Opto-acoustic Relative-Colorization of Blood Oxygen Saturation in Biologically Relevant Phantoms

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Ryerson University

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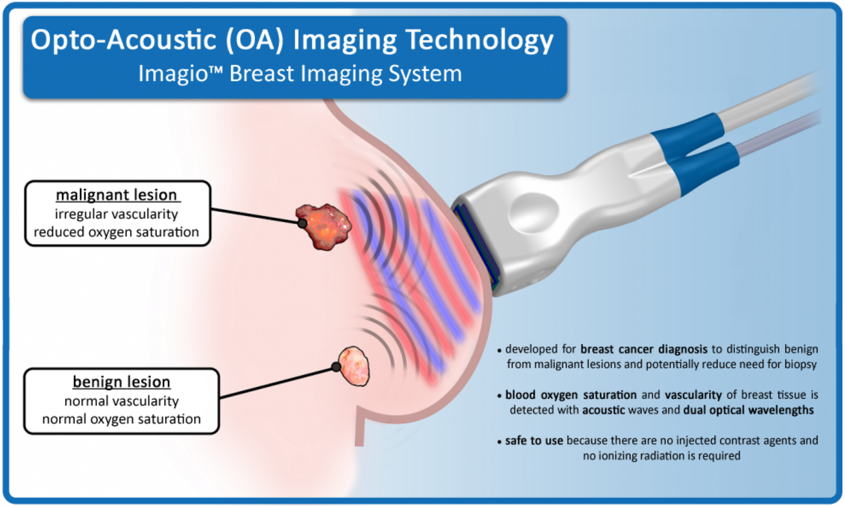
Opto-acoustic Imaging



Pivotal Study

findings from clinical study of 2100 subjects

OA **improved specificity** to distinguish benign from malignant lesions

(source: Neuschler, E. et al. "A Pivotal Study of Optoacoustic Imaging to Diagnose Benign and Malignant Breast Masses: A New Evaluation Tool for Radiologists.". In: *Radiology* 287.2 (2018), pp. 398–412)

Motivation

for today's talk

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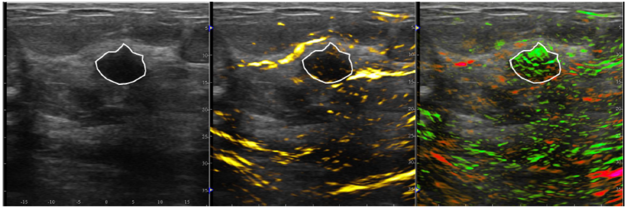
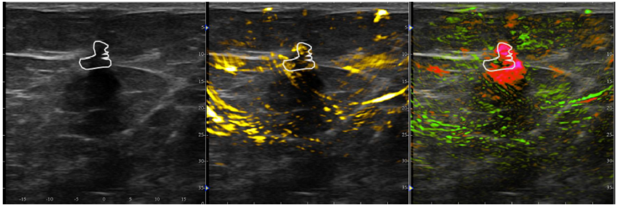
- **blood oxygen saturation (sO_2)** is an important parameter for assessing differences between benign and malignant lesions
- accurate diagnosis involves proper interpretation of **color mapped images** and an understanding of how images relate to tumor physiology
- necessary to perform **system characterization** that relates RGB image colorization to known oxygen saturation values

Opto-acoustic Images



(a) **benign lesion** (fibroadenoma)



(b) **malignant lesion** (grade II invasive ducal carcinoma)

(source: Zalev, J. et al. “Opto-acoustic image fusion technology for diagnostic breast imaging in a feasibility study”. In: *SPIE Medical Imaging*. International Society for Optics and Photonics. 2015, pp. 941909–941909)

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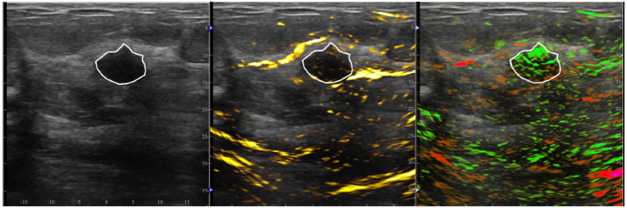

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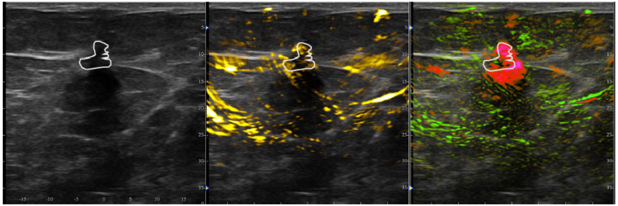

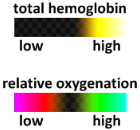

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  - perform quantitative measurement using **biologically relevant phantoms** and **bovine blood** at controlled oxygenation levels
  - assess the ability to distinguish **small differences in oxygenation** as the **oxygenation level is varied**

Statistical Color Mapping

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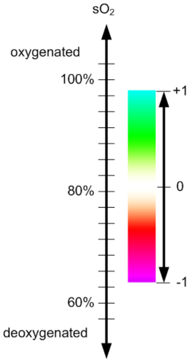
- performs color mapping to display opto-acoustic contrast using **relative colorization**
- visualizes structural and functional information from areas of strong blood oxygenation and total hemoglobin **relative to background tissue**

Statistical Color Mapping

relative colorization of blood oxygen saturation



a)

Statistical Color Mapping

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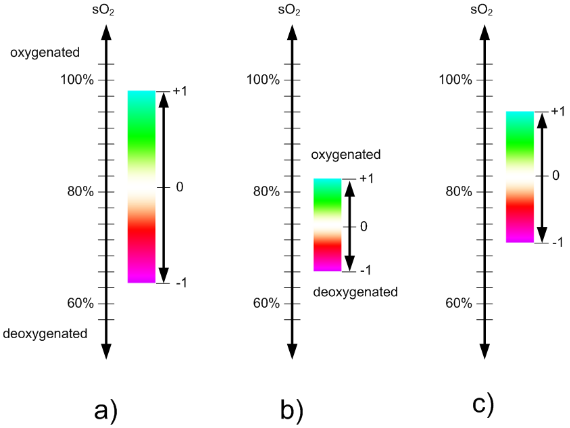

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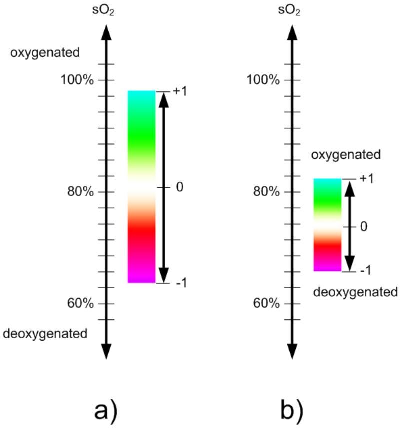
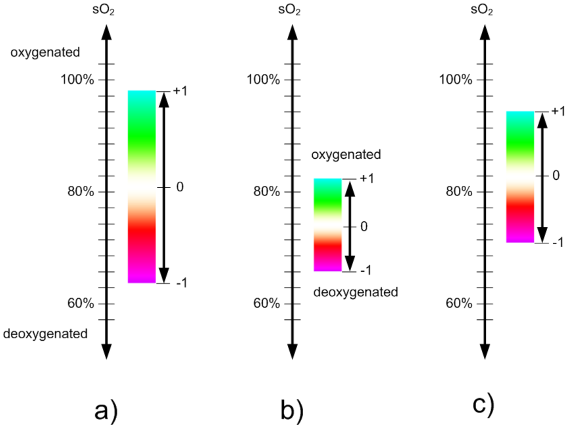


- color midpoint corresponds to average sO_2 value of reference region

Statistical Color Mapping

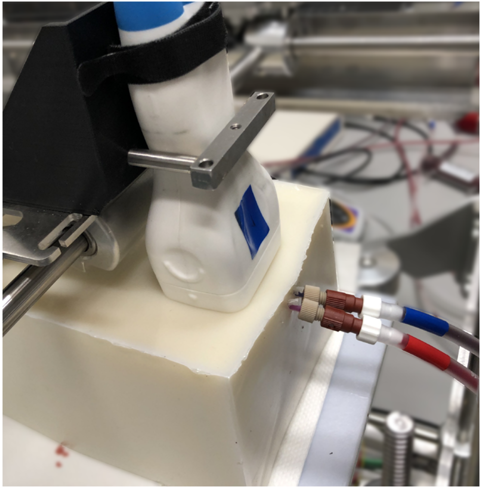
relative colorization of blood oxygen saturation



- color midpoint corresponds to average sO_2 value of reference region
- color limits determined by sO_2 variability of reference region

Biologically Relevant Phantoms

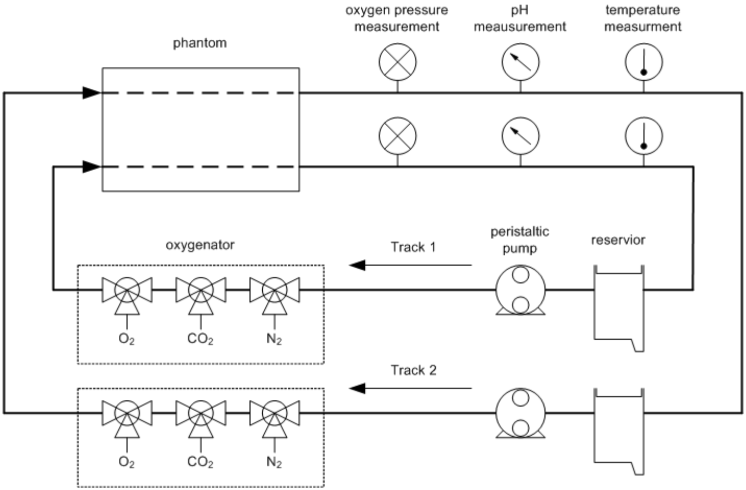
optical and acoustic properties emulate breast tissue



Phantom properties

Material	PVCP (plastisol)	
Optical Properties	757nm	1064nm
Absorption μ_a (1/cm)	0.47 ± 0.10	0.82 ± 0.38
Scattering μ_s' (1/cm)	9.18 ± 0.06	5.89 ± 1.35
Acoustic Properties		
Speed of sound (m/s)	1477	
Attenuation (dB/cm)	$0.8 - 8.2$	
Vessel depth	15mm	
Vessel diameter	1.6mm	

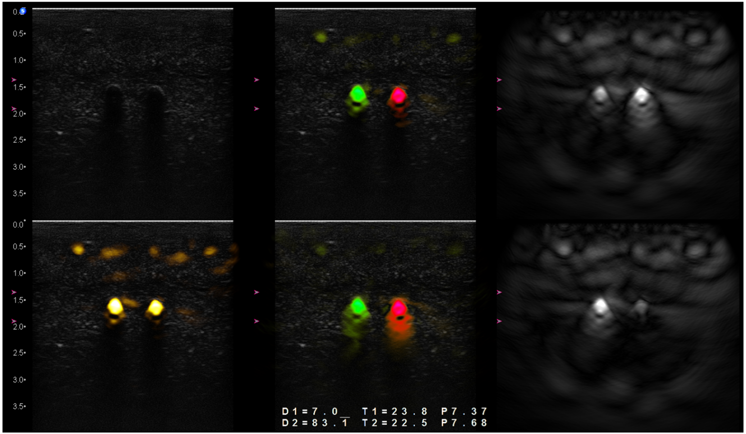
Experimental Setup



two independent tracks of bovine blood at controlled oxygenation levels

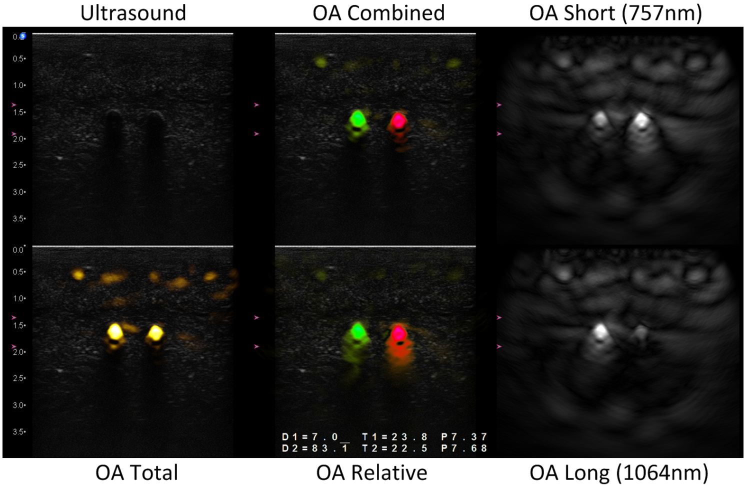
Imagio Output

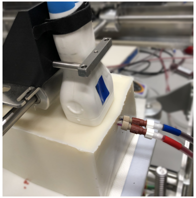
Ultrasound | OA Combined | OA Short (757nm)



OA Total | OA Relative | OA Long (1064nm)

Imagio Output





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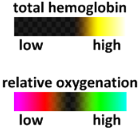

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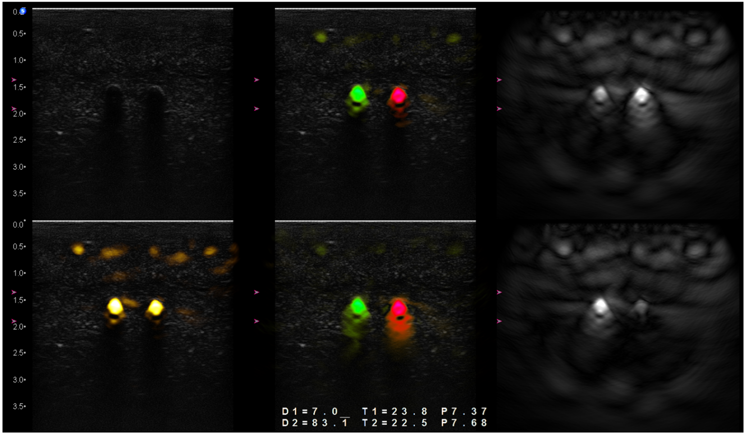

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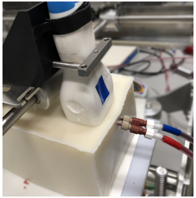

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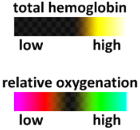

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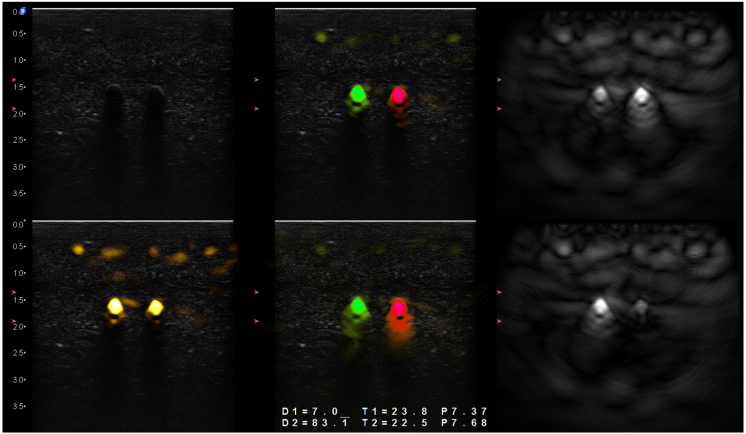

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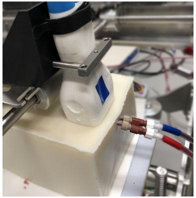
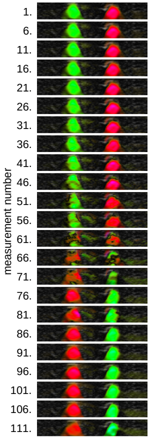


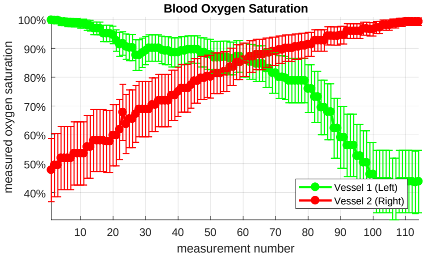
$[sO_2]_{left} = 99\%$, $[sO_2]_{right} = 40\%$

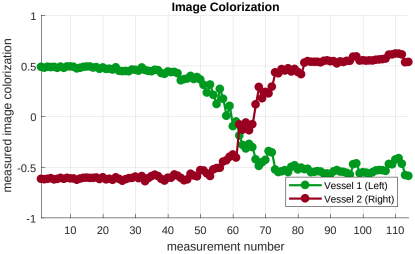
arrow markers indicate reference region, which includes both vessels and phantom background

Effect of Varying sO_2 on RGB Color

Experiment 1







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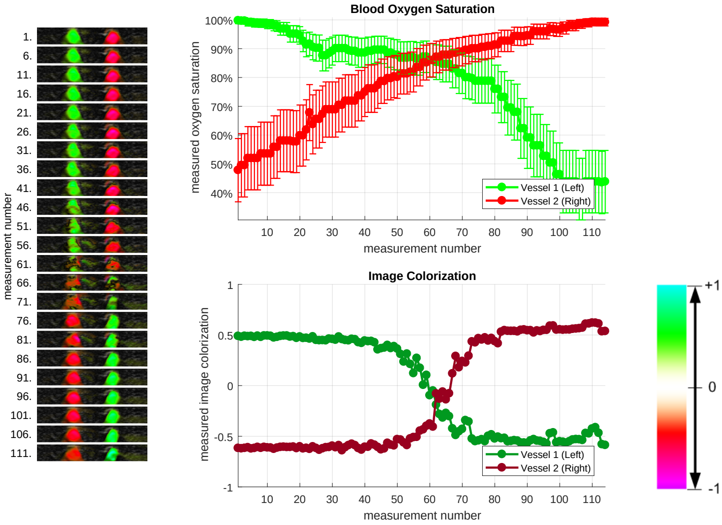
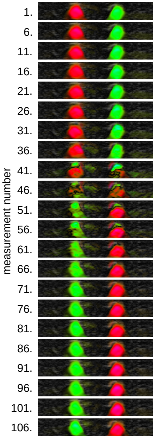
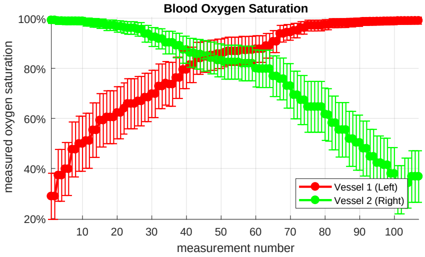
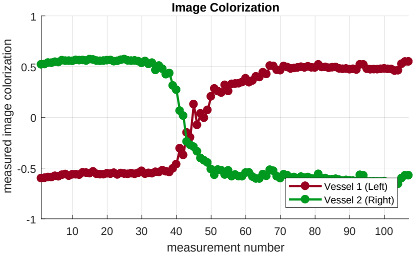


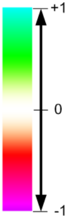
Effect of Varying sO_2 on RGB Color

Experiment 1 (repetition)





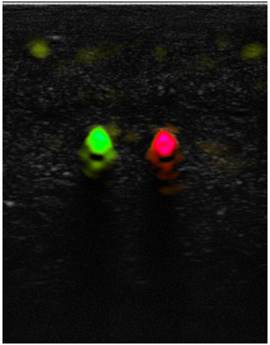




Measure RGB Color Distinction (Experiment 2)

Vessel 1 (left) is **held constant** as reference

Vessel 2 (right) is **varied**



$\Delta[\mathsf{sO_2}] = 60\%$

color distinction depends on **sO_2 difference** between the vessels

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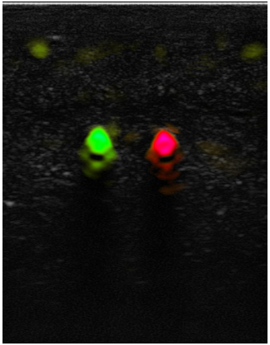

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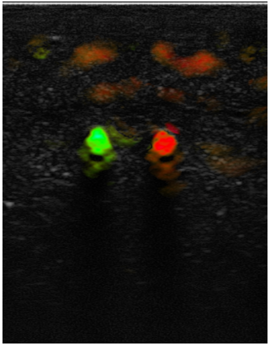

$\Delta[\mathsf{sO_2}] = 14\%$

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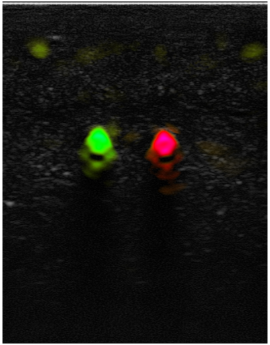

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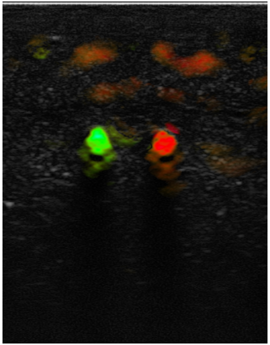

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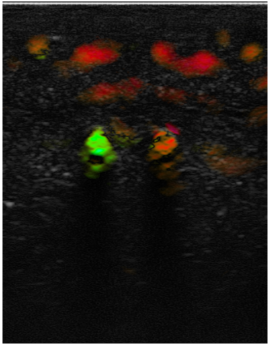

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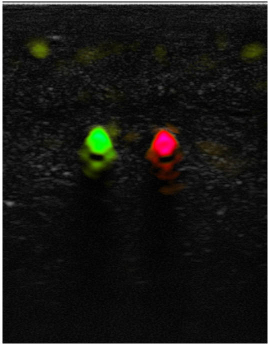

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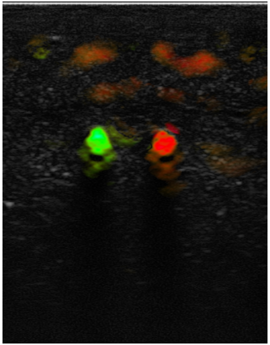

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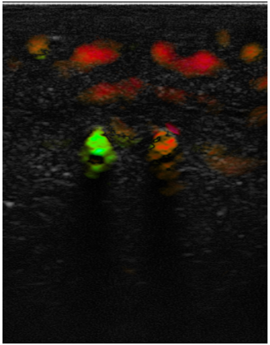

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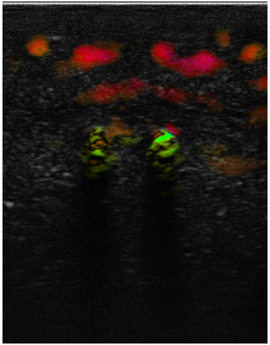
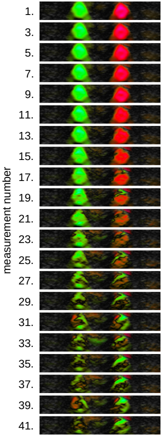


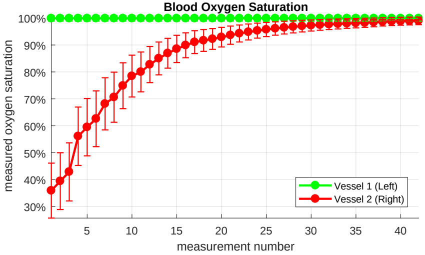
$\Delta[\text{sO}_2] = 2\%$

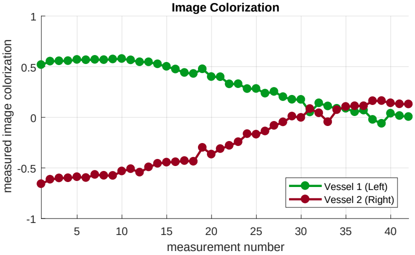
color distinction depends on **$\mathbf{sO_2}$ difference** between the vessels

Effect of Varying sO_2 on RGB Color Distinction

Experiment 2







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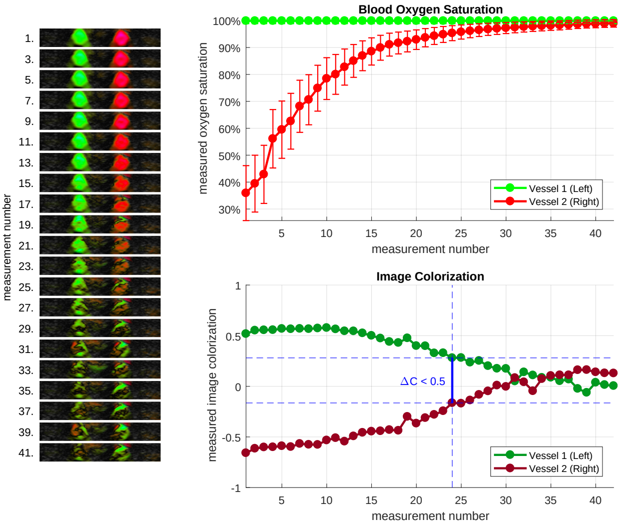

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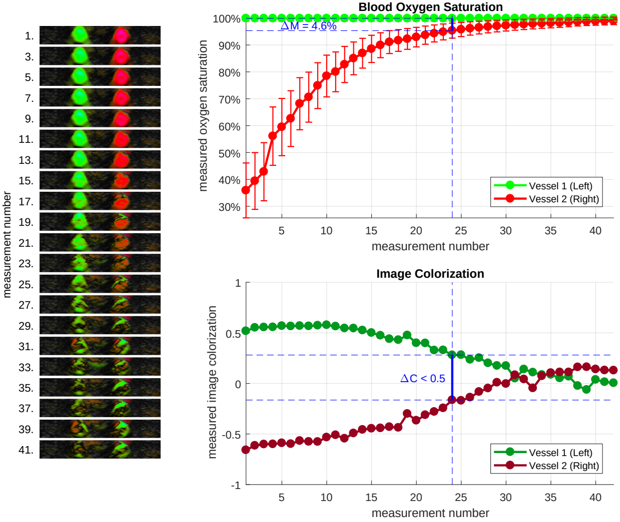

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- proposed a technique to characterize the ability to distinguish small differences in blood oxygen saturation when using relative colorization
- measuring effects of additional parameters (vessel depth, hematocrit, etc.) on ΔM will be most effective if one reference vessel is held at constant sO_2
- in PVCP phantom with reference vessel at 99% sO_2, the image colorization threshold ΔC was reached at sO_2 difference ΔM of 4.6%

Future Work

- perform additional measurements and characterize ΔM while varying:
  - blood hematocrit level
  - vessel depth

References I

[1] Dash, R. K. and Bassingthwaighte, J. B. "Erratum to: blood HbO 2 and HbCO 2 dissociation curves at varied O 2, CO 2, pH, 2, 3-DPG and temperature levels". In: *Annals of biomedical engineering* 38.4 (2010), pp. 1683–1701.

[2] Neuschler, E. et al. "A Pivotal Study of Optoacoustic Imaging to Diagnose Benign and Malignant Breast Masses: A New Evaluation Tool for Radiologists.". In: *Radiology* 287.2 (2018), pp. 398–412.

[3] Vogt, W. C. et al. "Biologically relevant photoacoustic imaging phantoms with tunable optical and acoustic properties". In: *Journal of biomedical optics* 21.10 (2016), p. 101405.

[4] Zalev, J. et al. "Opto-acoustic image fusion technology for diagnostic breast imaging in a feasibility study". In: *SPIE Medical Imaging*. International Society for Optics and Photonics. 2015, pp. 941909–941909.

[5] Zalev, J. and Clingman, B. *Statistical mapping in an optoacoustic imaging system*. US Patent 9,330,452. 2016.

Acknowledgement

Ryerson University

SENO

NSERC CRSNG

CIHR IRSC
Canadian Institutes of Health Research
Instituts de recherche en santé du Canada

Canada Research Chairs
Chaires de recherche du Canada

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

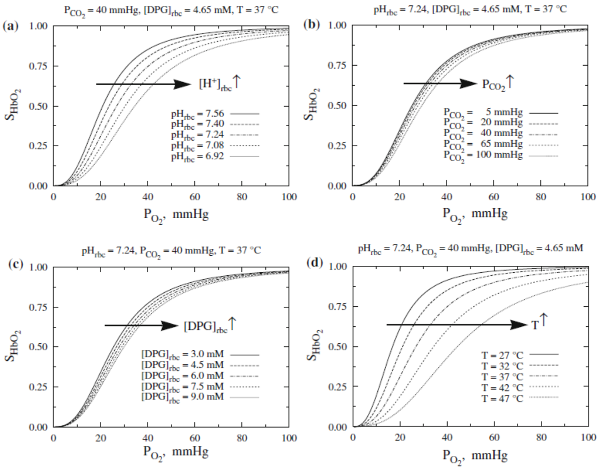
Breast Tissue Properties

	Optical properties		Acoustic properties	
	Absorption coefficient (cm^{-1})	Reduced scattering coefficient (cm^{-1})	Speed of sound (m/s)	Acoustic attenuation coefficient (dB/cm)
General soft tissue	0.1 - 0.5	10 - 20	1450 - 1575	0.5 - 30
Breast fat	0.05 - 0.3	3 - 8	1430 - 1480	1 - 18
Breast parenchyma	0.1 - 0.3	5 - 15	1460 - 1520	2 - 25
Blood	2.0 - 10.0	10 - 15	$\sim$1560	0.1 - 2

Optical and acoustic properties of representative soft tissues. Optical properties cover a spectrum from 600 to 900 nm, while acoustic properties span 1 to 10 MHz. (source: Vogt, W. C. et al. "Biologically relevant photoacoustic imaging phantoms with tunable optical and acoustic properties". In: *Journal of biomedical optics* 21.10 (2016), p. 101405)

Oxygen dissociation curves

Influence of Temperature, CO_2, DPG and pH



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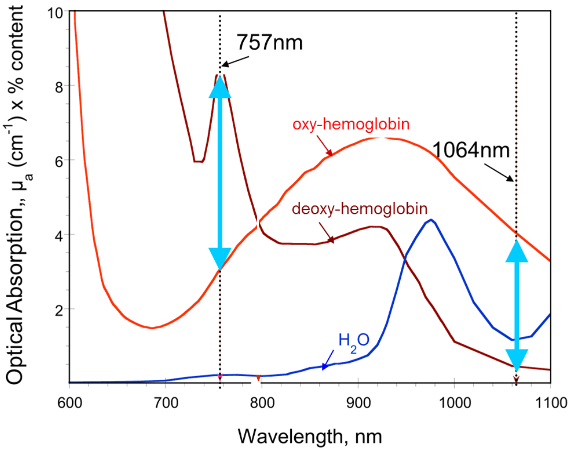
Optical Absorption



Optical absorption coefficient for primary chromophores of tissue in near-infrared optical spectrum. It is indicated that at 757nm, deoxy-hemoglobin absorbs light more strongly that oxy-hemoglobin. At 1064nm, oxy-hemoglobin absorbs light more strongly than deoxy-hemoglobin (adapted from: www.senomedical.com).