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Photoacoustic imaging of controlled blood oxygenation within a programmable dynamic flow system

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Introduction

- Blood oxygenation (sO_2) is an important physiological measure to assess hemodynamics on the macro- and micro-scales.
- Established methods for estimation of sO_2 include near-infrared spectroscopy[1] and calculation from measurements of the partial pressure of oxygen.[2]
- Wavelength-dependent photoacoustic (PA) signal intensities can be used to monitor sO_2 values spatiotemporally in vascular structures.
- sO_2 measurements with PA are perturbed by processes such as spectral coloring and inhomogeneous light fluence distributions.
- sO_2 estimation approaches would benefit from an in-depth understanding of experimental ground truth.

Aim

- To design and implement a phantom platform for investigation of the relationship between blood oxygenation measured using PA and ground truth oxygenation.

Methods

- The programmable dynamic flow system was introduced into a commercial PA system (iThera Medical inVision 256-TF).
- Mouse blood (~5 mL) was 100% oxygenated with hydrogen peroxide, introduced via an injection site. and air bubbles were removed by a depressurization vent.
- Data acquisition was performed synchronously. PA signals were acquired at 7 wavelengths (700 to 875 nm, no averaging).
- After spectroscopy and pO_2 readout stabilization, sodium hydrosulfite was introduced for deoxygenation.

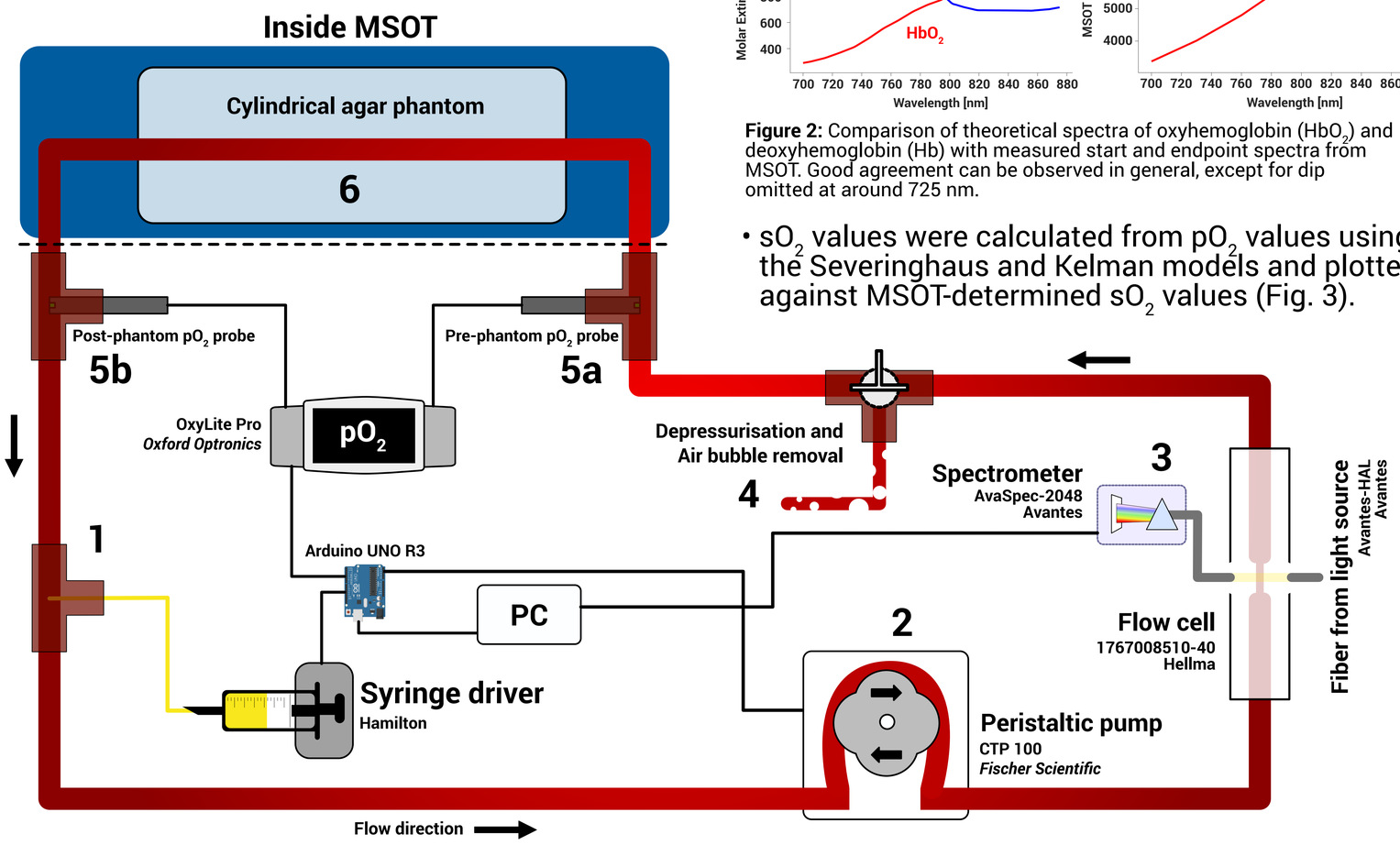

Figure 1: Overview of the flow phantom. (1) Injection site for introducing oxygenated blood into the flow system, and for subsequently deoxygenating the blood using sodium hydrosulfite delivered using the computer controlled syringe driver; (2) peristaltic pump provides blood circulation; (3) spectra are recorded as the blood passes through a flow cell; (4) air bubbles are released via a three-way tap; (5) pO_2 measurements are made before (a) and after (b) the blood passes through the agar phantom immersed in the MSOT (6).

Results

- We compared the theoretical spectra of oxygenated and deoxygenated blood with the start and end spectra measured in the MSOT (Fig. 2)

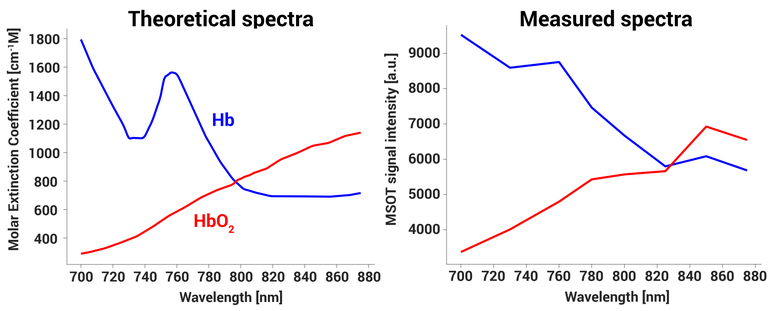

Figure 2: Comparison of theoretical spectra of oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb) with measured start and endpoint spectra from MSOT. Good agreement can be observed in general, except for dip omitted at around 725 nm.

- sO_2 values were calculated from pO_2 values using the Severinghaus and Kelman models and plotted against MSOT-determined sO_2 values (Fig. 3).

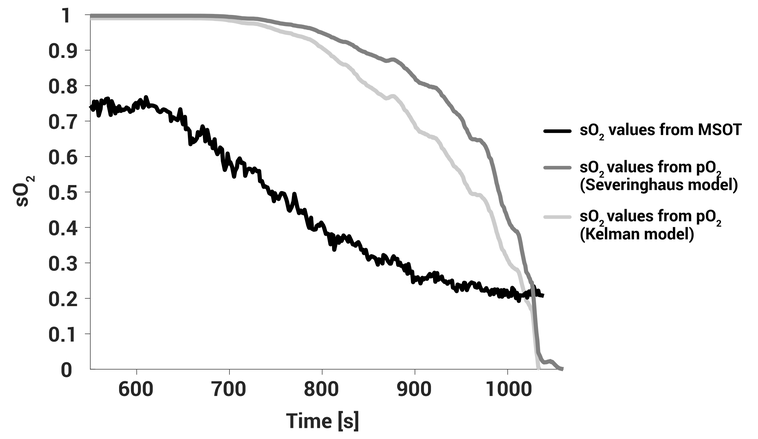

Figure 3: Time course of sO_2 values from MSOT plotted with sO_2 values from pO_2 data over time. Although a similar trend can be observed between the three curves, the dynamic ranges and gradients are different.

- At lower sO_2 levels, oxygenation was over-estimated in the tube center, as shown in Fig. 4.

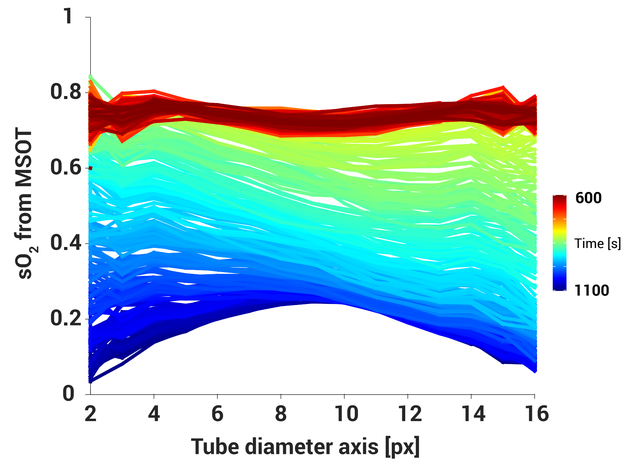

Figure 4: Evolution of sO_2 values measured over the course of the experiment where blood was progressively deoxygenated. sO_2 values were measured in each pixel across the tube diameter.

- Inner regions of the tube are susceptible to spectral coloring: for low sO_2, high absorption by Hb reduces light penetration especially of shorter wavelengths, thus reducing the signal in the tube centre, causing elevation in the calculated proportion of HbO_2.

Conclusion

- A programmable dynamic flow phantom was used to provide insights into the relationship between blood oxygenation measured using PA and ground truth oxygenation obtained by spectroscopy and/or pO_2.
- By improving the accuracy of the recovered spectra (e.g. fluence correction), we will improve the reproducibility of sO_2 measurements in order to derive reliable information about blood and tissue oxygenation.

References

[1] Cope, M., 1991. *The development of a near infrared spectroscopy system and its application for non invasive monitoring of cerebral blood and tissue oxygenation in the newborn infants* (Doctoral dissertation, University of London).

[2] Breuer, H.W., Groeben, H., Breuer, J. and Worth, H., 1989. Oxygen saturation calculation procedures: a critical analysis of six equations for the determination of oxygen saturation. Intensive care medicine, 15(6), pp.385-389.

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