Near-infrared Oximetry System to Monitor Anterior Positioned Placentas

Brandon Williams [1, 2], Afrouz Anderson[2], Siddharth Khare[2], Randall Pursley[3], Thomas Pohida[3], Amir H. Gandjbakhche[2]

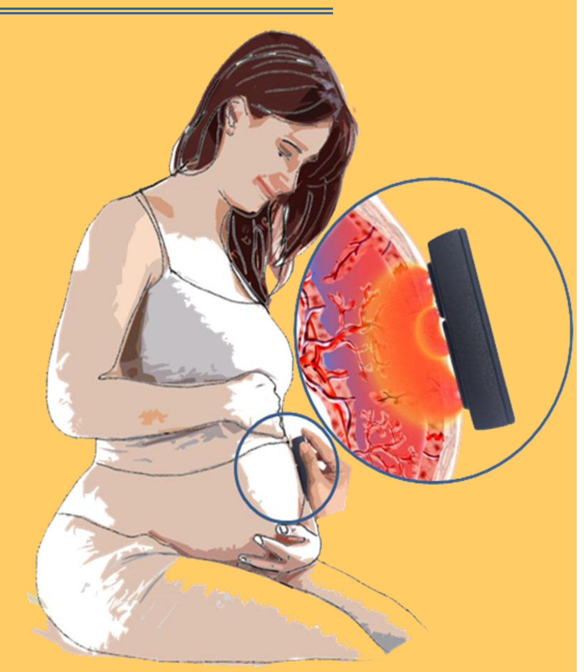
1. Section on Analytical and Functional Biophotonics (SAFB), NICHD, NIH
2. Computational Bioscience and Engineering Laboratory, CIT, NIH

INTRODUCTION

Monitoring the oxygenation of the vascular network which binds the expectant mother to the fetus is critical to ensure a healthy pregnancy outcome. Placental perfusion plays a vital role in both maternal and fetal health during pregnancy. Abnormal oxygenation in the placenta has been correlated with detrimental outcomes such as hypertension, abruption, gestational diabetes and delivery complication. Currently, there are no suitable devices available which can accurately measure the oxygen saturation in placental tissue.

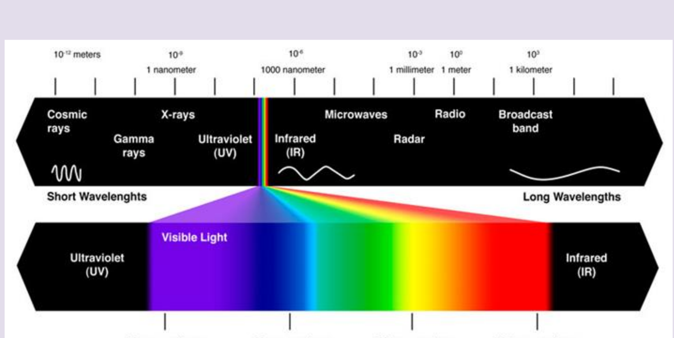
PURPOSE

To develop a wearable non-invasive near-infrared spectroscopy system, which is capable of continuously monitoring the oxygenation and hemodynamics of the anterior placenta in a subject-friendly environment.

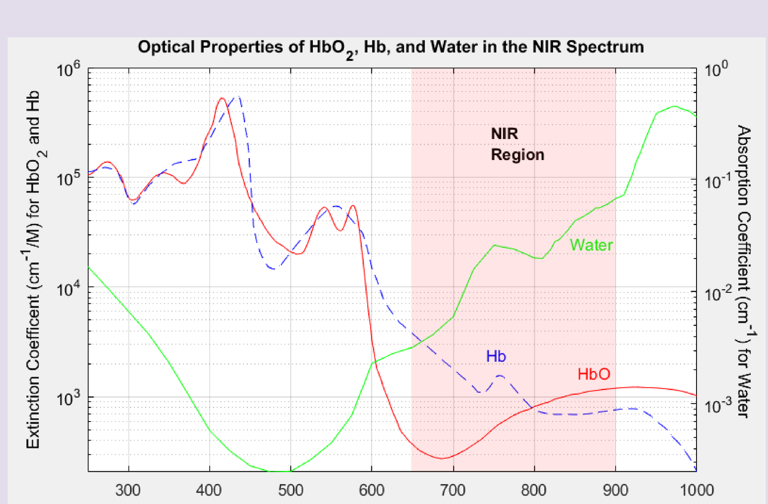


FUNCTIONAL NEAR INFRARED SPECTROSCOPY

Near Infrared Spectroscopy is a noninvasive optical imaging method that uses the near infrared range of the light (between 650-900 nm) to measure the optical properties of the tissue. Utilizing diffuse reflectance spectroscopy, we can detect and quantify the amount of light which is reflected by the tissue.



Light Spectrum Comparison of Visible, Infrared Light and Beyond[2]

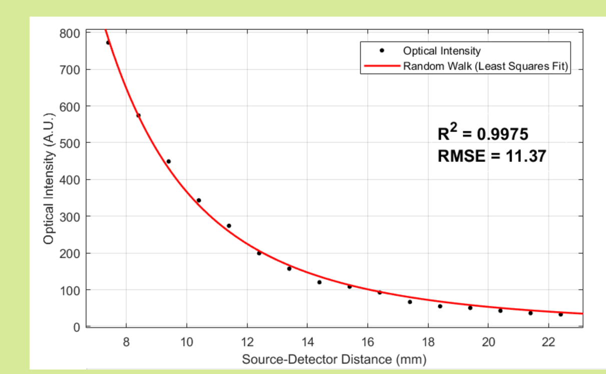


Optical Properties of Common Biomolecules

METHODS

Random walk theory of photon diffusion was utilized to fit the diffuse reflectance curve from perfused placental tissue using absorption (μ_a) and scattering (μ_s') coefficients as parameters.

Using the modified Beer-Lambert Law[1], we can solve for the concentration of oxy and deoxy hemoglobin and determine the tissue oxygenation index (TOI).



For a dual wavelength system:

$$\begin{bmatrix}\Delta OD_{\lambda 1}\\ \Delta OD_{\lambda 2}\end{bmatrix} = \begin{bmatrix}\varepsilon_{\lambda 1}^{HB} d & \varepsilon_{\lambda 1}^{HBO_2} d\\ \varepsilon_{\lambda 2}^{HB} d & \varepsilon_{\lambda 2}^{HBO_2} d\end{bmatrix}\begin{bmatrix}\Delta c^{HB}\\ \Delta c^{HBO_2}\end{bmatrix}$$

Substitute:

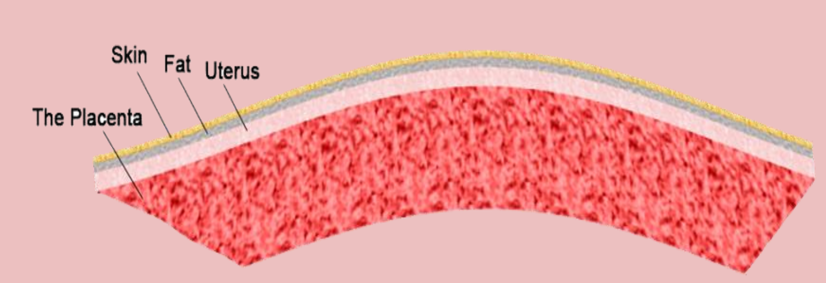
$$\Delta\mu_a = \frac{\Delta OD}{d}$$

Solve:

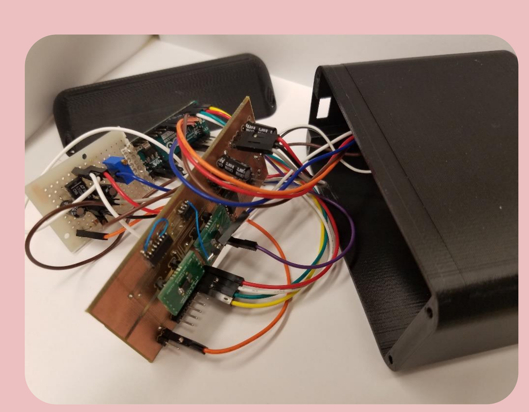
$$TOI = \frac{[c]^{HbO_2}}{[c]^{HbO_2} + [c]^{Hb}}$$

PROTOTYPE DEVICE DESIGN

1. Six LED light sources which emit two wavelengths of near-infrared light (750 and 850 nm)
2. Several Source-Detector Separation
   - Source-detector distances are strategically chosen to allow penetration of the light at different depths of the tissue



3. Using Variable Gain
   - Programmable amplification allows the user to increase the signal for higher resolution data and avoid saturation

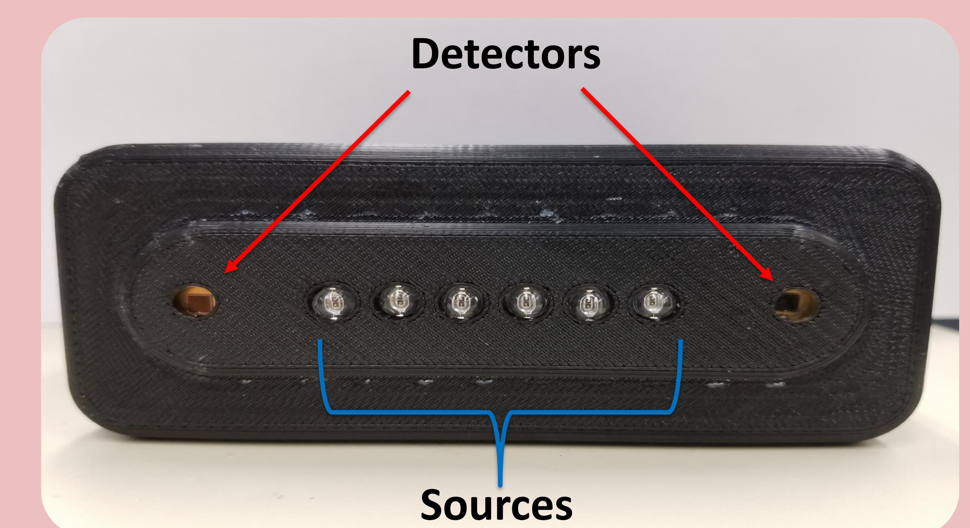


4. Noise Filtering
   - Removing high frequency noise was essential to increasing the signal to noise ratio
5. Offset Calibration
   - Due to non-ideal amplification electronics and the "dark" current of the photodiode shifted DC signal needs compensation

Analog Signal Processing
- Microcontroller Data Acquisition
- Digital Signal Processing

Transimpedance Amplifier → Low Pass Filter → Multi-stage Programmable Gain Amplifier w/ Offset Calibration

6. Symmetric Design
   - Confirm accurate results
   - Edge-detection for determining placental location



CONCLUSION & FUTURE DIRECTION

- Utilizing near infrared spectroscopy and diffuse reflectance, we have developed a hand-held device that can determine the optical properties of the placenta
- The device will be made portable (battery powered) with an LCD display to show real time placental oxygen saturation
- By continuously monitoring the oxygenation of the placenta, this device will be used to research the correlation between placental oxygenation and adverse pregnancy outcomes

REFERENCES

1. Ayaz et al. (2011). "Using MazeSuite and Functional Near Infrared Spectroscopy to Study Learning in Spatial Navigation". Journal of Visualized Experiments (56). doi:10.3791/3443. PMC 3227178 2
2. Hunt, Laura. "Light As Medicine?" Wisconsin Academy, www.wisconsinacademy.org/magazine/light-medicine.
3. Prahl, Scott. "Optical Absorption of Hemoglobin." Olmc.com, SAP, 15 Dec. 1999, omlc.org/spectra/hemoglobin/.