL) treatments based on selective photothermolysis are widely used to target adnexal structures of the skin, e.g. hair and blood vessels [Refs. 1-5]. The objective of these treatments is to deliver enough light energy to adequately damage the target with minimal injury to the non-targeted, surrounding tissue. However, all therapeutic light must pass through the epidermis which contains a highly absorbing chromophore, melanin. Melanin is derived from melanocytes in the basal layer of the epidermis which produce melanin-shuttling vesicles known as melanosomes. These vesicles are transported to the nucleus of the cell where melanin granules are released. The range in hair and skin color we see can be attributed to the size and density of the granules and relative proportions of the two different melanin pigments: eumelanin and pheomelanin. Perceived skin color is also influenced by the presence of hemoglobin [Ref. 6]. The higher density of melanin in darker skin types affords more protection from ultraviolet light yet also makes such skin types more susceptible to injury by light energy in the visible and near-infrared spectrum. Assessment of skin reaction to treatment parameters often requires multiple test spot visits, especially in challenging skin types. Concern for skin injury also leads to conservative treatment settings resulting in less than optimal treatment. An accurate measurement of melanin index could save time and effort and provide greater confidence in the selection of treatment settings.

The Fitzpatrick Skin Type (FST) classification scale (Table 1) is often referenced in discussions of proper laser and IPL dosimetry but its use is limited by the fact that it was not specifically designed to measure melanin density of the skin [Ref. 7]. Dr. Fitzpatrick introduced the concept of skin types in order to estimate exposure for phototherapy with ultraviolet (UV) light where higher fluences are more appropriate for darker skin types. Exactly the opposite is true for treatment with the visible and near-infrared spectrum. Sensitivity to UV also depends on metabolic factors, which influence FST but have little or no effect on sensitivity to treatment with the visible and near-infrared spectrum. Furthermore, there is a wide range of individual pigmentation within each level of FST, especially within FST VI.

Table 1. Fitzpatrick Skin Types (FST)

FST	Skin Phototype
I	Highly sun-sensitive, always burn, never tans.
II	Very sun-sensitive, burns easily, tans minimally.
III	Sun-sensitive skin, sometimes burns, slowly tans to light brown
IV	Minimally sun-sensitive, burns minimally, always tans to moderate brown.
V	Sun insensitive skin, rarely burns, tans well.
VI	Sun insensitive skin, never burns, deeply pigmented.

In contrast, direct quantitative measurement of epidermal melanin may be useful as a guide in treatment dosimetry. In fact, skin reflectance at red wavelengths to measure skin pigmentation, and at a combination of red and green wavelengths to measure skin erythema have been used for this purpose since the mid-20th century. Within the 630 to 900 nm (red, near-infrared) spectral range, epidermal melanin is the most significant cutaneous chromophore.

A quantity most appropriate for measuring epidermal melanin is melanin optical density (MOD), an optical term that quantifies how much optical energy is absorbed by melanin. This quantity accounts for the density of the melanin, its distribution in the skin, and its variation in absorption across different wavelengths of light. Historically, it has been difficult to measure melanin optical density in skin. Various arbitrary scales have been used as approximations but don't accurately discern between the different sources of color [Refs. 8-10]. Specifically, there are at least two different categories of measurement; diffuse reflectance and autofluorescence. Four different type of devices have been employed for these approaches: 1) spectrophotometers that measure skin diffuse reflectance spectra over a wide, continuous range of wavelengths; 2) spectrofluorimeters that use skin autofluorescence also over a wide range of wavelengths; 3) chromometers that measure skin reflection in suitable spectral bands (blue, green and red); and 4) specialized instruments that measure diffuse reflectance at several specific wavelengths. Of these, the first two involve equipment that is prohibitively expensive and bulky for clinical use and the third, chromometers, lack appropriate resolution and are incapable of discerning, for example, between hemoglobin and melanin absorption. The fourth, specialized instrument, offers the most practical approach.

The primary challenge in the measurement of skin melanin optical density is to account for the effects of optical scattering in the skin. Many devices exist that can accurately measure a chromophore's concentration in a non-scattering medium, e.g., the various hemoglobin concentrations in lysed blood in the field of cooximetry. First, the chromophore's absorption spectrum must be known. Second, a simple mathematical formula called Beer's law is used to relate the absorption by a chromophore at specified wavelengths to a concentration of that chromophore. When scattering is also present in a sample, such as skin, Beer's law is no longer applicable. Various approximations to Beer's Law or to the radiative transfer theory have been tried for this purpose, but the accuracy of these models is highly sensitive to the geometry of the instrument and to the variations in skin structure thus making application to a wide range of skin types difficult.

Two principal features set the Palomar Skintel Melanin Reader apart from other currently available instruments. First, the Skintel reader uses three (versus the usual two) precisely selected wavelengths for the diffuse reflectance measurements to minimize effects of scatter and blood content; second, the Skintel reader is based on a model for the skin MOD value that is specifically matched to the geometry of the device at the design level.

History

Palomar has spent considerable efforts over the past decade to develop an accurate and reliable technique for measuring skin melanin. As part of those efforts, three generations of melanin meters have been designed, tested, and subjected to clinical trials. A brief summary of Palomar-sponsored clinical studies of these instruments is given in Table 2.

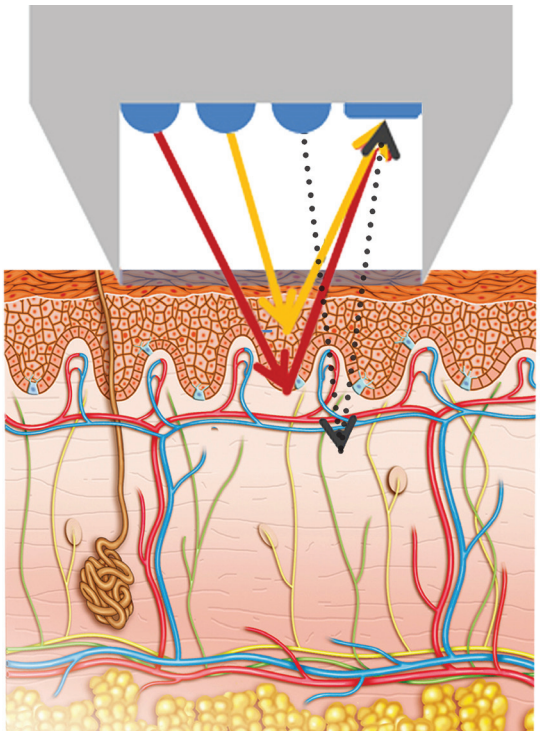
Table 2. Palomar-sponsored clinical studies of skin melanin meters.

Year	Location	Laser or IPL Device Used	Melanin Measuring Device Used
2001	Palomar (Burlington, MA)	EsteLux®/LuxY™	EMM-01 prototype
2004	Palomar (Burlington, MA)	StarLux®/LuxR™, LuxRs™, modified LuxG™, LuxY™, LuxV™	Palomar DermaType™
2004	Mass. General Hospital (Boston, MA)	Palomar prototype hair-removing laser at 800 nm, gliding mode	1) Palomar DermaType™ 2) Courage-Khazaka Mexameter MX16 3) Cortex Technology DermaSpectrometer
2008	Palomar (Burlington, MA)	Palomar prototype hair-removing laser at 800 nm, stamping mode	Skintel Melanin Reader Prototype
2010	Palomar (Burlington, MA)	Palomar Icon™/ MaxY™, MaxG™, MaxR™	Skintel Melanin Reader

Principle of Operation

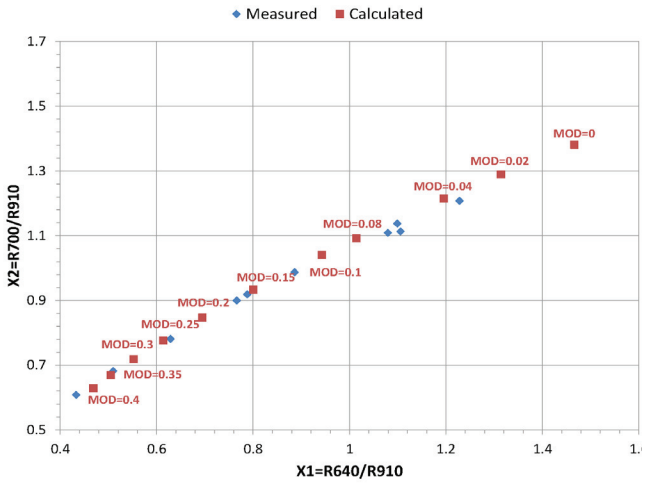
Melanin absorbs light in a wide range of wavelengths, from UV where the absorption is highest to infrared where the absorption is lowest. To estimate skin melanin density, the Skintel Melanin Reader measures skin reflectance in three narrow wavebands using a silicon detector and three light emitting diodes (LEDs) operating at center wavelengths of 640 nm, 700 nm, and 910 nm (Figure 1).

Figure 1. Schematic illustrating the Skintel Melanin Reader's three wavelength measurement of skin reflectance.



The Skintel reader's real-time determination of MI uses an algorithm that runs quickly. To accomplish this, a Monte Carlo model was validated against the measured diffuse reflectances in melanin-less skin at the three wavelengths with accepted optical properties of skin taken from independent measurements. Melanin was then introduced into the model at known MODs and simulations were performed to determine the corresponding diffuse reflectance signals (e.g. R640) for each MOD value at the three wavelengths, R640, R700 and R910. Ratios were then calculated and fitted to the corresponding values of MOD. These equations are used by the Skintel reader's processor in an algorithm to estimate MOD from the skin reflectance ratio measurements. A correlation plot of the ratio signals from the simulation (red box) and from the Skintel reader measurements on the skin of volunteers with various FSTs (blue diamonds) is shown in Figure 2 where MOD values from the Monte Carlo simulation are noted.

Figure 2. Calculated with Monte Carlo technique (squares) and measured (diamonds) values of the ratios of skin reflectance.



The estimated MOD is then used to determine the Melanin Index (MI), a quantity proportional to the skin's melanin optical density (MOD) at 800 nm that is normalized and varies between 0 (melanin-less skin) and 99 (darkest skin).

Clinical Evaluation of Skintel Melanin Reader

Clinical testing was performed with the Skintel reader to ensure the ability of the device to provide reproducible measurements of melanin optical density (MOD) and to evaluate the "robustness" of the device over various measurement conditions.

Reproducibility of MI Readings by Test Area

For reproducibility testing, triplicate MI readings were conducted on 20 subjects at each of four different test sites including the forehead, cheek, and neck and one sun non-exposed test site (e.g. buttocks). Measurements were performed with two Skintel Melanin Readers with FST ranging from II to V. Mean readings collected from two Skintel readers were highly similar with very low standard deviations. Skintel reader #1 gave a mean MI value of 27.2 ± 0.4 for the forehead as compared to 27.5 ± 0.5 for Skintel reader #2. Mean values for the cheek were 25.4± 0.4 and 25.2 ± 0.5 for #1 and #2, respectively. Mean neck values were 26.6 ± 0.5 and 26.7 ± 0.6 for #1 and #2 respectively. Finally, mean values on unexposed test sites were 21.4±0.4 and 21.6 ± 0.4 for Skintel reader #1 and Skintel reader #2, respectively. The high level of agreement between the two devices (less than 1.1% difference) and the low variance observed between the three readings at each area (standard deviation was 1.3 – 2.1% of the mean) indicated excellent instrument-to-instrument and within-instrument precision, respectively, of the Skintel™ Reader.

Robustness of the Skintel Melanin Reader
Robustness of the Skintel reader was evaluated in 13 subjects with FST ranging from II to VI by measuring the effect different lotions, pressure, and angle of the Skintel reader window had on MI values. Water, Lux Lotion™ (coupling agent used with Palomar IPL handpieces), baby oil gel (generic), and no lotion were evaluated for ease of operation with the device. Consistent MI readings were obtained on all subjects when either a small amount of Lux Lotion or baby oil gel was used. However, activation of the window contact sensor was inconsistent when used without lotion or with only water due to the contact sensor design.

The effect on the Skintel reader of various device orientations and degrees of skin-compression at the same skin site is shown in Table 3. The mean for the light compression readings was 30.4 compared to 29.8 for the firm compression (difference 0.6 ± 0.9 p<.05) and 29.9 (difference (0.5 ± 0.7 p<.05) for the off-angle. Although these differences were statistically different (n=13, student t-test), the difference between the two readings was less than one MI unit.

To evaluate the interference of blood on the Skintel MI value, the dual effect of light compression with and without erythema was compared. The mean reading in the presence of erythema was 27.7 (difference 2.7 ± 1.1 p<.001) which means that erythema reduced the MI reading by 2.2. The impact of erythema was considered in determination of fluences based on Skintel measurements as described in the Skintel Clinical Paper.

Table 3: Robustness of the Skintel Melanin Reader: Effects of Pressure, Angle, and Erythema on MI Values

	Light Compression	Firm Compression	Off Angle	Light Compression w/Erythema
Average	30.4	29.8	29.9	27.7
Difference ± □		0.6 ± 0.9	0.5 ± 0.7	2.7 ± 1.1
P value		P<.05	P<.05	P<.001

Conclusions

Palomar's Skintel Melanin Reader provides a new method of quantifying melanin that relies on a model matched to the geometry of the device at the design level. The inclusion of three wavelengths for diffuse reflectance measurements improves the measurement by reducing the effect of interfering chromophores and increasing the robustness and precision of the measurement. Subsequent testing (described in the Skintel™ Clinical White Paper) demonstrates that this objective method for estimating skin melanin can be used to provide more specific treatment guidelines for laser and IPL treatments.

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