Theory for Microvascular Oxygenation Measurements

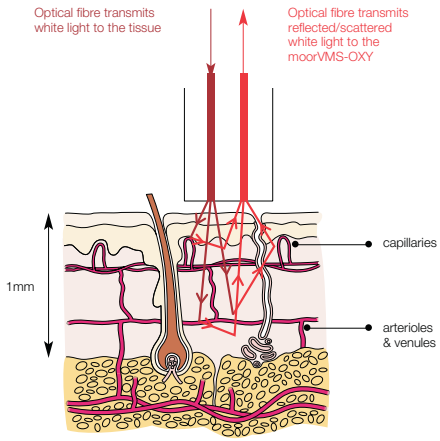
Introduction

The theory for two non-invasive techniques for microvascular oxygenation measurements are covered: white light spectroscopy, as used in the moorVMS-OXY device, and two-wavelength Spatially Resolved Spectroscopy, as used by moorVMS-NIRS. The former is typically used for superficial microvasculature of skin, and the latter, spatially resolved NIRS technique, is used for deeper tissues, e.g. muscle and brain.

OXY and the Principles of White Light Spectroscopy

The moorVMS-OXY is based on the theory of white light reflectance spectroscopy. Its measurement relies on spectrophotometric principles that relate light absorption to chromophore concentrations. Measurements are taken using probes placed in contact with the tissue at the measurement site.

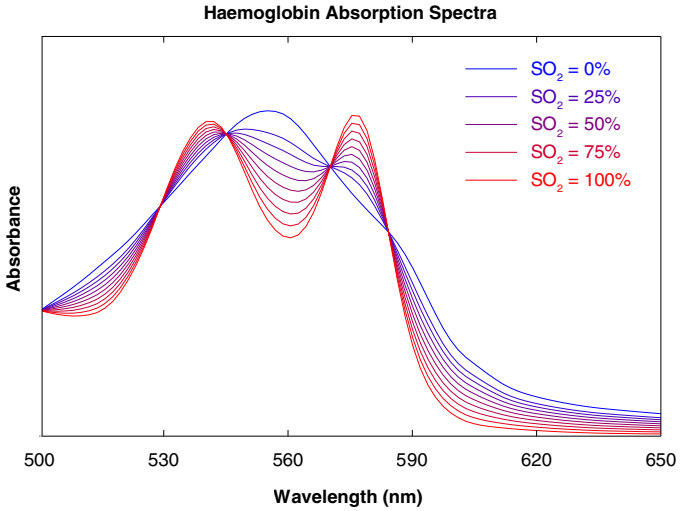
Optical fibres are used to deliver light to the tissue and transmit scattered light to the instrument for processing. For measurements in superficial tissue layers, probes with small delivery-collection fibre separations (0.5 - 1 mm) are used:



From the end of the probe, the light spreads out in a diffuse pattern through the tissue. The transport of the photons is governed both by the absorption and scattering properties of the tissue.

A fraction of the light is absorbed when the white light interacts with haemoglobin in the red blood cells. As the absorption of light by haemoglobin depends on the wavelength of the light and on the state of its oxygenation, both the total haemoglobin concentration in tissue and the oxygen saturation determine the colour of the tissue, which is the foundation of the spectroscopic measurements.

The analysis is performed with spectra in the visible wavelength range between 500 - 650 nm:



The Percentage of Oxygenated haemoglobin of total haemoglobin, SO2 is found from:

$$SO_2 \text{ (percentage)} = \frac{[oxyHb]}{[deoxyHb] + [oxyHb]} \times 100$$

where [oxyHb] and [deoxyHb] are the concentration of oxygenated and deoxygenated haemoglobin, respectively. Appropriate algorithms take into account confounded factors for the spectra, e.g. the effect of light scattering by all tissue compartments and the absorption by melanin.

The measurement depth is dependent upon the light wavelengths and the fibre spacing in the probe head. The further the fibre separation or the longer the light wavelength, the deeper the possible measurement depth.

Further reading

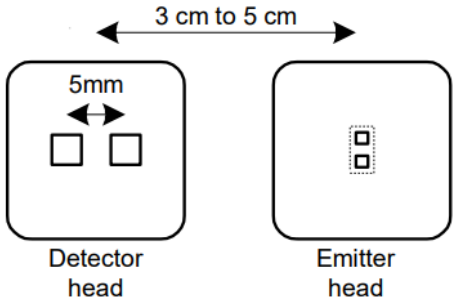
Hongyuan Liu, Matthias Kohl-Bareis, Xiabing Huang.
Design of a tissue oxygenation monitor and verification on human skin.
Proc. SPIE 8087, Clinical and Biomedical Spectroscopy and Imaging II, 80871Y (10 June 2011).
https://doi.org/10.1117/12.889197

Sørensen H, Secher N, Siebenmann C, Nielsen H, Kohl-Bareis M, Lundby C, Rasmussen P.
Cutaneous Vasoconstriction Affects Near-infrared Spectroscopy Determined Cerebral Oxygen Saturation during Administration of Norepinephrine.
Anesthesiology August 2012, Vol. 117, 263–270.
https://doi.org/10.1097/ALN.0b013e3182605afe

Superficial Tissue Oxygenation Monitor (moorVMS-OXY)

NIRS and the Principles of Spatially Resolved Spectroscopy

The spatially resolved spectroscopy technique (Matcher et al. 1995 and Suzuki et al. 1999) is used to measure absolute* concentrations of oxygenated haemoglobin (oxyHb) and deoxygenated haemoglobin (deoxyHb) in human tissue. The moorVMS-NIRS measures oxygenation using a probe which is placed in contact with the skin. Each probe consists of a detector head which contains two identical photodiodes and emitter head which contains near infrared LEDs emitting light at approximately 750 nm and 850 nm. The position and orientation of the detectors and emitters is shown below:



Light from the emitter head enters the tissue where it is subject to scattering and absorption. A small proportion of the incident light passes through the tissue to the photodiodes. The resulting photocurrents are amplified and acquired by the instrument. The orientation of the photodetectors allows the change of attenuation with respect to emitter-to-detector distance to be measured.

*Concentrations of oxyHb and deoxyHb can then be estimated using the measured attenuation slope, known optical characteristics of haemoglobin, known probe geometry and assumptions about typical tissue scattering characteristics. For a homogeneous medium, the absorption coefficient, μa(λ), can be derived from the slope of attenuation with respect to emitter to detector distance:

$$\mu_a(\lambda) = \frac{1}{\mu_s'(\lambda)} \cdot \frac{1}{3} \cdot \left(\ln(10) \cdot \frac{\delta A(\lambda)}{\delta \rho} - \frac{2}{\rho} \right)^2 \quad (1)$$

Where:

$\mu_a(\lambda)$ = Absorption coefficient
$\mu_s'(\lambda)$ = Tissue transport scattering coefficient
A = Attenuation, $\log_{10}(I_0/I)$
I = Measured intensity at wavelength λ
ρ = Emitter to detector distance

Here the exact value of the transport scattering coefficient $\mu_s'(\lambda)$ is required, which is generally not known. For most tissues the transport scattering coefficient is a simple function of wavelength. The moorVMS-NIRS uses the following transport scattering coefficients based on values published by Matcher et al. (1997):

μ_s'(750 nm) = 0.962
μ_s'(850 nm) = 0.885

Absorption coefficients can be related to absolute concentrations of haemoglobin:

$$\mu_a(\lambda) = \sum_{i=1}^{2} \varepsilon_i(\lambda) \cdot c_i \qquad (2)$$

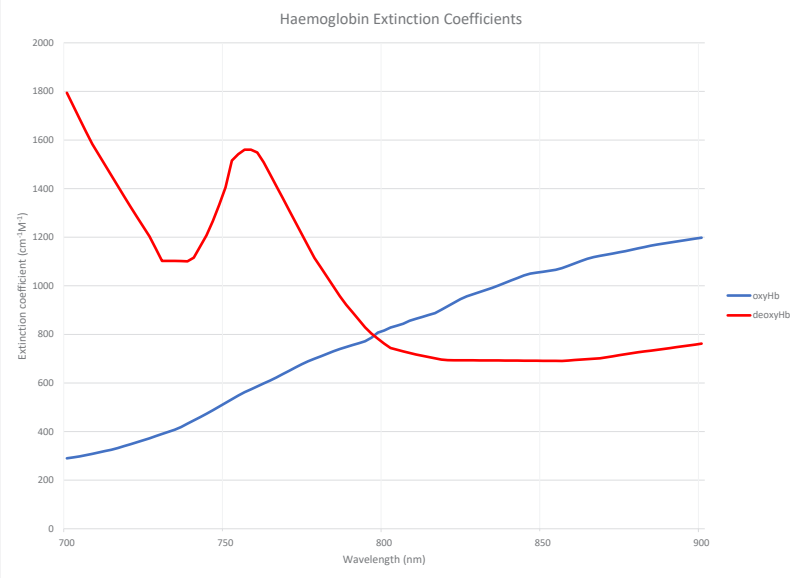
Where:

c = Haemoglobin concentration

ε = Extinction coefficient

i = 1 for oxyHb , 2 for deoxyHb

Extinction coefficients for oxyHb and deoxyHb compiled by Prahl, 1999, are shown below:



Absolute concentrations of oxyHb and deoxyHb can then be calculated using Equation 2, based on measured absorption coefficients and known extinction coefficients. Tissue oxygen saturation (SO2) can be calculated from oxyHb and deoxyHb concentrations and expressed as a percentage:

$$SO_2 = 100 \times \frac{oxyHb}{oxyHb + deoxyHb} \qquad (3)$$

References

Steven J. Matcher, Peter J. Kirkpatrick, K. Nahid, Mark Cope, David T. Delpy.
Absolute quantification methods in tissue near-infrared spectroscopy.
Proc. SPIE 2389, Optical Tomography, Photon Migration, and Spectroscopy of Tissue and Model Media: Theory, Human Studies, and Instrumentation, (30 May 1995).
https://doi.org/10.1117/12.209997

S. J. Matcher, M. Cope, and D. T. Delpy.
In vivo measurements of the wavelength dependence of tissue-scattering coefficients between 760 and 900 nm measured with time-resolved spectroscopy.
Applied Optics Vol. 36, Issue 1, pp. 386-396 (1997).
https://doi.org/10.1364/AO.36.000386

Scott Prahl.
Optical Absorption of Hemoglobin.
https://omlc.org/spectra/hemoglobin/

Susumu Suzuki, Sumio Takasaki, Takeo Ozaki, Yukio Kobayashi.
Tissue oxygenation monitor using NIR spatially resolved spectroscopy.
Proc. SPIE 3597, Optical Tomography and Spectroscopy of Tissue III, (15 July 1999).
https://doi.org/10.1117/12.356862

For further information on product details, specifications, references and probes for the moorVMS-OXY and moorVMS-NIR, respectively, use the following links:

Superficial Tissue Oxygenation Monitor (moorVMS-OXY)

Deep Tissue Oxygenation Monitor (moorVMS-NIRS)

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