A Self-Calibrating Fiber-Optic Probe for Tissue Optical Spectroscopy

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Tissue Optical Spectroscopy

Optical spectroscopy is sensitive to the absorption, scattering and/or fluorescence properties of biological molecules in tissue.


Sources of Intensity Fluctuations

- Lamp intensity fluctuates 25% from 3-60 minutes and 3% after 30 minutes for 575 nm.
- The ratio $I_{575}/I_{475}$ changes 4.4% after 30 minutes.

- The lamp intensity varies as much as 6.8% from day to day.

5% change in intensity $\rightarrow ~20\%$ error in $\mu_a$ & $\mu_s'$
Sources of Spectrum Variations

- Instrument: wavelength-dependence
- Devices: degradation over time

5% change in intensity $\rightarrow \sim 20\%$ error in $\mu_a$ & $\mu_s'$

- Fiber bending loss during measurements
- $> 6\%$ at a diameter of 3cm
- $> 11\%$ at a diameter of 2cm
# Traditional Calibration Methods & Limitations

A real-time, faster, more robust and accurate calibration approach is needed!

<table>
<thead>
<tr>
<th>Tissue Type</th>
<th>Calibration Method</th>
<th>Corrected for</th>
<th>Through-put</th>
<th>Day-to-Day</th>
<th>Real-time Lamp Drift</th>
<th>Real-time Fiber Bend</th>
<th>Warm-up NOT Required</th>
<th>Cal. Meas. NOT Required in Clinic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feld M.S. [1]</td>
<td>Colon polyps, Liquid phantom</td>
<td>Y</td>
<td>?</td>
<td>N</td>
<td>N</td>
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<tr>
<td>Richards-Kortum F. [2,3]</td>
<td>Ovarian, Cervix, Liquid phantom</td>
<td>Y</td>
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<td>N</td>
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</tr>
<tr>
<td>Thueler P. [4]</td>
<td>Stomach, Solid phantom</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td>N</td>
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</tr>
<tr>
<td>Foster T. [5]</td>
<td>Phantoms, Ref. fiber &amp; liquid phantom</td>
<td>Y</td>
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<tr>
<td>Our Group (Old) [6]</td>
<td>Breast, Cervix, Diffuse refl. Standard &amp; Phantom</td>
<td>Y</td>
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**Accuracy**

**Efficiency**

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Experimental Setup

Schematic of the System

- Xenon Lamp
- Mono-chromator
- Spectrograph
- CCD
- Laptop
- Computer
- Sample
- Calibration Source Fiber
- Fiber Optic Probe
- Calibration Return Fiber
- Source Fiber
- Detection Fiber
- Probe Tip
- Stainless Steel Tube
- Reflective Rod
- Probe Housing
Correction for Intensity Variations

Raw spectra from a mirror at different levels of attenuation by an ND filter and no attenuation.

The variation in the illumination intensity due to the ND filters is minimized to less than $\pm 3\%$. 

Ratio between mirror and self-calibration spectra normalized to the first scan (no filter).
Correction for Wavelength-Dependence

Correction of the SC channel for wavelength response:

\[ F_{corr}(\lambda) = \frac{R_{Puck}(\lambda)}{R_{SC}(\lambda)} \]
Data Analysis Procedures

Calibration with Spectralon Reflectance Standard (Puck)

Collect Phantom Spectrum → Collect Puck Spectrum

Collect Tissue Spectrum → Collect Puck Spectrum

Calibrated Phantom Spectrum

Calibrated Tissue Spectrum

Reference

Target

Inverse Monte Carlo Model \([1]\)

Extracted Tissue \(\mu_a\) and \(\mu_s'\)

Phantom Experiments

Tissue-mimicking phantoms:

- Absorber: hemoglobin
- Scatterer: 1 μm polystyrene microspheres
- \([\text{Hb}]: 1 – 32 \ \mu\text{M}\)
- \(\mu_a = 0.006 – 37 \ \text{cm}^{-1}\)
- \(\mu_s' = 11.2 – 22.3 \ \text{cm}^{-1}\)
- Reference phantom: \([\text{Hb}]=8.42 \ \mu\text{M}, \ \mu_s' = 16.8 \ \text{cm}^{-1}\)
Calibrated Phantom Spectra

\[ R_{\text{puck\_calibrated}} = \frac{R_{\text{tissue}}}{R_{\text{puck}}} \quad \text{v.s.} \quad R_{\text{sc\_calibrated}} = \frac{R_{\text{tissue}}}{R_{\text{sc}} \cdot F_{\text{corr}}(\lambda)} \]

Wavelength (nm)

Calibrated Diffuse Reflectance (a.u.)

- Spectralon Puck Calibrated
- Self-Calibrated

ua=0.24\text{cm}^{-1}, \text{us}'=18\text{cm}^{-1}

ua=1.73\text{cm}^{-1}, \text{us}'=17\text{cm}^{-1}

ua=7.50\text{cm}^{-1}, \text{us}'=13\text{cm}^{-1}
Extracted vs Expected Phantom Optical Properties

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<td>Error in $\mu_a$</td>
<td>6.9±7.2%</td>
<td>6.8±5.1%</td>
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<td>Error in $\mu_s'$</td>
<td>3.5±1.5%</td>
<td>5.6±2.9%</td>
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**Conclusions**

Combined with a one time, single-reference phantom measurement, the self-calibrating probe can provide instrument-independent optical properties.

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Acknowledgements

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