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A WIDE GAP SECOND DERIVATIVE NIR SPECTROSCOPIC METHOD FOR MEASURING TISSUE HEMOGLOBIN OXYGEN SATURATION

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1. INTRODUCTION

Absolute quantification of tissue chromophores can, in principle, be obtained by applying second derivative methods[1-4] to near-infrared spectroscopy. These methods transform optical attenuation measurements into second derivative units in order to provide robustness to wavelength dependent scattering, chromophores with constant absorption, baseline/instrumentation drift, and movement artifact.

Previous methods are more sensitive to deoxyhemoglobin than oxyhemoglobin because oxyhemoglobin lacks significant absorbance curvature within the wavelength region used to calculate a second derivative attenuation value. These methods have relied on broad spectrum wavelength measurements, spectral smoothing and component fitting. Excessive noise at high hemoglobin oxygen saturation is a problem.

A simple four wavelength method for quantifying tissue hemoglobin oxygen saturation (StO_2) having greatest spectral sensitivity occurring at high hemoglobin oxygen saturation (>50%) is described. Measurement performance was tested in isolated blood, isolated blood perfused animal organs, and healthy human volunteers with induced limb ischemia.

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2. METHODS

2.1 Equipment

Two spectrometer designs were used. A first full spectrum spectrometer, Biospectrometer-NB (Hutchinson Technology Inc, Hutchinson, MN), consisted of a tungsten halogen light source and a reflective grating model SD2000 CCD array photodetector (Ocean Optics, Tampa Bay, FL). Six 400 micron glass receive fibers were coupled to the grating in a slit pattern and resulted in a bandwidth resolution of 15 nm full width half maximum (FWHM). Fiber optic reflectance probes had numerous 200 micron optical send fibers to provide sufficient illumination of the tissue for probe spacings of 8 mm and 15 mm. Known transmission peaks of didymium glass were used to calibrate the CCD array pixels to a corresponding wavelength.

A second commercially available spectrometer, InSpectra™ Tissue Spectrometer Model 325 (Hutchinson Technology Inc, Hutchinson, MN), consisted of four photomultiplier tube detectors coupled to interference filters having center wavelengths of 680, 720, 760, and 800 nm. All filters had a bandwidth of 10 nm FWHM. Reflectance probes consisted of a single 400 micron glass optical receive fiber and four similar fibers each coupled to a light emitting diode. A 12 inch length of 1.5 mm diameter plastic optical fiber coupled and mixed each fiber light source to the measurement sample. Probe spacings of 12 mm, 15 mm, 20 mm, and 25 mm were used.

A closed cell polyethylene foam light scattering calibrator, Plastazote® LD45 (Zotefoams Inc, Walton, KY), was used to capture reference light intensity at each wavelength prior to placing a reflectance probe on the tissue measurement sites.

An isolated blood perfusion apparatus (Figure 1) consisted of a Minimax™ 3381 fiber membrane oxygenator (Medtronic, Minneapolis, MN) connected to a peristaltic pump and controlled temperature water bath. A custom flow cell, to mimic blood-perfused tissue, distributed the blood within the optical path of the measurement probes and was constructed to provide a variable thickness of blood flowing over a block of LD45 Plastazote foam of sufficient volume to contain all emitted light paths. Two 0.05 mm thick Mylar D plastic film layers, (DuPont Teijin Films, Hopewell, VA) separated flowing blood from the top mounted reflectance probes and the bottom mounted foam scattering layer. A co-oximeter was used to measure $\%SO_2$ for sampled blood.

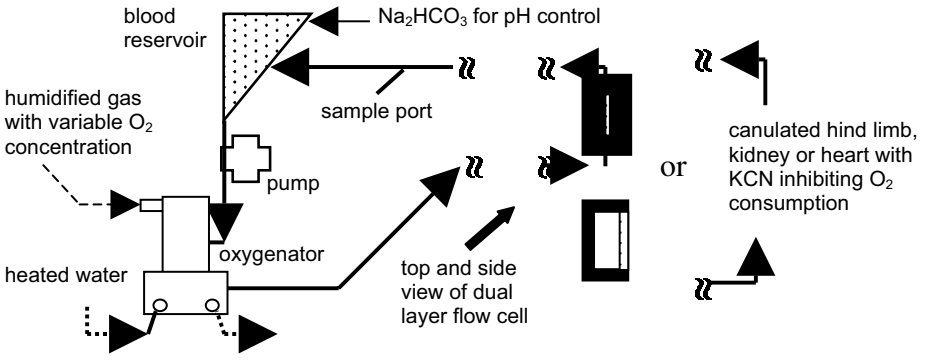

Figure 1. Schematic of isolated blood perfusion circuit for testing StO_2 performance.