Where? Evaluation of Source-Detector Position in Spatially Resolved Spectroscopy

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I. Abstract

Continuous-wave near-infrared spectroscopy (CW-NIRS) has found clinical use in monitoring tissue oxygen saturation, particularly in continuous monitoring of cerebral oxygenation in surgical patients. Recently, there has been interest in miniaturized, implantable NIRS sensors to directly interface internal organs such as the spinal cord [1]. This study establishes a starting point in assessing the effects of sensor miniaturization on NIRS-based oxygenation measurements.

Spatially resolved CW-NIRS is widely used in clinical applications [2], wherein multiple source-detector pairs (channels) are used to measure the optical density gradient with respect to distance from the light source. The optical density gradient, with assumed scattering properties, can be used to calculate tissue absorbance, as per equation 1 [3]. d is source-detector distance, OD is optical density, h is the wavelength dependence of scattering, and k is an unknown constant.

$$k\mu_a = \frac{1}{3(1-h\lambda)}\left(\ln(10)\frac{\partial OD(\lambda,t)}{\partial d} - \frac{2}{d}\right)^2 \qquad (1)$$

Haemoglobin concentrations are then calculated with subsequent use of the Beer-Lambert Law. Finally, the ratio of oxyhemoglobin to total hemoglobin concentration is a measure of tissue oxygenation referred to as the tissue oxygenation index (TOI), or tissue saturation index (TSI). The spatially resolved approach assumes that the distance between subsequent channels is much smaller than the first channel [2], which may not be true for small sensors, such as the PortaLite mini (PLM, Artinis, Einsteinweg, Netherlands), which has source-detector distances of 1.6, 2.1, and 2.6 cm.

In this study, a PLM was placed on the thenar eminence of 7 subjects. Upper limb ischemia was then induced via surgical tourniquet. 1 minute of baseline data was collected prior to 3x 3-minute ischemia challenges, each separated by a 5-minute recovery. 29 recordings were collected for a total of 725 minutes of data. Using this dataset, we implemented a 3 channel TOI calculation with an average error of less than 1% compared to values exported by the PLM. Subsequently, the 3 channel TOI calculation was compared to each of the 3 possible 2 channel TOI calculations. Figure 1 displays the 4 TOI calculation methods on a representative recording.

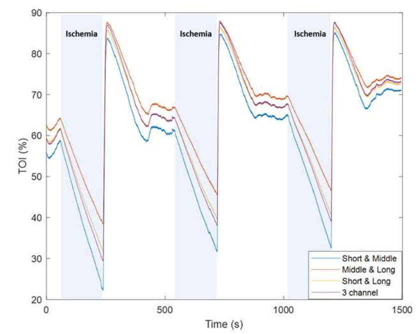

Fig. 1 TOI for a representative dataset using each possible set of channels.

The 3 channel and short & long channel TOI calculation obtained similar results, suggesting that the addition of a third channel has minimal effect on TOI accuracy. The TOI obtained by the three 2 channel calculations differed by 5% in mean baseline TOI, and by 7% in the average TOI decrease during ischemia. The observed TOI variation based on detector position could lead to inaccurate prediction of a patient's tissue oxygen saturation. These results highlight the need for the development of novel TOI algorithms and calibration methods that are insensitive to source-detector distance.

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References

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