ADDRESSING THE EFFECTS OF SKIN TONE ON PHOTOACOUSTIC IMAGING

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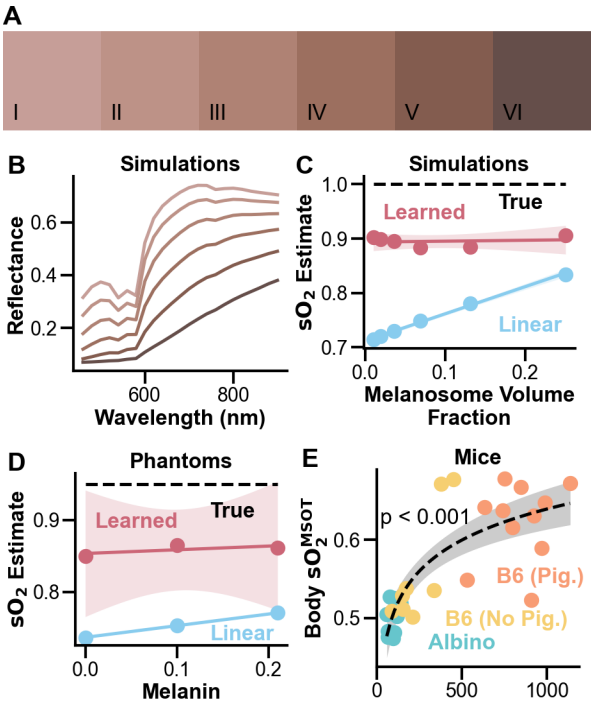

Figure 1: Melanin in the skin substantially affects quantitative photoacoustic imaging. RGB rendering of diffuse reflectance simulations are assigned to the Fitzpatrick scale (A). Diffuse reflectance spectra for each model (B). Unmixed sO_2 depends strongly on melanin concentration and is improved with a learned unmixing approach, shown in simulations (C) and phantoms (D). Linear sO_2 estimates increase with skin photoacoustic signal in pigmented (pig.) mice (E).

Optical sensing and imaging technologies are known to be sensitive to melanin in the epidermis, limiting their effectiveness in people with darker skin tones. Biases have been observed in several techniques where light passes through the skin. Pulse oximeters, bilirubinometers and wearable technologies have all been affected, with worse outcomes for people with darker skin (*1*–*3*). Early studies in photoacoustic imaging (PAI) have identified similar biases (*4*, *5*). Tackling this issue is crucial for ensuring standardization, reproducibility, and equity in clinical PAI. We assessed the effects of skin tone on PAI in a controlled setting using computational skin models with varying blood oxygenation and melanin concentration (Fitzpatrick scale, logarithmically from 1% to 25% melanosome volume fraction, Figure 1A). We obtained diffuse reflectance values consistent with typical variation in the population (0.20 to 0.72 at 685 nm, Figure 1B). Light transport was simulated using a Monte-C arlo model. We observed a linear relationship between melanosome volume fraction and linear-unmixed sO_2 ($R^2 = 0.998$, $p < 0.001$, gradient = 0.500 $\pm$ 0.014); this trend was reduced using a gradient-boosted regressor trained on independently simulated data ($R^2 = 0.026$, $p = 0.76$, gradient = 0.017 $\pm$ 0.051) (Figure 1C). Consistent results were observed in skin-mimicking blood oxygenation phantoms. Agarose phantoms with two layers were constructed with an outer 1 mm layer containing synthetic melanin. Standard spectral unmixing and learned spectral unmixing were applied and compared to pO_2 probe measurements. We observed an increase in linear-unmixed sO_2 with melanin concentration ($p < 0.001$, gradient = 0.162 mL/mg). sO_2 quantification was improved using the learned unmixing approach, removing the dependence on melanin concentration ($p = 0.50$, gradient = 0.051 mL/mg) (Figure 1D).

Finally, we demonstrated the impact of skin pigmentation on PAI *in vivo* using mouse models. We compared an albino mouse (C57BL/6 albino) strain to pigmented black 6 (C67BL/6, B6) mice. Albino mice were imaged once and B6 mice twice to allow pigmentation to develop. We observed a strong correlation between skin photoacoustic signal and linear-unmixed sO_2 in the body of the mice ($p < 0.001$) (Figure 1E).
PAI demonstrates a clear measurement bias due to melanin in the skin. Reproducible and equitable application of quantitative PAI will likely require a combination of physics-based, data-driven, and empirical methods to account for varying light fluence and tissue properties fairly across the population.

1. M. W. Sjoding, R. P. Dickson, T. J. Iwashyna, S. E. Gay, T. S. Valley, N. Engl. J. Med. 383, 2477–2478 (2020).
2. L. Holland, K. Blick, Am. J. Clin. Pathol. 132, 555–561 (2009).
3. P. J. Colvonen, P. N. DeYoung, N. O. A. Bosompra, R. L. Owens, Sleep. 43, 1–3 (2020).
4. Y. Mantri, J. V. Jokerst, Biomed. Opt. Express. 13, 875 (2022).
5. X. Li et al., J. Biophotonics. 12 (2019), doi:10.1002/jbio.201800442.

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