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Calibration of an optical fibre cerebral oximeter using a Monte Carlo model.

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Background and purpose:
In some high-risk patients, such as those recovering from severe head injury, secondary brain damage caused by cerebral ischaemia and/or hypoxia is a common and potentially preventable cause of mortality and residual disability [1]. We are currently developing an optical fibre based system for measuring tissue haemoglobin oxygen saturation with the aim of providing an indicator of cerebral hypoxaemia.

A probe consisting of two parallel optical fibres has been designed for insertion into a trans-cranial bolt allowing the oxygen saturation of blood within the cerebral cortex to be measured. This is achieved by illuminating the tissue with red (660 nm) and infrared (850 nm) light and measuring the backscattered intensity at each wavelength. The optical fibres penetrate approximately 10 mm into the brain tissue and are laterally separated by a distance of 2 mm. A Monte Carlo model was used to develop an algorithm for calculation of oxygen saturation to be calculated from the detected light intensities. The model was validated by comparing results from the model with empirical results obtained from samples of whole blood over a range of oxygen saturation values.

Method:
Blood samples of haematocrit (HCT) = 0.45 with varying oxygen saturation were produced using an IL–237 blood gas tonometer and and the oxygen saturation measured on a Radiometer 700 series whole blood oximeter. The red and infrared reflected intensities of these samples were measured with the oximetry system by immersing the probe in each sample and the results compared with results from the model. The absorption coefficient, scatter coefficient and anisotropy factor of blood of varying oxygen saturation were taken from published data. [2]-[3]. The predicted reflected intensities for brain tissue were then calculated using a Monte Carlo model based on published optical coefficients for white matter [4].

Results:
Figure 1 shows a graph of the measured backscattered intensities plotted against oxygen saturation for whole blood, compared with the values predicted by the Monte Carlo model. It can be seen that there is good correlation between the measured values and the values predicted by the model.

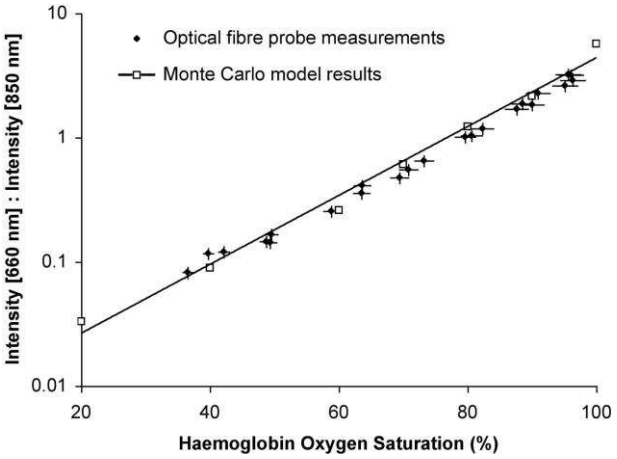

Figure 1: Graph of the ratio of red:infrared backscattered intensity plotted against oxygen saturation for whole blood (HCT = 0.45) as measured by the oximetry probe and as predicted by the Monte Carlo model.

The tissue oxygen saturation ($StiO_2$) for brain tissue, for a cerebral blood volume (CBV) of 0.29%, and an HCT of 0.45 was predicted by the model to be related to the red:infrared intensity ratio (R) by the following linear approximation:

$$StiO_2 = 236.5R - 178.3$$

Conclusions:
The values of the reflected intensities predicted by the model were found to be strongly dependent on the CBV and the HCT. The CBV is known to vary due to autoregulation of cerebral vascular resistance [1]. Using the Monte Carlo model, it would be possible to calculate a series of calibration curves for all values of CBV and HCT in the clinical range. To produce a practical algorithm for the calculation of oxygen saturation would require the CBV to be continuously measured.

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