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Authors

Chen, Katherine

An, Miranda B

Kirk, Stephanie D

et al.

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Spatial Frequency Domain Imaging of the Oculofacial Region in Control Patients

Katherine Chen^{1*}, Miranda B. An¹, Stephanie D. Kirk¹, John Abdelmalek¹, Divya Devineni¹, Shijun Sung¹, Kaylyn C. Mattick¹, Claire Malley¹, Jaylen M. Lee³, Danny Xie¹, Gordon T. Kennedy¹, Bernard Choi^{1,4,5}, Anthony J. Durkin^{1,4}, Lilangi S. Ediriwickrema^{1,2}

1. Beckman Laser Institute and Medical Clinic, University of California, Irvine. 1002 Health Sciences Rd, Irvine, CA 92612, USA.
2. Department of Ophthalmology, Gavin Herbert Eye Institute, University of California, Irvine. 850 Health Sciences Rd, Irvine, CA 92617, USA.
3. Biostatistics, Epidemiology, and Research Design Unit, University of California, Irvine. 850 Health Sciences Rd, Irvine, CA 92617, USA.
4. Department of Biomedical Engineering, University of California, Irvine. 850 Health Sciences Rd, Irvine, CA 92617, USA.
5. Department of Surgery, University of California, Irvine. 850 Health Sciences Rd, Irvine, CA 92617, USA.

ABSTRACT

Spatial frequency domain imaging (SFDI) is a wide-field optical imaging modality that applies patterned illumination at multiple center wavelengths (470-851 nm) to quantify the properties of subsurface tissue *in vivo*. Imaging of the periocular region will guide diagnostic and therapeutic decision making in inflammatory and infiltrative conditions by quantifying parameters such as tissue oxygen saturation and hemoglobin concentration. We previously used a fabricated tissue simulating facial phantom to study the geometric impact of complex ocular adnexal anatomy inherent to the periocular region and identified robust and accurate regions of interest (ROI) by which to image patients. Twenty-five control patients were imaged under an approved IRB protocol using the Reflect RSTM (Modulim, Inc., Irvine, CA) to measure calibrated diffuse reflectance images over a 15 x 20 cm² field of view, with a spatial resolution of ~0.5 mm. “En face” and “side profile” views were captured along established regions of interest (ROIs): inferior temporal quadrant (ITQ), inferior nasal quadrant (INQ), superior temporal quadrant (STQ), and forehead (control), as well as a cast polydimethylsiloxane-based tissue-simulating reference facial phantom with known optical properties as a geometric control. The normative range for μ' s and μ a values for periocular and forehead ROI are presented. Measurement angle did not significantly impact the measured optical properties. Data from the pool of measured subjects demonstrated an increase in μ a with increasing Fitzpatrick score, whereas μ' s artificially reduced with increasing Fitzpatrick score, consistent with previous findings. This is the first study to quantitatively characterize normal human periocular skin using SFDI across a range of skin types. Measurements were robust to imaging angle but varied with Fitzpatrick score.

Keywords: SFDI, Wide-field Imaging, Spatial Frequency Domain Imaging, Facial Phantom, Periocular Skin

1. INTRODUCTION

Spatial frequency domain imaging is a non-invasive imaging technique that utilizes spatially modulated light (visible to near infrared light) to measure quantitative properties of the tissues examined.¹ This groundbreaking method to objectively gather optical properties and chromophore concentrations of *in vivo* subsurface tissue allows for readily imaging patients in the clinical setting. SFDI has demonstrated utility in evaluating burn severity, tissue flap viability following surgical reconstruction, laser treatment efficacy in patients with port-wine stains, and changes in cerebral blood flow following cardiac arrest.²⁻⁶

Current work is ongoing in the Durkin and Ediriwickrema Lab to assess the geometric implications of wide-field imaging along the periocular region using a solid tissue simulating facial phantom (Figure #2). Results suggest that certain regions of

*kathec14@uci.edu

interest (ROI) of a generalized face have minimal impact on SFDI measurement accuracy. Areas with heightened topographic variation exhibit measurement variability.⁷ Human patients demonstrate a unique periorcular signature profile for each ROI (Figure #3). Human controls demonstrated an increase in the magnitude of the wavelength-dependent absorption coefficient (μ_a) as a function of increasing Fitzpatrick score, whereas the value of the wavelength-dependent reduced scattering coefficient (μ'_s) artificially decreased with increasing Fitzpatrick score as previously described in the literature.⁸

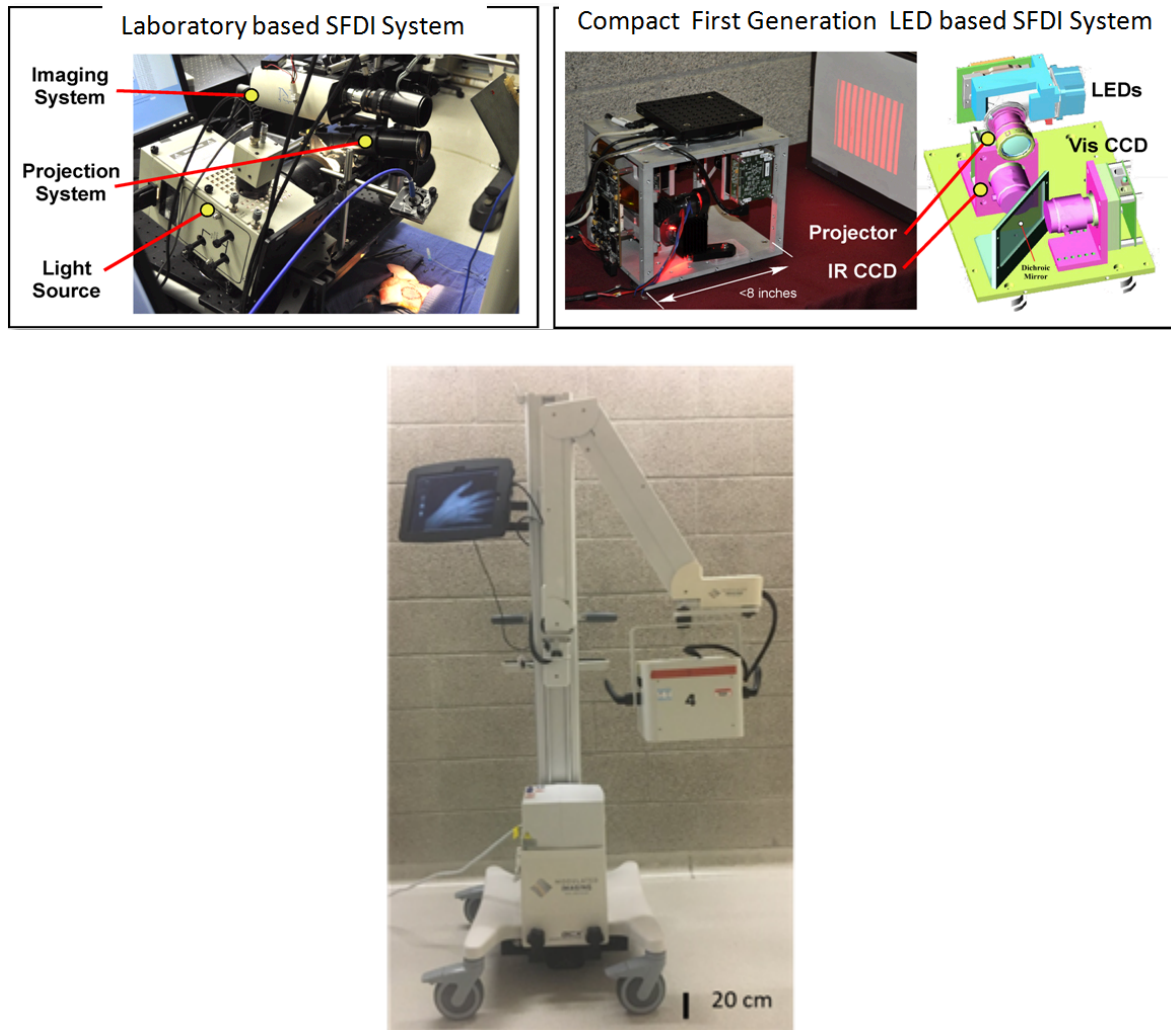


Figure 1. First generation LED based SFDI hardware (left) and its configuration (right) (*adapted from Durkin et al.*) Cart-based SFDI instrument (bottom), OxImager RS™ (Modulim, Inc., Irvine, CA), composed of 9 discrete LED light sources. Eight of these (471-851nm) are modulated at 5 to 7 spatial frequencies (0-0.3mm⁻¹). The 971 nm LED is not spatially modulated, but can still be used to extract quantitative information about water fraction

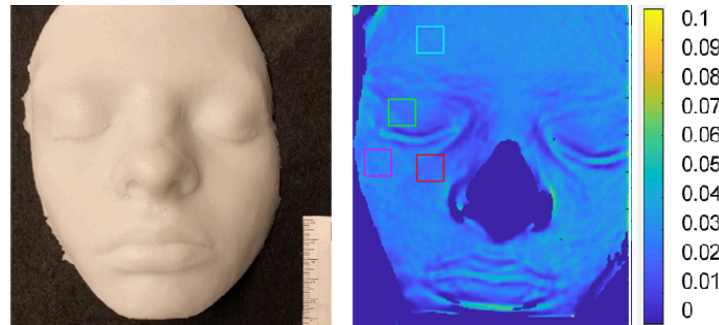


Figure 2. Facial phantom with (C-D) corresponding absorption (μ_a) coefficient maps obtained at 659 nm for various region of interests (ROI), inferior temporal quadrant (ITQ), inferior nasal quadrant (INQ), superior temporal quadrant (STQ), and forehead (FH).

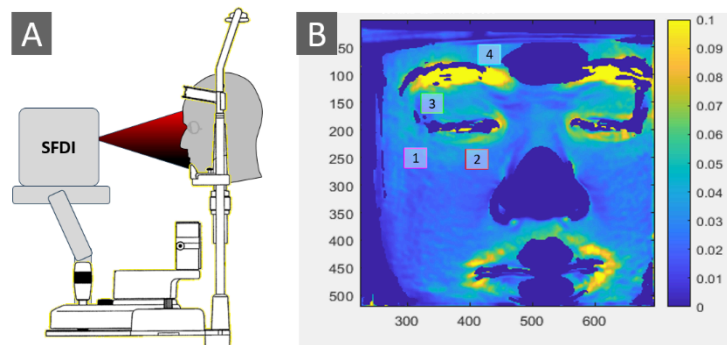


Figure 3. (A) SFDI system consisting of a light source projecting spatially modulated light onto a subject's face positioned in a chin rest. (B) 'En face' SFDI image with regions of interest (ROI) in a control subject: inferior temporal quadrant (1 - ITQ), inferior nasal quadrant (2 - INQ), superior temporal quadrant (3 - STQ), and control: forehead (4 - FH).

2. METHODOLOGY

Under approved UCI IRB protocol (HS#2019-5254), SFDI measurements are obtained using the Reflect RSTTM (Modulim, Inc., Irvine, CA) to measure calibrated diffuse reflectance images over a 15 x 20 cm² field of view, with a spatial resolution of ~0.5 mm (Figure 1). The SFDI light sources consist of eight light emitting diodes (LEDs) with center wavelengths ranging from 470-851 nm. For each wavelength, sinusoidal light patterns at five to seven spatial frequencies (from 0-0.3/mm) are projected onto the tissue. "En face" and "side profile" views were captured along established ROI: inferior temporal quadrant (ITQ), inferior nasal quadrant (INQ), superior temporal quadrant (STQ), and forehead (FH), as well as a cast polydimethylsiloxane-based tissue-simulating reference phantom with known optical properties. 25 control patients were selected and imaged. Medicated numbing eye drops were administered before inserting corneal protectors and proceeding with imaging. Data processing was performed in Matlab with the MiAcquire software and the four patient ROI's were manually selected with MiVis software. Mean and standard deviation of the absorption and reduced scattering coefficients at 851nm were then calculated with a separate Matlab code and analyzed for significance across patients.

3. DATA

Four regions of interest were examined. The spread of data for each region of interest is presented along the ITQ for the 25 control patients. The mean μ_a was 0.02, 0.022, 0.036, and 0.025 mm⁻¹ for the ITQ, INQ, STQ, and forehead regions, respectively; the mean μ_s was 1.21, 1.36, 1.16, and 1.44 mm⁻¹ for the ITQ, INQ, STQ, and forehead ROI, respectively (Table 1). Control patients were imaged from two vantage points ("side profile" and "en face") to evaluate variability in patient positioning within the chin-rest and aligning the light source. A T-test was used to determine the significance of patient positioning on mean μ_a and μ_s for each region of interest. The values for each ROI are reproducible independent of the angle of incidence, similar to that observed with the facial phantom (Table 2, Fig. 4).

Table 1. Oculofacial Regions of Interest (ROI) Optical Characteristics. The mean and standard deviation of the absorption and reduced scattering coefficients for each measured ROI at 851 nm are presented.

<i>n</i> =25	ITQ	INQ	STQ	Forehead
μ_a (mm^{-1})	0.02 (0.015)	0.022 (0.017)	0.036 (0.0288)	0.025 (0.022)
μ'_s (mm^{-1})	1.21 (0.16)	1.36 (0.23)	1.16 (0.15)	1.44 (0.24)

Table 2. Oculofacial ROI Optical Measurements obtained from “en face” vs. “side profile” vantage points.

ROI	Property	“en face”	“side profile”	p-value
ITQ	μ_a	0.011 (0.001 , 0.021)	0.011 (0.002 , 0.02)	0.624056
	μ'_s	1.239 (0.969 , 1.508)	1.256 (0.956 , 1.557)	0.372803
INQ	μ_a	0.012 (0.005 , 0.018)	0.011 (0.003 , 0.019)	0.437767
	μ'_s	1.407 (0.902 , 1.912)	1.376 (0.757 , 1.995)	0.435817
STQ	μ_a	0.017 (0.005 , 0.029)	0.017 (0.002 , 0.033)	0.904905
	μ'_s	1.224 (0.953 , 1.495)	1.302 (0.994 , 1.609)	0.257038
Forehead	μ_a	0.013 (0.003 , 0.022)	0.014 (0.004 , 0.023)	0.491657
	μ'_s	1.523 (1.068 , 1.978)	1.441 (1.073 , 1.808)	0.071104

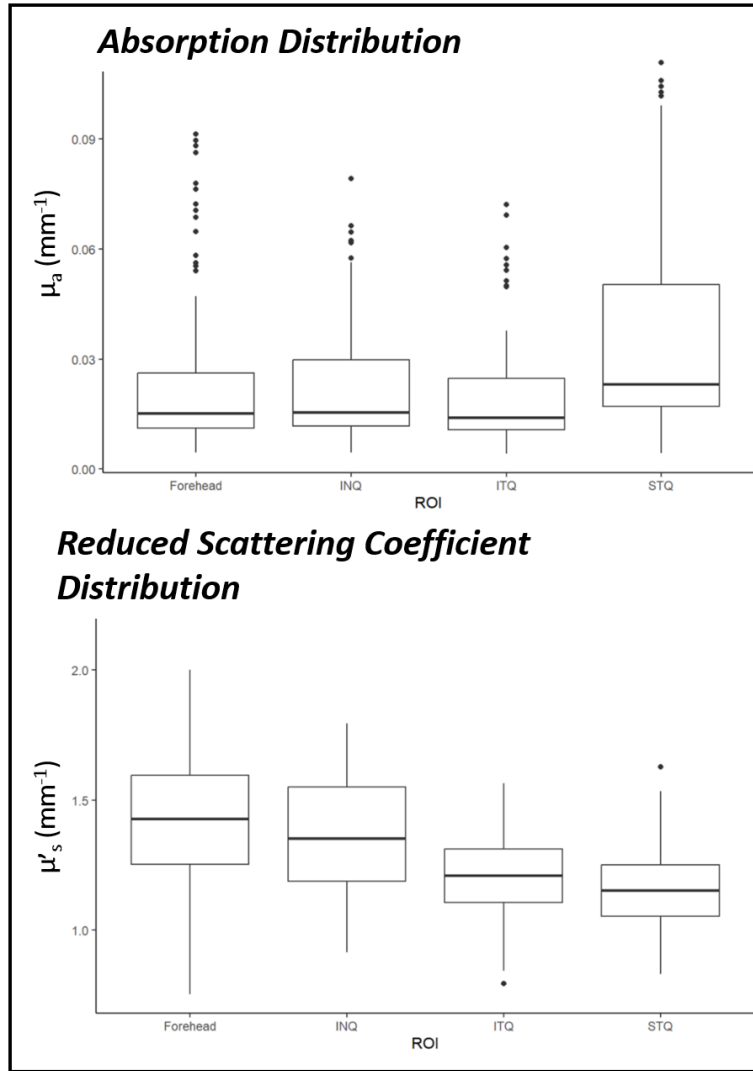


Figure 4. Oculofacial Optical Characteristics. Box and Whisker plot demonstrating the spread of absorption and reduced scattering coefficient values for each ROI.

4. RESULTS

Across the ITQ, INQ, STQ, and forehead regions, the mean μ_a was 0.02, 0.022, 0.036, and 0.025 mm⁻¹ for each; the mean μ'_s was 1.21, 1.36, 1.16, and 1.44 mm⁻¹ (Table 1). The STQ region comprises a large section of the eyelid, which presents some of the thinnest skin humans have, possibly contributing to the high mean absorption coefficient. In contrast, the forehead region of interest demonstrated the highest mean scattering, which is consistent with average relative skin thickness of the human face. The values for each ROI being replicable independent of imaging angle validates SFDI's imaging flexibility and consistency in imaging patients.

5. CONCLUSIONS

This study presents normative periocular and forehead SFDI optical property measurements for future implementation of SFDI in clinical settings. From the results, device and/or patient positioning does not impact patient measurements when obtained using a chin-rest and forehead stopper. Differences in mean absorption and scattering coefficients were not significant across control patients in varied imaging positions and lighting, thus future periocular disease measurements will be obtained and compared to this data set.

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AJD is a co-founder of Modulim Incorporated, a business entity with interests related to the development and commercialization of spatial field domain imaging (SFDI). He is in compliance with UC Irvine and National Institutes of Health policy regarding conflict-of-interest management.

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