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QUANTIFICATION OF ADULT CEREBRAL BLOOD VOLUME USING THE NIRS TISSUE OXYGENATION INDEX

Ilias Tachtsidis[§], Terence S. Leung[§], Caroline Oliver[¤], Julian R. Henty[§], Holly Jones[¤], Martin Smith[¤], David T. Delpy[§], Clare E. Elwell[§]

1. INTRODUCTION

Near-infrared spectroscopy (NIRS) is increasingly used as a non-invasive technique for monitoring cerebral oxygenation and haemodynamics[1, 2]. Simple continuous-wave (CW) NIRS systems utilising differential spectroscopy can measure quantitative changes in oxy- and deoxy- haemoglobin ($\Delta[O_2Hb]$, $\Delta[HHb]$) but only from an arbitrary baseline. Numerous studies of changes in cerebral oxygenation and haemodynamics in adults have been published but only few absolute quantitative measurements have been reported. Recent advances in the NIRS technology have enabled quantitative assessment of haemoglobin concentration in tissue using near-infrared (NIR) phase and time resolved systems; and absolute measurements of tissue saturation using phase, time or spatially resolved spectroscopy (SRS) systems[3, 4, 5, 6].

This paper suggests a way to use a commercially available spectrometer, which has both CW and SRS capabilities in order to measure absolute tissue haemoglobin (Hb_{tc}) and hence cerebral blood volume (CBV). The methodology is based on that of Wyatt et al.[7] who developed a method for measuring absolute CBV, using NIRS measurements during controlled changes in inspired O_2 fraction. By using NIRS measured tissue $\Delta[O_2Hb]$ and comparing it to changes in arterial saturation (SaO_2) measured with a pulse oximeter it is possible to calculate absolute Hb_{tc} concentration. This is the so-called 'de-saturation method' or 'O_2 method' or 'SaO_2 method'[8, 9, 10, 11]. The purpose of the present study was to compare measurements of CBV made using the conventional 'SaO_2 method' with those using a new method employing the SRS derived absolute cerebral tissue oxygenation index (TOI), which will be called the 'TOI method'.

[§]Medical Physics and Bioengineering, University College London, Shropshire House, 11- 20 Capper Street, London WC1E 6JA; iliastac@medphys.ucl.ac.uk

[¤]Department of Neuroanaesthesia & Neurocritical Care, The National Hospital for Neurology & Neurosurgery, London

2. THEORY

2.1 Hb_{tc} Calculation

The theory for absolute quantification of Hb_{tc} relies upon the induction of a small change in the inspired oxygen. During the manoeuvre the consequent change in cerebral $\Delta[O_2Hb]$ is equivalent to the product of the Hb_{tc} and the change in fractional tissue saturation. If CBV is constant then $\Delta[Hb_{diff}]$ (i.e. $\Delta[O_2Hb]$- $\Delta[HHb]$) can be used to derive Hb_{tc}. The 'SaO_2 method' uses a CW NIRS system to monitor the changes in $\Delta[O_2Hb]$ and $\Delta[HHb]$ and a pulse oximeter to measure SaO_2. If cerebral blood flow (CBF), CBV and O_2 consumption remain constant during the manoeuvre the ΔSaO_2 measurement can be related to the tissue saturation. Therefore absolute Hb_{tc} can be obtained using Eq. (1).

Instead of using ΔSaO_2 as an indicator of tissue saturation one can use a direct measurement of tissue saturation, which modern NIRS systems measure. One such system the Hamamatsu NIRO 300 utilises the SRS technique, in which multiple closely separated detectors measure the attenuation slope[12]. From these measurements it is possible to calculate scaled absolute haemoglobin concentrations and hence accurately obtain a tissue oxygenation index (TOI) as $k[O_2Hb]/[kO_2Hb+kHHb]*100\%$ where k is a scaling factor dependent upon the tissue scattering coefficient (μ_s). TOI is a measure of oxygen saturation in tissue; therefore one can use Eq. (2) to measure absolute Hb_{tc}.

$$Hb_{tc}(\mu moles/l) = \frac{\Delta[Hb_{diff}]}{2 \cdot \Delta SaO_2} \qquad (1) \qquad Hb_{tc}(\mu moles/l) = \frac{\Delta[Hb_{diff}]}{2 \cdot \Delta TOI} \qquad (2)$$

2.2 CBV Calculation

It is important to remember that NIRS measures change in chromophore concentrations in micromolar units. Estimates of blood volume are obtained from these measurements by converting the concentration data into the more conventional clinical units of millilitres/100 grams (see Eq. (3)). This conversion requires knowledge of the red blood cell concentration, which is measured from a venous sample.

$$CBV(ml/100g) = \frac{[Hb_{tc}] \cdot MW_{Hb} \cdot 10^{-4}}{d_t \cdot [Hb_t \cdot 10^{-2}] \cdot CLVHR} \qquad (3)$$

where MW_{Hb}=64500 is the molecular weight of haemoglobin, d_t=1.05g/ml is the cerebral tissue density, Hb_t (g/dl) is the haemoglobin concentration obtained from a venous sample, and CLVHR=0.69 is the cerebral to large vessel haematocrit ratio[13].

3. PARTICIPANTS AND PROCEDURE

3.1 Participants

Data were recorded during three consecutive graded arterial hypoxaemias in 12 healthy volunteers of mean ±SD age 32 ±4years (the local ethics committee approved the protocol for the study, and all subjects gave informed consent for participation).