Analysis of Translucency of Skin by Volume Reflection for Color Formulation of Facial Prostheses

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Purpose: A facial prosthesis demands a good visual match with the adjacent skin. Skin color and translucency must be mimicked by the prosthesis. Translucency can be defined as allowing the passage of light, yet diffusing it so as not to render the bodies beyond clearly visible, therefore being semi-transparent. The translucency of skin hampers color measurements of color meters recommended by the Commission Internationale de l'Eclairage (CIE) due to edge loss. The aim of this study was to analyze the translucency of skin at different body sites by measuring volume reflection in a cohort of Caucasian individuals. ***Materials and Methods:*** To analyze skin translucency, a volume reflection meter (VRM) was applied to the skin of the forehead, cheek, palm of the hand, and lower forearm. The VRM measures the volume reflection of a small incident light beam at three different distances from the incident beam. To describe the impact of translucency on skin color and the impact of volume reflection at different distances of an incident beam, the VRM spectra were converted into CIE L*a*b* coordinates. ***Results:*** VRM measurements were carried out on a cohort of 48 individuals during spring. The mean age was 40.8 years (± 11.7 years). Statistically significant interactions between body site, distance from the light source, and L*, a*, and b* values were found. L* values decreased and a* and b* values increased at longer distances from the incident light beam since the light path was increased. ***Conclusion:*** Skin on the forehead, cheek, palm of the hand, and lower forearm each have their own specific volume reflection and thus, translucency, absorption, and scattering characteristics. These location-specific characteristics are due to known local differences in the skin's multilayered structure. For a good visual match between a facial prosthesis and the adjacent skin, volume reflection measurements of the skin close to the intended site of the prosthesis are necessary. *Int J Prosthodont 2009;22:623–629.*

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The ablation of facial structures due to oncology treatment, trauma, or a congenital disorder can be reversed using surgical reconstruction and facial prostheses. The composite materials of facial prostheses include silicone elastomers, fillers, and pigments. Facial prostheses have a relative short lifetime, caused by internal and external discoloring and disintegration, which results in frequent indications for retreatment.[1]

Interpersonal interactions relevant for facial prostheses focus on facial expressions, edge adaptation, form, and facial color harmony. The typical interpersonal distance is about 1 to 1.5 meters.[2] A facial prosthesis requires a good color match with the surrounding skin areas. An isometric spectral color match of the

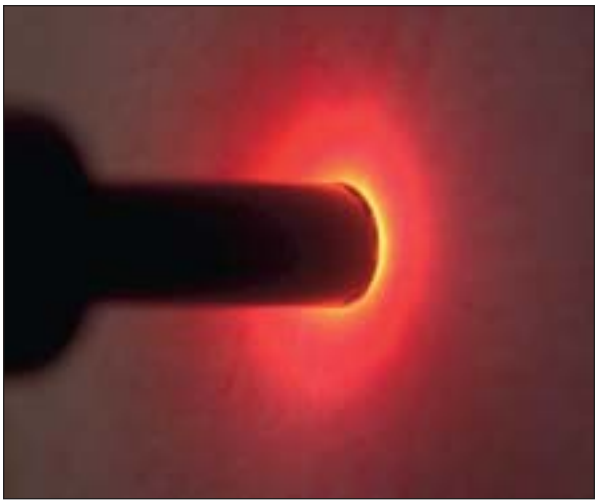

Fig 1 Visualizing edge loss: A fiber-optic light guide 3 mm in diameter in contact with the skin (cheek) is lighted by a halogen light source. The volume-reflected light has a diameter of about 15 mm and varies in color. The increase towards a red color is due to absorption of the light by blood in the dermis.

prosthesis with the adjacent skin structures is of importance for interpersonal interactions under different light circumstances.[3] To achieve a spectral color match, quantification of the skin color and a color formulation system are needed.

The optical properties of skin are complex. It is a translucent biomaterial with a functional multilayered structure. Each layer has its own thickness and layer-determined scattering and absorption coefficient.[4] The thickness of the skin layers differs between body regions. The epidermis in body regions subject to friction, such as the palm of the hand and sole of the foot, is thick (> 300 μm) compared to other body regions (~ 100 μm). Light-scattering, absorption, and reflection behavior of the skin depend on age, surface roughness, density of the stratum corneum, surface skin oils, and sweat. The main chromophores that determine the visible spectrum are melanin (any type) in the epidermis and hemoglobin in the dermis. The density of melanocytes, cells that produce melanin, is larger in regions exposed to sunlight. The amount of melanin is determined by sun exposure and perceived doses. High melanin concentration in the epidermis obscures translucency of the dermis. In winter, Caucasian skin contains relatively low concentrations of melanin. The amount of hemoglobin is determined by the local amount and position of small subsurface and deeper blood vessels in the dermis.[5]

By definition, "Color is what we see."[6] In the ideal color-measuring system, the measured reflection spectrum is exactly the same as what is observed by the naked eye using the same light source and lighting conditions. However, that is not true when International Organization for Standardization/Commission Internationale de l'Eclairage (ISO/CIE)–recommended color meters are applied to translucent materials. Present ISO/CIE–recommended color-measuring systems[7] are applicable to paints and materials having a small light penetration depth, compared to biologic translucent materials, such as human skin. The penetration depth of light, a depth where the incident light (I_0) is decreased by a factor e^{-1}, for paint is in the order of μm, but for human skin it is in mm. This relatively large penetration depth of light in the skin results in so-called edge loss in the ISO-recommended color meters.[8,9] Edge loss is determined by both the volume scattering and absorption coefficients of the object; both coefficients are wavelength-dependent. Edge loss, ie, light not being reflected within the detection area of the measuring spot of a color meter, can be visualized simply. Edge loss in human skin is shown in Fig 1. The impact of edge loss on the reflection spectrum of a color meter with a 30-mm diameter measuring area is considerable in the red area and dramatic when the measuring area is decreased to 15 or even 5 mm in diameter.[3] In the past, the problem of edge loss in color-measuring systems has been the topic of research.[9] No commercial color meters are available to quantify the color of translucent materials. Consequently, a straight application of commercially available color formulation software is not yet feasible.

The conventional method for matching the color properties of the prosthesis with the surrounding skin is by a visually correct mixing of color in the silicone.[10] Several methods to measure skin color and a method for the evaluation of skin pigmentation have been described.[11] Previously, the potential for an application of a color formulation software for facial prostheses was discussed.[12,13] However, in those publications, a spectrophotometer was used that did not account for the color-measuring problems stemming from the translucency of the skin. Additionally, when applying these spectrophotometers, it is not possible to achieve a good translucency match, reproducing the skin color and translucency into the prosthesis.

The translucency of skin has been explored within the biomedical optical field.[14] Small illuminating beams were applied and the volume reflection explored to determine the scattering and absorption behavior of tissue.[15,16] However, the responses of that type of optical diagnostic system cannot be used to quantify color because of the long pathway the light travels through the skin.

The aim of this study was to analyze skin translucency by measuring the volume reflection at different body sites in a cohort of Caucasian individuals during spring.

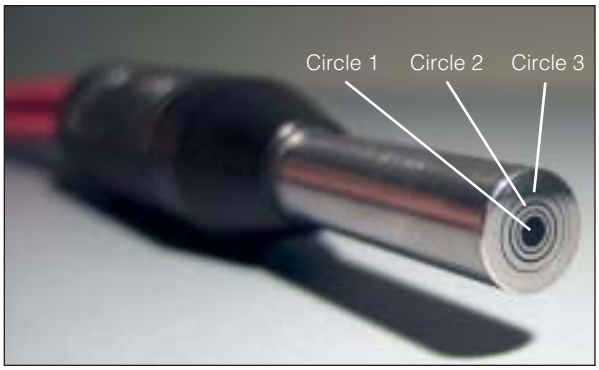

Fig 2 The VRM fiber-optic probe measuring at three concentric distances (circle 1, circle 2, and circle 3) from an incident small beam (circle 1).

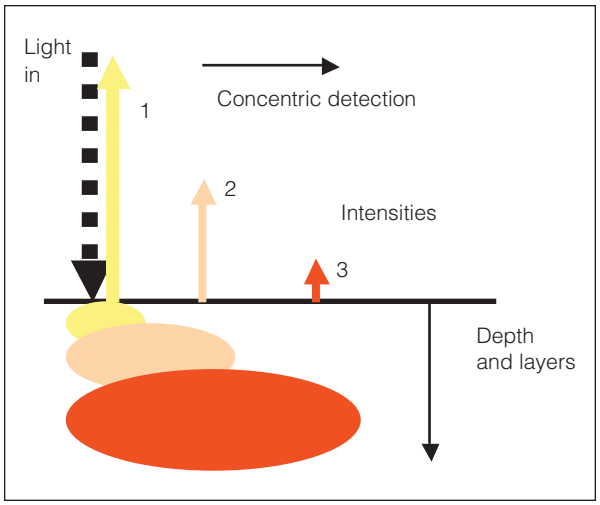

Fig 3 The hypothetical volume reflection behavior of skin and its relationship with the VRM fiber-optic measuring probe at three different detection distances.

Materials and Methods

Subjects

In 48 Caucasian individuals from the northern part of The Netherlands, the right cheek, forehead, palm of the hand, and inner part of the forearm were measured. These sites were chosen because of their differences in histologic characteristics as well as differences in UV influences. All measurements were carried out by one trained researcher during the spring.

Study Design

A volume reflection meter (VRM; PBSensortechnology & Consultancy) was used for this study. A VRM combines a fiber-optic probe design with a pulsed xenon light source and three detecting spectrophotometers.[17,18] The VRM detects the volume reflection at three different detector distances (circles) from the light source. Concentric circle 1 is a mix of illuminating and detection fibers. The fibers of concentric circles 2 and 3 detect light at a distance of 0.6 mm and 1.3 mm from the light source, respectively (Fig 2). The volume reflection behavior of skin and the VRM fiber-optic measuring probe are presented schematically in Fig 3. The volume of the reflected light at the three different distances is guided to three spectrometers with a measuring range 350 to 850 nm. Measuring time of the VRM is 0.5 seconds.

During measurements, the VRM fiber-optic probe was in direct contact with the skin. To avoid deformation of skin and changing the skin's color, contact pressure below the capillary blood pressure was visually observed. To enable this, the contact surface was extended,

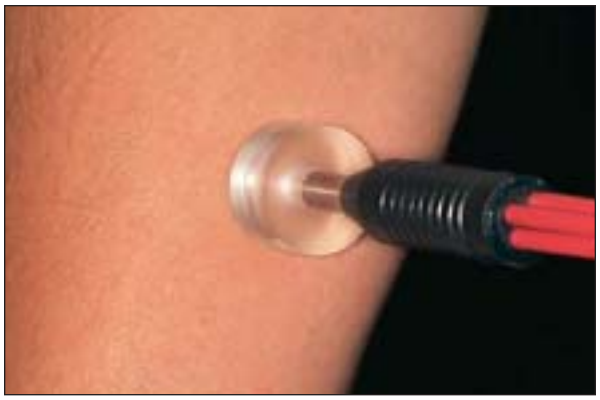

Fig 4 The VRM applied to the skin of the inner forearm with a polymethyl methacrylate ring that increases the contact surface to visually control skin deformation.

applying a transparent plastic (clear polymethyl methacrylate) ring around the fiber-optic measuring head. The total contact surface area was 25 mm in diameter (Fig 4). The VRM measures volume reflection at the edge of the illuminated spot.

To interpret the optical differences of skin at the different body sites, the VRM spectra were converted into CIE L*a*b* coordinates. In this rectangular coordinate system, the coordinates are L* (representing lightness), a* (representing the red-green spectrum), and b* (representing the yellow-blue spectrum).[6] CIE L*a*b* color coordinates connect reflection spectra with visual color observations.[19]

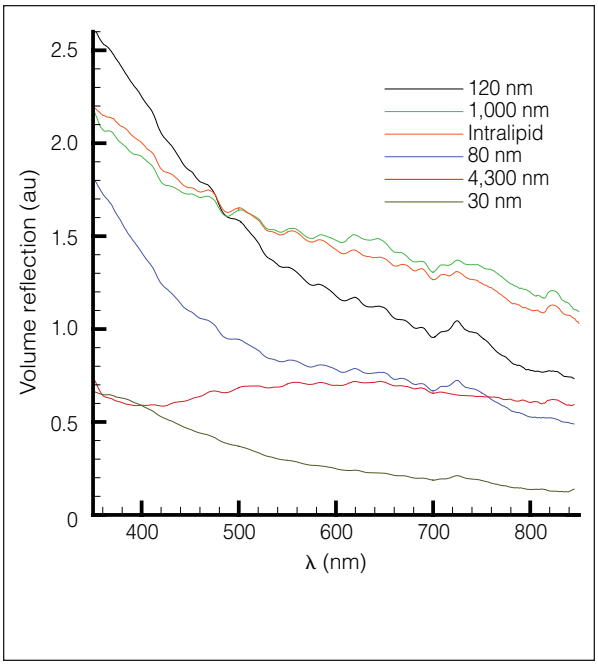

Fig 5 VRM particle size–dependent responses (at centric circle 1) were measured with a series of 1% mass fraction monodisperse latex suspensions.

Table 1 Mean CIE L*, a*, b* Coordinates at the Three Distances and Four Body Sites

Site/ coordinate	Circle 1		Circle 2		Circle 3	
	Mean	SD	Mean	SD	Mean	SD
Forearm						
L*	91.19	5.20	75.69	4.72	67.79	4.50
a*	−1.06	1.58	3.68	2.62	11.06	3.46
b*	17.29	4.33	28.40	3.83	39.05	3.58
Palm						
L*	85.37	3.04	75.94	3.20	71.68	3.73
a*	−0.60	1.71	3.68	2.74	10.15	3.74
b*	12.34	2.55	19.91	2.77	29.49	3.11
Forehead						
L*	83.84	4.15	71.76	4.12	64.69	4.64
a*	2.44	2.47	9.42	3.58	18.27	4.51
b*	21.04	3.37	35.22	3.15	46.19	2.91
Cheek						
L*	80.68	4.70	68.16	5.13	61.18	5.01
a*	4.24	3.08	12.49	4.79	22.12	5.90
b*	18.03	3.55	32.27	2.97	43.80	2.64

SD = standard deviation.

Calibration of the VRM to Determine Measurement Precision

The VRM was calibrated to determine whether it fulfilled international measuring methods and color standards using a white reflection standard (SRS-99-620, Labsphere). The result was a spectral flat response, indicating a good calibration of the VRM. To equal the three detection channel responses, a homogeneous light source (emitting at 560 nm) was used. To scale the VRM regarding translucency, a commercially available 1% mass fraction monodisperse suspension of latex particles (1 µm in size) was used as a reference. To analyze the influence of particle size on VRM response, a series of measurements (at centric circle 1) at 1% mass fraction monodisperse latex suspensions with different particle sizes were carried out (Fig 5). Due to small positional variations of the arc of the pulsed xenon light source at the entrance of the lighting fibers, some noise (~ 2%) was introduced into the VRM spectra. This noise was small compared to the response. For measurements and calculations, VRM spectral responses in the visible wavelength area of 400 to 700 nm were used.

Statistical Analysis

A repeated-measures analysis of variance was performed with site (cheek, forehead, palm of the hand, and inner forearm), distance (circles 1 to 3), and coordinates (L*, a*, and b*) as within-subject factors (SPSS 14). A Greenhouse-Geisser adjustment for degrees of freedom was applied due to violations of sphericity. For all tests, a significance level of .05 was chosen.

Results

Subjects

A cohort of 48 Caucasian individuals (11 men, 37 women) was composed from the northern part of The Netherlands during spring. The mean age was 40.8 years (± 11.7 years).

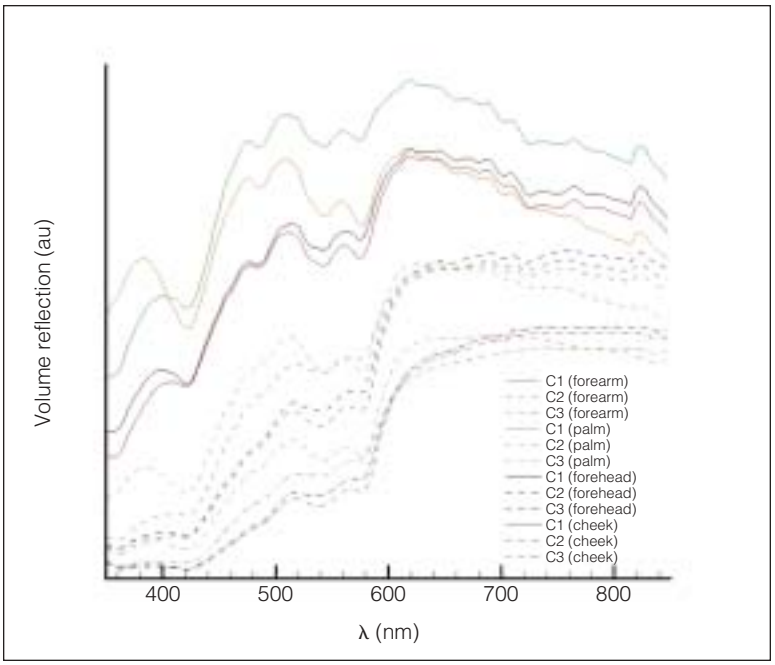

Fig 6 VRM-averaged spectra at different locations and distances (circle 1, circle 2, and circle 3). C= circle.

VRM Measurements

The VRM spectra (wavelength area 400 to 700 nm) of the forearm, palm, forehead, and cheek were computed in L*, a*, and b* color coordinates for circle 1, circle 2, and circle 3 (Table 1). The L* value decreased with increasing distances in circles 1, 2, and 3. The a* and b* values increased for circles 1, 2, and 3.

The highest L* value was found at circle 1 at the forearm, followed by the palm, forehead, and cheek measurements at circle 1. The same tendency was found in circles 2 and 3, except for the L* value at the palm of the hand, which was higher than the forearm for both circles. The a* value at the cheek was higher compared to the other locations; the b* value at the forehead was higher compared to the other locations.

The average reflection spectra (Fig 6) showed a higher volume reflection at the forearm for circle 1. At circles 2 and 3, the palm delivered a higher volume reflection. The spectra showed the impact of the light path in the skin (see Fig 3). The light path in skin increased with an increase in detection distance (circle 1 < circle 2 < circle 3).

Statistical Analysis

All main effects and all interactions (two-way and three-way) were significant ($P < .001$).

Clinically, these results indicate that the effects of the volume reflection of light differ per site, per circle, and per coordinate. Additionally, the effects of the volume reflection of light differ between circles on different sites, between coordinates on different sites, and between coordinates in different circles. Finally, the significance of the three-way interaction indicates that the effects of the volume reflection of light on the different coordinates differ between the sites and circles on these sites.

Discussion

The volume reflection VRM spectra measured clearly demonstrate the effects of translucency of the skin. The measured volume reflection at a short distance from the incident light at circle 1 differs from the reflections at the larger distances of circles 2 and 3. The distance between the incident light and detection site determines

the light path in the skin. The L* value decreases when a longer light path is due. The length of the light path determines the absorption. Consequently, a* and b* values increase when the distance from the incident light (and therefore the light path) increases. Clinically, this means that the reflected light at a longer distance from the light source becomes darker, redder, and more yellow. However, due to the optical geometry of the VRM, the calculated CIE L*a*b* values are not interchangeable with results obtained from CIE-recommended color meters.

The calibration results of the VRM indicate that it has a high sensitivity (Fig 5). All particle sizes could be distinguished from one another, except intralipids and a particle size of 1 μm. However, since an intralipid has a particle size of about 1 μm, a comparable volume reflection is expected. These findings indicate that the VRM can detect small differences in the scattering properties of translucent materials.

Scattering is a wavelength-dependent effect determined by particle size, particle size distribution, particle concentration, and differences in the refractive index (particles/medium). Scattering of light in the skin can explain its wavelength-dependent translucency. Blue light is scattered more than red light.[20,21] Absorption of light by melanin and hemoglobin is present in the UV and visible ranges. Low absorption of light is shown in the red–infrared range of 600 to 800 nm.[22] The volume reflection in the green-blue area (400 to 600 nm) is determined by skin tissue scattering and by the absorption behaviors of melanin and blood. The volume reflection in the red area (600 to 700 nm) is mainly determined by scattering since the absorption is very low.

The relatively high volume reflection of the inner forearm is directly related to low sun exposure and thus, low melanin content. The cheek is much more exposed to the sun than the inner forearm. The cheek shows the highest a* value at the three distances from the incident light and in most cases, the cheek contains more blood vessels than the other body sites. The forehead shows the highest b* value at the three distances from the incident light. The relatively thin skin layer at the forehead and the bone (skull) basis is most likely the origin of the observed yellow color. The palm has a thick epidermis layer and relatively low melanin content, explaining a higher volume reflection of the palm of the hand and a higher L* value at circles 2 and 3 compared to the other body sites.

The scattering and edge loss of light is, among other things, dependent of the thickness of the layers, the translucency, and consequently, the reflectance of the opaque backing.[9] The differences between circles 1, 2, and 3 are related to the depth the light has travelled in the skin. These findings are in agreement with the findings of Meglinski and Matcher,[23] who found that blood vessels in the deeper layers determine the redness of the skin.

In general, variations between the individuals were larger in the blue-green spectrum than in the red spectrum. The cohort of Caucasian people in the current study was measured during spring in The Netherlands and the content of melanin in the skin is low at that period of time. Despite this low melanin content, the VRM was able to detect differences in the volume reflection of the skin between the subjects at different sites.

To perform reliable color measurements of translucent materials, it is important to avoid edge loss. The sizes of the illumination and detection areas have to be adapted to the conditions of the visual color observations. A simple experiment measuring at a small series of white monodisperse suspensions (latex) and at the opaque white reflection standard varying the illumination and the detection areas can help to find an edge loss–free reflection spectrum.

Other experiments regarding the dispensing dyes needed for the color formulation of facial prostheses are currently being done. With those experiments, a dedicated color formulation and investigation regarding the construction of the prosthesis could improve the quality of the color of facial prostheses, providing a good color match with the surrounding skin areas.

Conclusion

Every subject and every site within the subjects had its own specific volume reflection and thus, translucency, absorption, and scattering characteristics. For a good visual match between a facial prosthesis and the adjacent skin, volume reflection measurements of the skin close to the intended site of the prosthesis are necessary. As a consequence, location-specific color and translucency measurements have to be carried out to attain color formulation for facial prostheses.

Acknowledgments

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Literature Abstract

A novel decision-making process for tooth retention or extraction

Implant-supported restorations have gained popularity in recent years as an option for the restoration of missing teeth. Implants have a high success rate and can be considered as a viable treatment alternative to extensive procedures to save a compromised tooth. However, tooth extraction and implant placement may not always be the best solution, and we frequently face the dilemma of whether to retain and restore or extract a compromised tooth. This article proposes a decision-making chart for the extraction or maintenance of such teeth. It guides clinicians through a series of questions to determine whether to save or extract a tooth based on the currently available literature. The chart is color-coded with green suggesting a favorable outcome if saving the tooth is attempted, yellow indicating that saving the tooth can be tried but to proceed with caution, and red indicating an unfavorable long-term outcome. There are six levels in the chart: initial assessment, periodontal disease severity, furcation involvement, etiologic factors, restorative factors, and other determinants. The authors recommend starting at level one and progressing through to level six. Extraction or conservation is determined by the number of reds, yellows, or greens a tooth receives. It is important to note that this chart was created for individual tooth prognosis and does not consider the overall prognosis of the dentition. The long-term success or failure of a tooth is multifactorial and the proposed chart presents a systematic method of evaluating a compromised tooth.

Avila G, Galindo-Moreno P, Soehren S, Misch CE, Morelli T, Wang HL. *J Periodontol* 2009;80:476–491. **References:** 130. **Reprints:** Dr Hom-Lay Wang, Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, 1011 N. University, Ann Arbor, MI 48109-1078. Email: homlay@umich.edu—*Clarisse Ng, Singapore*