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Reconstructive

Establishing a Clinically Applicable Methodology for Skin Color Matching in Vascularized Composite Allotransplantation

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Summary: Skin color matching in vascularized composite allotransplantation (VCA) is an important determinant of aesthetic outcomes. The process of color matching is infrequently described in the literature. The Pantone SkinTone Guide (PSTG) is a handheld tool comprised of realistic skin tone swatches with a corresponding virtual swatch system. A color match acceptability threshold (AT) is defined as the point beyond which >50% of observers deem a given skin tone pairing as unacceptable. In this study, color match acceptability thresholds were developed using the PSTG to help standardize donor-recipient color matching. Four representative colors were chosen across the skin tone spectrum. These standard colors were used to develop a survey asking participants to determine the acceptability of color pairings. Using survey results, ATs were determined for changes in lightness, undertone, and lightness and undertone combined for each of the standard colors. Inter- and intra-rater reliability were determined using Fleiss's Kappa. Participants were more critical of skin tone pairings on the darker versus the lighter end of the spectrum, as evidenced by higher thresholds observed for lighter sample pairs. Additionally, observers were more critical of differences in skin lightness compared with differences in undertone. Intra-rater reliability was fair to substantial, and inter-rater reliability was fair to moderate. The PSTG can be used as a clinical tool to improve the aesthetic outcomes of skin-containing vascularized composite allotransplantation procedures by optimizing donor-recipient skin color matching. This can allow clinicians to complement visual judgment with quantitative reference. *(Plast Reconstr Surg Glob Open 2020;8:e2655; doi: 10.1097/GOX.0000000000002655; Published online 6 February 2020.)*

INTRODUCTION

Vascularized composite allotransplantation (VCA) has emerged as a viable reconstructive method for severe facial and upper extremity injuries.[1,2] In conjunction with functional outcomes, aesthetics play a major role in self-esteem, identity, and societal reintegration.[3–5] Ensuring acceptable donor-recipient skin color matching is an essential component of aesthetic success.[2] Regardless, there is no standard color matching system for VCA. Colorimeters, mexameters, and spectrophotometers are examples of instruments used to quantitatively characterize skin color to diminish the variability of visual assessment.[6–9] However, such devices have been found to yield results comparable with plain visual assessment, while being expensive, cumbersome, and difficult to attain.[9]

The Pantone SkinTone Guide (PSTG) (Pantone LLC, X-Rite Inc., NJ) is a system used for skin color matching by artists, researchers, and prosthetic manufacturers.[10,11] It is a user-friendly handheld tool consisting of 110 color swatches that realistically mimic human skin tones, with stepwise variations in lightness and undertone.[12] This study aims to demonstrate the utility of this tool in standardization of donor-recipient color matching.

MATERIALS AND METHODS

Tool and Sample Acquisition

The PSTG provides a handheld tool as well as a digital version with corresponding virtual swatches (Fig. 1). Four standard swatches representative of the color spectrum

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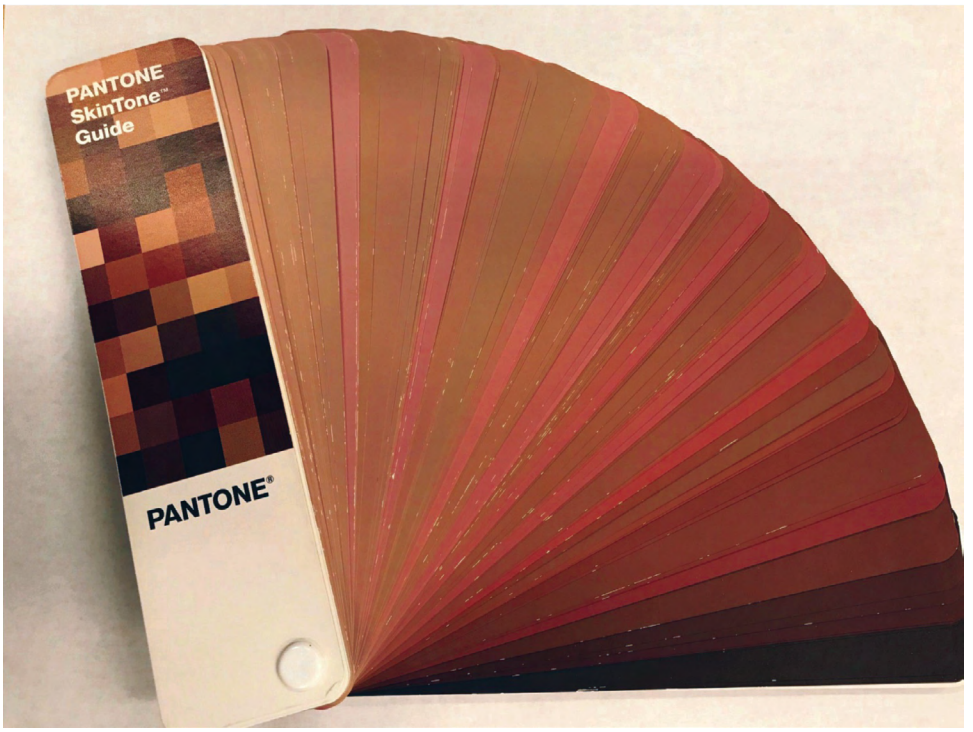

Fig. 1. Handheld Pantone SkinTone Guide.

were chosen as starting points, and color pairings were created using stepwise variations in lightness, undertone, and lightness and undertone combined (Fig. 2). A negative control was created pairing the lightest and darkest swatches on opposite ends of the spectrum.

Survey Development and Administration

Qualtrics software (Qualtrics, Provo, Utah) was used to develop a survey adapted for iPad and mobile devices. Triplicates of each color pair were included in the survey to assess for intra-rater reliability. A randomizer provided each participant with a uniquely ordered survey, also incorporating the negative control. Participants from the general public were approached in public New York City parks, and medical professionals from New York University (NYU Langone Health) were recruited via email blast. Purpose of the study was disclosed in detail, and participants were asked to determine whether each pair was an acceptable match using "Yes" or "No" binary responses. After Institutional Review Board approval and verbal consent, participants 18–65 years of age were anonymously recruited, including members of the general public and medical professionals of different training levels. Exclusion criteria included color blindness, significant visual deficiencies, and inability to read or speak English.

Data Analysis

Data were analyzed using Statistical Package for the Social Sciences software (version 25.0, IBM Corp. Armonk, New York). The mode response from each triplicate set was used to determine acceptability frequencies. Acceptable color pairings were summed, then divided by total responses to determine acceptability percentages. Plots to illustrate changes in lightness, undertone, and lightness and undertone were created using GraphPad Prism 8.0 (GraphPad Software, San Diego, Calif.). The best fitting curves (R^2) were estimated, and cubic curves were chosen. Color match acceptability threshold (AT) was defined as the point at which >50% of observers deemed a skin tone pairing unacceptable. Thresholds were determined by the intersection of the regression curve with the point of 50% acceptability. Inter-rater and intra-rater reliability were calculated using Fleiss's Kappa.

RESULTS

Sixty-three individuals provided complete responses (females: 42.9%, males: 57.1%). Thirty (47.6%) were sampled from the general public and 33 (52.4%) from the medical community (Table 1). ATs were determined (Fig. 3). Participants were found to be more critical of skin tone pairings on the darker versus the fairer end of the color spectrum. Participants were also more critical of differences in lightness versus differences in undertone. Inter-rater reliability was fair to moderate (k = 0.454). Intra-rater reliability was substantial (k = 0.725). There was no significant difference between general public and medical professional groups in threshold determination.

DISCUSSION

Current methodologies for skin color matching in VCA largely rely on subjective assessment. The process typically involves an initial assessment by the Organ Procurement Organization, followed up with non-standardized photographic and in-person assessment by the operating surgeon. Most conventional tools, such as handheld silicone

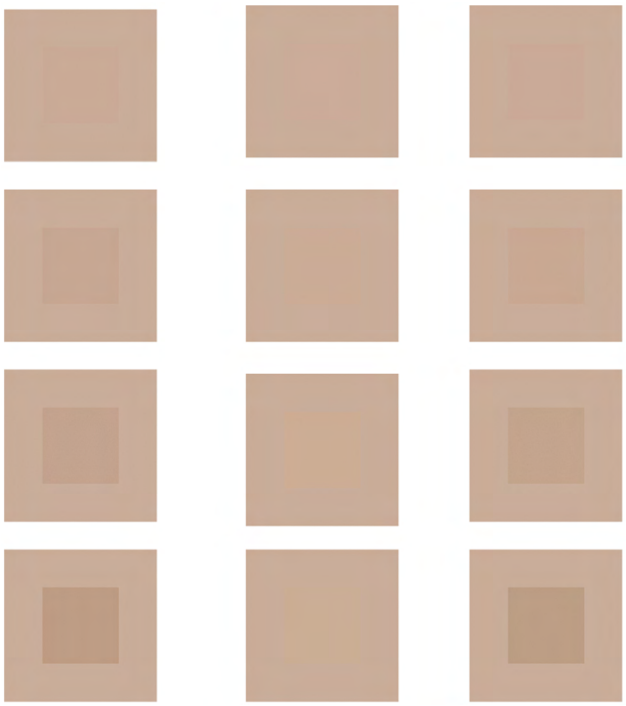

Fig. 2. Examples of color pairings used in the survey. Inset squares show the standard as the outer square, and the variable swatch as the inner square.

Table 1. Demographics of Survey Participants

Demographics		n = 63 (%)
Age		
	18–25	26 (41.3)
	26–35	18 (28.6)
	36–45	8 (12.7)
	46–55	5 (7.9)
	56–65	4 (6.3)
	65+	2 (3.2)
Gender		
	Males	36 (57.1)
	Females	27 (42.9)
Race/ethnicity		
	White	38 (60.3)
	Black or African American	5 (7.9)
	Hispanic	4 (6.3)
	Asian	12 (19.0)
	Other	2 (3.2)
	Prefer not to say	2 (3.2)
Highest level of education		
	High school/GED	4 (6.3)
	College	28 (44.4)
	Graduate degree	15 (25.4)
	Post-Graduate/doctoral	15 (25.4)
	Some high school (no diploma)	1 (1.6)
Profession		
	Medical field	33 (52.4)
	Medical student	18 (28.5)
	Resident	10 (15.9)
	Attending physician	5 (7.9)
	Other	30 (47.6)

color swatches, only cover a limited spectrum of skin colors, and more complex tools are restricted by cost, practicality, or availability. Furthermore, areas of the skin perceivably change color with movement, shadowing, and

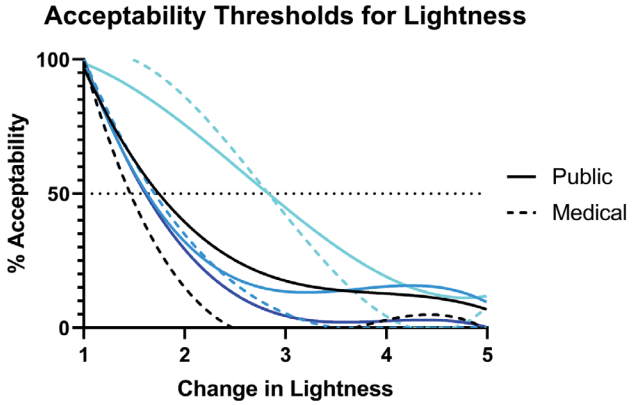

Fig. 3. Percent acceptability with changes in lightness. This graph demonstrates that as lightness of the standard color increases, observers are less critical. The darker regression lines correspond to the darker standards, and lighter regression lines correspond to lighter standards. Regression lines that are the same color represent the same color pairing; the dashed lines represent results obtained by the medical subgroup, while solid lines represent those of the general public.

light scatter, making color characterization a complex process.[6–8] We aimed to refine the approach to donor-recipient color matching by supplementing visual assessment with quantitative data using an accessible, handheld tool.

The PSTG was chosen for its comprehensiveness and relative ease of use. Observers were found to be more critical of pairings on the darker as opposed to the fairer end of the spectrum (Fig. 3). Findings in the literature are mixed; some studies have demonstrated that differences may be more *perceptible* at the darker end of the spectrum.[13] We surmise that *perceptibility* of color difference does not directly correlate with *acceptability* of a pairing. Our results also show that observers were more critical of differences in lightness as opposed to differences in undertone, which is consistent with prior studies.[6,8]

In the clinical setting, practitioners could use ATs to calculate the percentage of people who would deem a color match acceptable. The process would involve assigning a Pantone code to each the potential donor and recipient and referring to the threshold data for a quantitative assessment of how the match would be perceived by observers. These quantitative data would supplement visual assessment. Although the threshold in this study is defined at 50%, it can be altered depending on the clinical context.[14] Additionally, the proposed system could be applied to free tissue transfer procedures, to optimize aesthetic outcomes and guide clinical decision-making.

Despite important implications in VCA and autologous free tissue transfer, our study is not without limitations. A larger sample of color pairs and a larger, more varied population of survey participants could define the ATs with greater granularity. The lack of significant difference observed between the general public and medical professionals may be secondary to relatively small sample size. Future surveys should employ more controlled parameters to account for variations in external factors such as ambient light and background, factors known to

produce changes in visual color assessment.[13,15] Other factors such as vascularity, immune phenomena, aging, and sun exposure produce quantifiable changes in skin color. These changes could be monitored over time using the PTSG system. Finally, linking the threshold data derived from the PSTG to advanced colorimeter technology could increase reliability.

CONCLUSIONS

This study proposes the PSTG as a clinical tool to standardize color matching in VCA. This tool augments current methods by covering a broad spectrum of skin colors and assigns a numerical code to each tone. Color match ATs can supplement visual assessment using quantitative data. This has important potential implications for aesthetic outcomes in VCA and autologous free tissue transfer.

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