Invited Paper

Standardization and Quantification of Skin Tone Measurements for Patient-Centered, Optics-Based Biomedical Devices

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ABSTRACT

This invited contribution discusses three common measurement options to report skin tone for standardization of any optics-based device: (1) Fitzpatrick skin type (FST) scale, (2) Monk Skin Tone (MST) scale, and (3) Individual Typology Angle (ITA). Two examples of the benefit of the objective ITA option are summarized with respect to photoacoustic breast imaging, followed by perspectives on challenges and opportunities for the field.

1. INTRODUCTION

Variations in skin tone impact the performance of optics-based devices that require light transmission through the skin. Examples include laser treatments used for dermatological applications,[1] smartphone camera-based skin diagnostics,[2] pulse oximetry,[3] and photoacoustic imaging.[4,5] The impact of skin tone was amplified during the COVID-19 pandemic,[6–8] although historically, it has been known for decades that optics-based technologies perform differently when interacting with lighter vs. darker skin tones.

To achieve more equitable healthcare surrounding optics-based technology, skin tone can be objectively measured and reported along with data acquisition, similar to the importance of reporting of age and sex in biomedical studies.[9–11] Multiple types of scales have been designed or utilized to assess and report skin tone, with three of the most commonly reported in recent years being the Fitzpatrick skin type (FST) scale, the Monk Skin Tone (MST) scale, and the Individual Typology Angle (ITA). The FST is a six-point scale, developed by dermatologist Thomas Fitzpatrick.[12] This scale was originally designed to assess UV sensitivity, with more gradations for lighter skin tones and less for darker skin tones. The MST Scale is a ten-point scale developed by sociologist Ellis Monk.[13] ITA is an objective six-class classifier of skin tones based on colorimeter measurements of L* (lightness) and b* (yellowness/blueness) values, with higher angles classified as lighter skin tones and lower angles classified as darker skin tones.[14,15]

Research performed by the Photoacoustic & Ultrasonic Systems Engineering (PULSE Lab) at Johns Hopkins University has gravitated toward reporting ITA values due to its objectivity and ability to be quantified. Our studies are centered on its impact in photoacoustic imaging and the ability of ITA to enable standardization by providing quantitative measurements of skin tone. This report summarizes two use cases of ITA that have the potential to enable greater standardization in non-invasive biomedical optics technologies, including demonstrations that: (1) skin is the source of a detrimental artifact known as acoustic clutter in non-invasive photoacoustic imaging and (2) short-lag spatial coherence (SLSC) imaging[16,17] is a potential solution to mitigate this skin tone bias. Perspectives on related challenges and opportunities are then discussed.

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Molecular-Guided Surgery: Molecules, Devices, and Applications XII, edited by Summer L. Gibbs, Kenneth M. Tichauer,
Proc. of SPIE Vol. 13832, 1383204 · 2026 Published by SPIE
0277-786X · doi: 10.1117/12.3093145

2. SKIN AS THE SOURCE OF ACOUSTIC CLUTTER

Breast photoacoustic imaging is an emerging clinical application that requires non-invasive illumination through skin.[18–20] However, the melanin content of skin can introduce unwanted acoustic clutter, which compromises target visibility and overall image quality.[5] A series of multidomain photoacoustic simulations were conducted using a previously validated 3D breast model, which confirmed skin as the primary source of acoustic clutter.[21,22] This confirmation was provided by performing simulations with a photoacoustic target surrounded by breast tissue with and without skin, as shown in Fig. 1, with three key insights. First, it is increasingly difficult to visualize the photoacoustic target as skin tone darkens, with some optical wavelengths (e.g., 810 nm) producing better target visibility, though poor target consistently persists for darker skin tones. Second, higher wavelengths (e.g., 1064 nm) have lower skin absorption, enabling the simulated photoacoustic targets to appears similarly regardless of skin tone. Third, because this is a simulation of virtual patients, skin was completely removed, resulting in improved appearance of the target relative to all skin tones simulated. Clutter levels ranged -11 dB to 11 dB with skin and was reduced by up to 39 dB with skin removed.[21] The associated target contrast improved by up to 39 dB, revealing skin as most responsible for the degradation in target visibility as skin tone darkened.[21] These results, obtained with a Fast Fourier Transform (FFT)-based image reconstruction approach, provide a more general framework that uses objective ITA measurements to understand and assess the impact of varying skin tones on biomedical device performance.

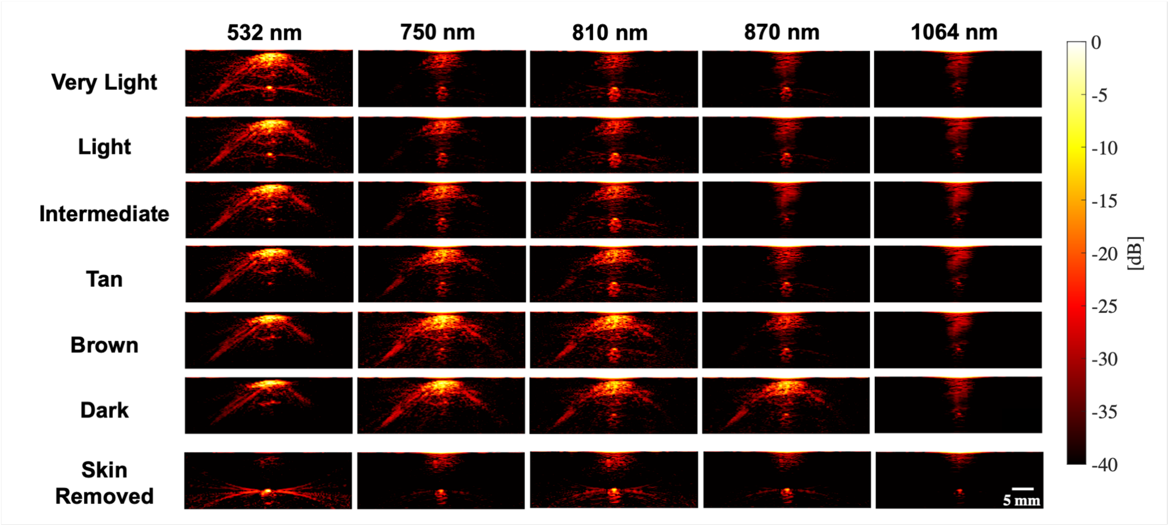

Figure 1. Demonstration that skin is primarily responsible for the presence of acoustic clutter, regardless of skin tone or wavelength. Adapted from Fernandes *et al.*[21]

3. CLUTTER REDUCTION WITH SHORT-LAG SPATIAL COHERENCE IMAGING

With skin present and a 1064-nm transmit wavelength, target visualization in the same multidomain photoacoustic breast simulations shown in Fig. 1 was improved with SLSC beamforming rather than FFT reconstruction. When implementing SLSC beamforming, as shown in Fig. 2, the 1064-nm wavelength enabled visualization of simulated target sizes ranging from 0.5 to 3 mm underlying very light to dark skin tones with mean SNR $\geq$3.47 and mean gCNR $\geq$0.57.[23,24] In addition to enhanced target visualization, acoustic clutter is reduced for multiple skin tones (rows) and for multiple target sizes (columns) with the SLSC beamformer. These results provide insights into coherence-based signal processing techniques as a potential solution to standardize outcomes across multiple biomedical devices with performance indicators that are impacted by skin tone variations.

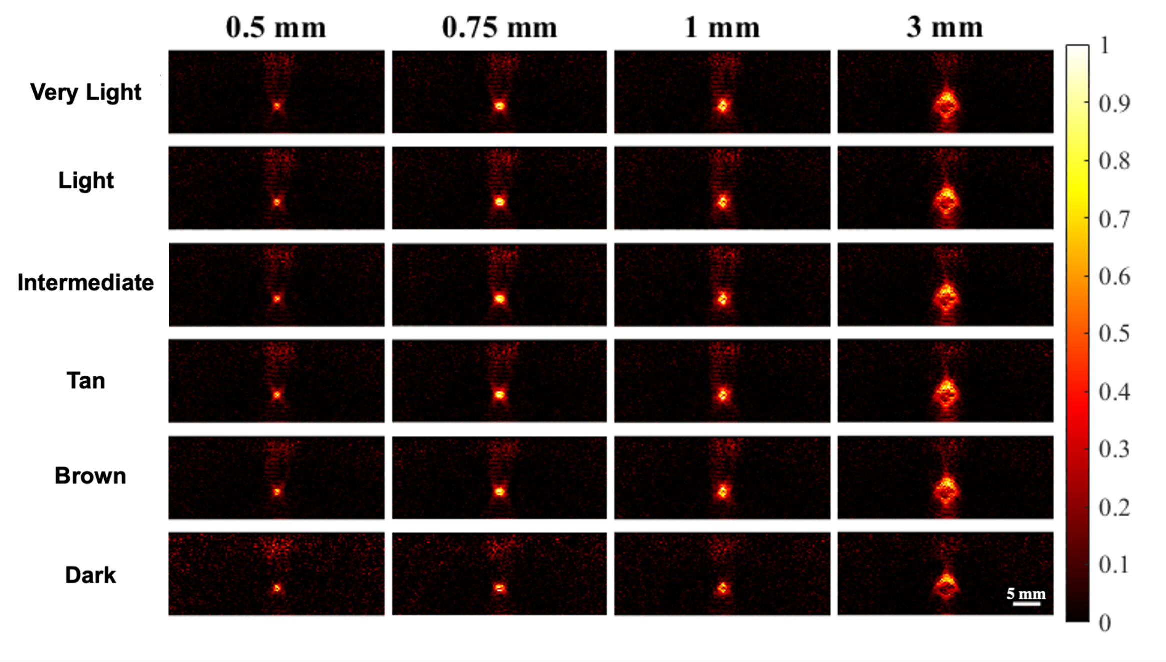

Figure 2. Demonstration that SLSC beamforming reduces acoustic clutter and enhances visualization of targets underlying multiple skin tones (rows) and for multiple target sizes (columns) when using an optical transmission wavelength of 1064 nm. Adapted from Rasquinha *et al.*[23]

4. CHALLENGES AND OPPORTUNITIES

Given the resurgence in interest surrounding standardization and quantification of skin tones for optics-based devises, it is promising that the Food & Drug Administration recently published a guidance document on this topic. The guidance contained within is highly anticipated to assist with better standardization,[25] with noted strengths and weaknesses.[26] In addition, while ITA is more objective than MST for the purpose of standardization, ITA values can potentially be calculated incorrectly.[27] Therefore, care must be taken to ensure accuracy when comparing across study results. In addition, in the event that a colorimeter may not always be available to make requisite measurements to calculate ITA, the MST scale is a suitable alternative that is better than not reporting any skin tones in patient-centered, non-invasive biomedical optics research. Finally, although it is the more historical approach to characterize skin tones when device performance depends on this variable, the FST scale should ideally be retired as an acceptable standard, due to its inequitable distribution of skin tones.

ACKNOWLEDGMENTS

This work is supported by by the Chan Zuckerberg Initiative DAF (an advised fund of the Silicon Valley Community Foundation) Grant No. 2022-309513 and the National Science Foundation (NSF) Alan T. Waterman Award Grant No. IIS-2431810.

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