

Skin translucency: what is it and how is it measured?

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Abstract

Objective: Translucency is the most nebulous attribute that describes ideal skin appearance. Physics would define an object as translucent if light can partially pass through it. However, skin translucency is not only about light passing through the skin. P&G research shows that the perception of skin translucency is a holistic term that involves the integration of skin color, glow and texture. I set out to develop new methods to simultaneously measure the integration of these parameters and develop a technical model for translucency.

Methods: A panel of 30 judges visually evaluated facial images of 32 female subjects to determine translucent skin and dull skin clinically. The images were captured using dual-polarized imaging system. It captures facial images including and excluding specular components simultaneously at RGB color channels. Specular rate defined from the specular and non-specular images was calculated as a numerical index for skin translucency. Relevancy of specular rate to visual translucency was examined statistically. Tri-ring spectrophotometer which is designed to measure internal skin color at different three depths was used to investigate internal colorimetric structure of translucent skin and dull skin for technical modeling.

Results: Specular rate mean and standard deviation distinguished translucent skin from dull skin with statistical significance. Translucent skin has lower mean and standard deviation at blue and green channel while the mean of red channel was greater than dull skin. The upper layers of translucent skin is less-colored than dull skin. The deeper layers of translucent skin are, on the contrary, more-colored than dull skin.

Conclusion: The sensorial perception of skin translucency was successfully translated into numerical descriptions using dual-polarized imaging system. Translucent skin is structured in multi-layers having larger color gradation from the surface to the deeper layers. Dull skin has rather mono-layered or uniformly colored structure from the surface to the deeper layers.

Introduction

Translucent skin is one of ideal skin appearances that look radiant, fair, smooth and even younger. The appearance is originated in the physics occurred across multi-layered skin structure that involves transmittance, reflectance, absorbance and scattering.^[1] However, perception of translucent skin includes psychological elements on top of the physics. A visual evaluation study conducted by P&G showed significant correlation between translucent skin appearance and glow ($r = 0.932$), skin fairness ($r = 0.929$) and fine texture ($r = 0.939$). How can we evaluate such a perceptual translucency with objective measurement? Human eyes are not directly sensing the physical transmittance of the light that passes through the skin layers but recognize it as tone, glow and texture. The method for perceptual skin

translucency should be an optical measurement in the principle while the output should include the integration of the visible attributes. I set out to establish new methods that simultaneously measure the integration of these parameters and develop a technical model for skin translucency.

Materials and Methods

Dual-polarized imaging system (SAMBA[®], Bossa Nova Technologies, USA)

This system^[2] is composed of two illumination units, a digital camera and a head positioning stand (Fig. 1). The illumination units are covered with polarizer plate (A). The camera is equipped with liquid crystal polarizer (B) which can electrically flip its polarization angle from parallel to crossed (perpendicular) at 4 Hz. The parallel polarization image includes the specular component and one half of the color component. The other half of the color component is captured in crossed-polarization image without specular component.^[3] In this principle the system can extract net specular component as follows:

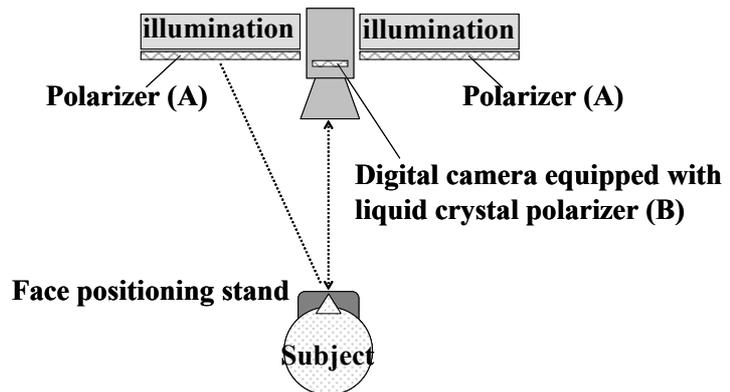


Fig. 1. Outline of dual-polarized imaging system. Liquid crystal polarizer (B) flips its polarization between parallel and crossed to polarizer (A).

$$\text{Net Specular Component} = \text{Parallel} - \text{Cross}$$

Total appearance (visibly seen by human eye) is

$$\text{Total Appearance} = \text{Color} + \text{Specular} = \text{Parallel} + \text{Cross}$$

Considering the larger influence of glow on sensorial perception for skin translucency, specular rate was defined as follows:

$$\text{SpecularRate} = \frac{\text{Specular Component}}{\text{Total Appearance}} = \frac{\text{Parallel} - \text{Cross}}{\text{Parallel} + \text{Cross}} \quad (1)$$

Calculation of specular rate is performed by matching exact pixels of parallel and crossed images. Specular rate at particular pixel #*i* is given by Equation (2). Here, $I_p(i)$ is a 8-bit (0-255) signal at pixel *i* of parallel image and $I_c(i)$ is the one of crossed image. $I_p(i)$ and $I_c(i)$ are collected within designated facial area (Region Of Interest; ROI afterwards) on the cheekbone (see Fig. 3 and Fig. 4). The ROI is a rectangle of 20mm height by 16 mm width. Two ROIs were taken symmetrically on the left and right side of the face. The data were averaged for the statistics. The cheekbone area was chosen because it is relatively flat from the camera view and the specular reflection can be observed stably. The mean and standard deviation of specular rate will be calculated across all the pixels in the ROI. Those parameters will be used for index of skin translucency.

$$\text{SpecularRate(at pixel \#i)} = \frac{I_p(i) - I_c(i)}{I_p(i) + I_c(i)} \quad (2)$$

Tri-ring spectrophotometer (Murakami Color Research Laboratory, Japan)

Tri-Ring Spectrophotometer is composed of three halogen lamps which are separately led to coaxial ring-shaped outputs of small (S), middle (M) and large (L) size (Fig. 2). The three coaxial rings emit the light around the central photo-detector one by one. As the distance from the photo-detector increases, the light from each ring must travel a longer, deeper pathway through the skin layers yielding skin color information at deeper and deeper depths (Fig. 2).^[4] The size (inner diameter / outer diameter) of the three rings are; S (2.2mm / 2.7mm), M (4.3mm / 5.0mm) and L (6.6mm / 7.5mm). The diameter of central photo-detector is 1.2mm. Tri-ring spectrophotometer records the color of internal skin collected along the three different pathways. In this present study, the internal color of translucent skin and dull skin was evaluated using Chroma (C*) value. The measurements were conducted in triplicate at different points of left cheekbone of the face. The three readings were averaged for statistics.

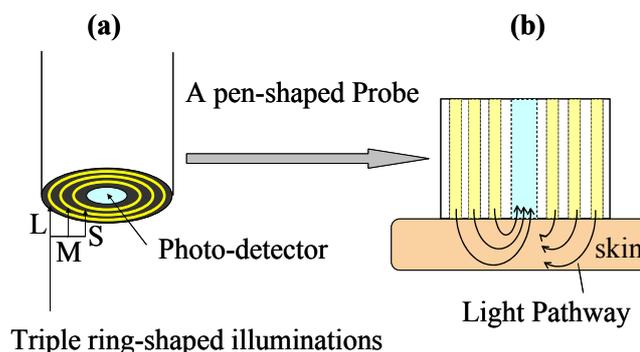


Fig. 2. Structure of probe of Tri-Ring Spectrophotometer and the light pathway model. L, M, S size ring illumination emits light into the skin directly and the central photo-detector collects the transmitted light.

Test design

Two studies were conducted. The environment of the test facility was maintained at 23±2°C and 50±10% ambient humidity throughout the study period. Voluntary willingness for participation was confirmed with written informed consent. Concurrence to publicize their facial images under appropriate privacy control was also confirmed. Entry of child under age 20 was agreed by her parent.

The first study involved 32 Japanese females age 23 to 49 years. Their facial images were captured using dual-polarized imaging system. The parallel (specular included) images were photo-printed and shown to a panel of 30 judges for visual evaluation with the questionnaire shown in TABLE 1. On the basis of consistency of the responses across 32 judges, the subjects were segmented into three groups (used two-step cluster analysis in SPSS version 12.0 for windows). This defined three groups of females who have either translucent, average or dull skin. These three groups were objectively evaluated for specular rate. Statistical analysis was performed to investigate the specular rate between dull skin and translucent skin.

The second study was conducted to understand internal colorimetric structure of translucent skin and dull skin. The subject of the second study was 45 Japanese females age 7 to 79 years. In this study skin translucency was determined using dual-polarized imaging system

and compared with internal skin color profiles measured using Tri-Ring Spectrophotometer.

TABLE 1 Questionnaire for visual evaluation to clinically determine translucent skin and dull skin.

Question: Please choose one statement below that best describes the facial appearance captured in the photograph.	Visual Assessment Score
A. I think she has translucent skin	+1.0
B. I think she has dull skin.	-1.0
C. Don't know or I think her skin is not either translucent or dull.	0.0

Results

Visual evaluation

The two-step cluster analysis segmented the 32 subjects into three groups (*TABLE 2*). Group #1 is a cluster of clinically defined translucent skin (visual translucency score = 0.64). This group consists of younger females (average age = 25.4). Group #3 is a cluster of clinically defined dull skin (visual translucency score = -0.63). The average of age (44.9) was highest among the three groups. The group #2 positions between the two clusters. Their skin was not clinically segmented into either translucent or dull. The average of visual grading and age of group #2 was -0.13 and 38.4, respectively. Representative images of group #1 and group #3 are shown in *Fig. 3* and *Fig. 4*.

TABLE 2 Cluster Analysis Result for Visual Assessment.

Name of Category	Group #1 Translucent	Group #2 Average	Group #3 Dull
# of population	9	14	9
Average age of the group (\pm SD)	25.4 \pm 1.9	38.4 \pm 7.8	44.9 \pm 2.8
Visual Translucency Score (\pm SD)	0.64 \pm 0.22	-0.13 \pm 0.20	-0.63 \pm 0.14

Specular rate of translucent skin and dull skin

Dual-polarized images were computer analyzed and the specular rate was calculated. The representative histograms are shown in *Fig. 5* and *Fig. 6*. These are the data of the subjects of *Fig. 3* and *Fig. 4*, respectively. The RGB signals correspond to the signal of red, green and blue channel. Remarkable differences were found between clinically defined translucent skin and clinically defined dull skin. The blue and green channel histogram of translucent skin was peaked at lower rate and has a narrower width compared to the histogram of dull skin. The red channel peak for translucent skin, unlike to blue and green channels, was greater than that of dull skin

The peak and width of specular rate can be described with mean and standard deviation of the histogram. The decline trend of mean and standard deviation over visual skin translucency was statistically confirmed at green and blue color channel (*Fig. 7*, *Fig. 8*). The incremental trend of red channel mean was also confirmed statistically.

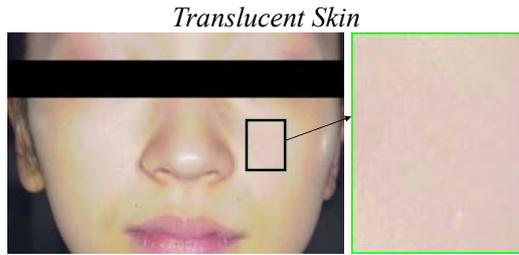


Fig. 3 Clinically determined translucent skin subject. The enlarged skin site is the ROI for specular rate image analysis. It looks fairer and smoother than dull skin.

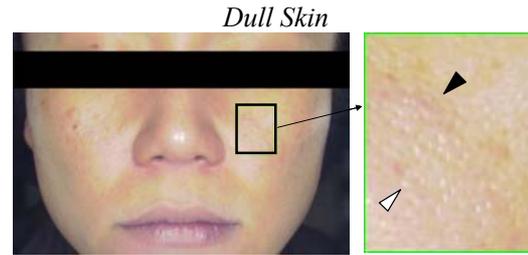


Fig. 4 Clinically determined dull skin subjects. Skin tone unevenness (mark in black) and rough texture (mark in white) are observed.

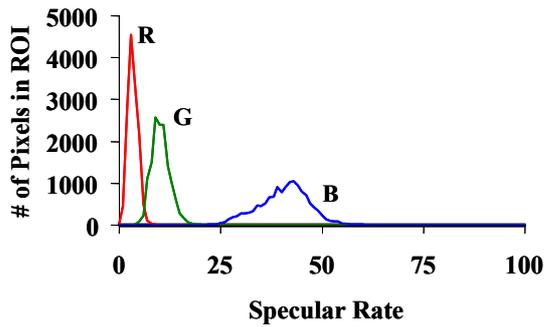


Fig. 5 A representative specular rate histogram of clinically defined translucent skin. The blue channel peak (mean) locates at lower and the width of histogram is narrower than dull skin's profiles.

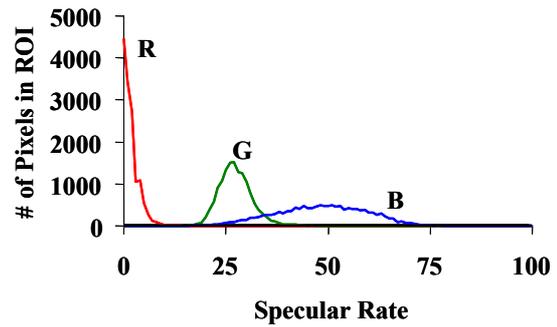


Fig. 6 A representative specular rate histogram of clinically determined dull skin. The blue channel peak (mean) locates at higher and the width of histogram is greater than translucent skin profiles.

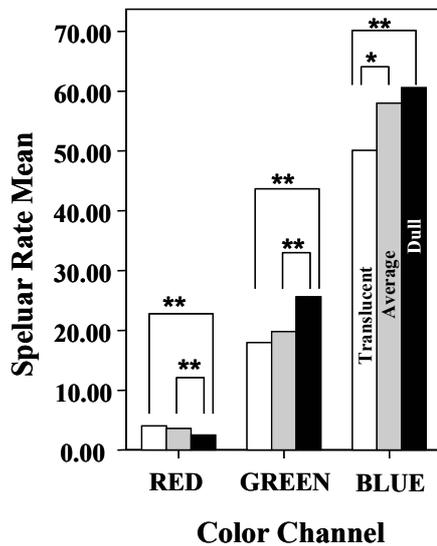


Fig. 7 Specular rate mean difference among the three groups. Increment of mean specular rate of blue and green channel, and decline of red channel mean was statistically confirmed using ANOVA followed by Fisher's LSD for multiple comparison. * $p < 0.05$, ** $p < 0.01$.

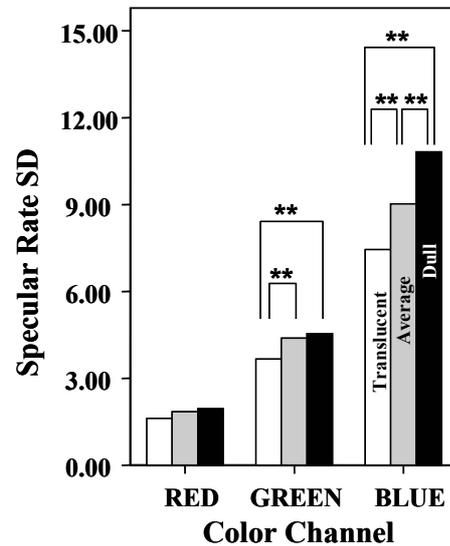


Fig. 8 Specular rate SD difference among the three groups. Dull skin has larger standard deviation than translucent skin. This corresponds to the wider peak width of dull skin. Significance was calculated using ANOVA and Fisher's LSD. * $p < 0.05$, ** $p < 0.01$.

Internal skin color of translucent skin and dull skin

Internal skin color was investigated by using Tri-Ring Spectrophotometer. Fig. 9 is the plotting of C* against skin translucency determined using dual-polarized imaging system. Specular rate mean of blue channel is the horizontal axis. Translucent skin locates at lower specular rate. Chroma yielded by S-ring was smaller for translucent skin and it elevates with specular rate. This suggests that the color of superficial layers of translucent skin is less-colored than dull skin. The C* gap between L ring (including deeper layer's color information) and S ring was larger for translucent skin than dull skin. This indicates that deeper layers of translucent skin has relatively much more colored than its superficial layers but the deeper layers of dull skin has rather similar color with its upper layers.

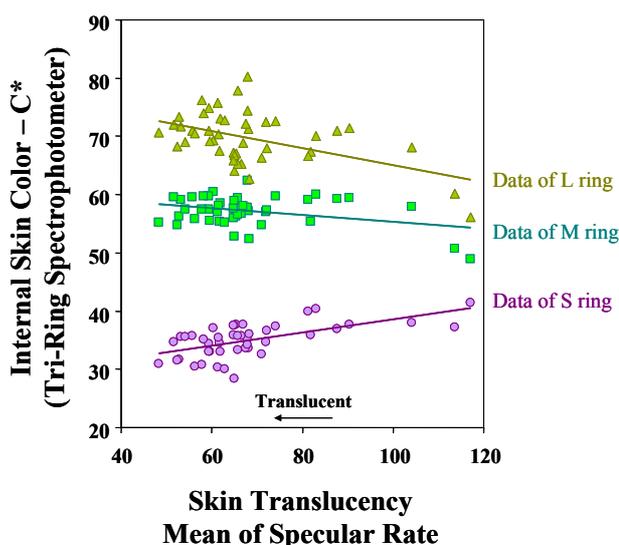


Fig. 9 Skin translucency and internal skin color. The horizontal axis is mean of blue specular rate measured with dual-polarized imaging system. The smaller specular rate is consistent to visually translucent skin. The L ring data must be more influenced by skin color of deeper layers than S ring. The difference of L ring and S ring indicated color gradation inside the skin. The data suggests that there is greater color gradation in translucent skin comparing to dull skin

Discussions

Appearance of the skin is composed of specular component and color component. The specular component consists of the reflection at the skin surface. The color component consists of the reflection from the internal skin layers. The internal reflection results from transmission, absorption and scattering of photons in the skin layers. The total skin appearance is the sum of surface and internal reflection. Thus the mean specular rate evaluates the balance of specular component in the total appearance. Lower blue and green specular rate of translucent skin occurs when internal reflection is higher and/or there is less surface reflection. Translucent skin, as shown in Fig. 3, has more even glow on the face. The low specular rate suggests that the glow is originated in internal scattering rather than surface reflection for blue and green color bands. Melanin and hemoglobin that absorb blue and green light may be responsible for the specular rate differences between translucent skin and dull skin. The opposite tendency for the red color channel (higher specular rate in translucent skin) can be a uniqueness of translucent skin in optical property. The balance of red, green and blue specular rate forms the basis for the appearance of skin translucency.

The standard deviation of specular rate is a measure of the uniformity of skin appearance. Highly specular regions (marked by white in Fig. 4) or darker tone regions (marked by black in Fig. 4) are observed on dull skin. These are responsible for the larger specular rate SD. The highly specular region appears at an open pore. These images were captured 20 minutes after face wash and therefore the effect of sebum is minimized. The higher specular rate SD

is due to rough skin texture and uneven skin tone. Thus the smaller standard deviation of translucent skin is consistent with the uniformity of translucent skin appearance including textural smoothness and color evenness.

Tri-ring spectrophotometer provided insight for the internal differences of translucent vs. dull skin. While the exact path of the three incident lights is unknown, it must depend on wavelength of the incident light in addition to individual skin conditions such as concentration of melanin and hemoglobin and number of folds of the stratum corneum. The light pathway model is calculated using a computer program for near infrared.^[4] The C* gap between S-ring and L-ring indicates the color gradation from the upper to deeper layers. The gap, and thus the internal color gradation, was larger for translucent skin and smaller for dull skin. This color gradation model can be visualized as *Fig. 10*. This suggests that translucent skin has uneven color distribution in the penetrating direction. The colorimetric structure of translucent skin is multi-layered that is consistent to anatomical structure. Dull skin has a more even color distribution from the surface to deeper layers like a substrate that only mimics skin color.

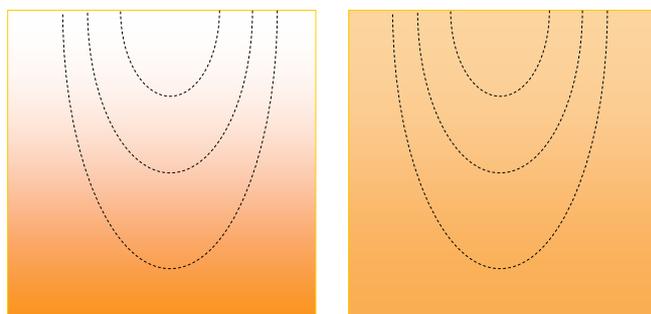


Fig. 10 Color gradation model for translucent skin (left) and dull skin (right). Tri-ring spectrophotometer suggests that the upper layer of translucent skin is less-colored and the color component is concentrated at deeper area. Dull skin is more uniformly colored from the surface to the deeper layers as a skin-mimic substrate. The dot-lines assume light pathway of the three rings of tri-ring spectrophotometer.

Conclusions

Dual-polarized imaging system successfully translated visual sensory perception into a measurable numerical parameter with significant correlation. Specular rate mean and SD that involves color, glow and texture simultaneously can be an index for skin translucency. Translucent skin has a larger color gradation inside and multi-layered colorimetric structure while dull skin has a more mono-layered structure.

References

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