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NIRS MEASUREMENT OF VENOUS OXYGEN SATURATION IN THE ADULT HUMAN HEAD

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1. INTRODUCTION

Knowledge of the venous oxygen saturation (SvO_2) is of significant interest for both general diagnostic purposes and in measurement of the cerebral metabolic rate of oxygen. While measurement of the tissue mixed oxygen saturation (StO_2), a weighted average of arterial, capillary, and venous oxygen saturations provides useful diagnostic information, it tells us little about the state of oxygen utilization in the brain.

In the case of hypoxic-ischemic injury, changes in blood flow and oxygen extraction are likely present before clinical manifestation of the injury[1-4]. However, as increases in blood flow serve to maintain oxygen delivery to the brain during mild hypoxic stress, measurement of StO_2 alone does not provide sufficient information to predict impending cerebral injury. With knowledge of both arterial oxygen saturation (SaO_2) and SvO_2 it is possible to determine cerebral oxygen utilization, or the oxygen extraction fraction (OEF), a measurement that may provide the ability to proactively assess the risk of cerebral hypoxic-ischemic injury[5].

Unfortunately, while non-invasive SaO_2 measurements are now commonplace, techniques allowing accurate non-invasive measurement of cerebral SvO_2 are lacking. The most promising technique, spiroximetry, first proposed by Wolf, has been used to non-invasively measure SvO_2 in the human and pig thigh[6], and in ventilated newborn infants[7], but has not yet been applied on the adult human head.

In the present paper we investigate the use of fast near infrared spectroscopy (NIRS) spiroximetry for the non-invasive measurement of SvO_2 in the adult human head. Furthermore, we determine both the oxygen extraction fraction and the distribution of cerebral blood volume into arterial and venous compartments using tissue, arterial, and venous oxygen saturations measured with spatially resolved NIRS.

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2. METHODOLOGY

2.1. Near-infrared Spectrophotometry (NIRS)

The NIRS system, MCP II, consists of 4 sets of light emitting diodes at 730 and 830 nm and four silicon PIN photodiode detectors arranged in a paired alternating rectangular pattern encased in medical grade silicon with source-detector separations of 3.75 and 2.5 cm. The system is capable of providing intensity measurements across all pairs with a temporal resolution of 100 Hz. Changes in attenuation are used to calculate changes in concentration of oxy and deoxyhemoglobin using standard NIRS techniques[8].

2.2. Tissue Mixed Oxygen Saturation (StO_2)

The combination of source-detector pairs at the outermost corners of the MCP II probe provide sufficiently different source-detector separation distances (3.75 and 2.5 cm) to allow for implementation of the multi-distance tissue oxygenation measurement[9, 10]. The MCP II enables calculation of StO_2 with a temporal resolution equal to the measurement frequency (100 Hz), providing one value per measurement. Presented StO_2 values are averages over the 30 second measurement period. SaO_2 was measured using a standard pulse oximeter.

2.3. Venous Oxygen Saturation (SvO_2)

The venous oxygen saturation calculation is based on a similar assumption to that used for the standard calculation of SaO_2. Here using the assumption that changes in blood volume at the respiratory frequency result primarily from venous blood.

Briefly, changes in attenuation at the breathing frequency, due to changes in venous blood volume, can be isolated from raw attenuation signals using an FFT approach[7]. Once isolated, these changes are used to calculate changes in concentrations of oxy and deoxyhemoglobin. Respiration induced changes in oxy and deoxyhemoglobin are used to calculate venous oxygen saturation as follows:

$$SvO_2 = \Delta O_2Hb_{resp} / (\Delta HHb_{resp} + \Delta O_2Hb_{resp})$$

where ΔO_2Hb_{resp}, and ΔHHb_{resp} are respiration induced changes in oxy and deoxyhemoglobin, respectively.

2.4. Compartmental Distribution and Oxygen Extraction Fraction (OEF)

Calculated StO_2 (multi-distance approach), SvO_2 (changes in blood volume at the breathing frequency), and SaO_2 (pulse oximeter) were used to determine the percentage of cerebral blood volume in venous and arterial compartments as follows:

$$StO_2 = x \cdot SvO_2 + (1-x)) \cdot SaO_2$$

where x represents the fractional distribution of cerebral blood volume in the venous compartment. OEF was determined by subtraction of SvO_2 from SaO_2.