

Monitoring Hemodynamic Changes in Preterm Infants Using Optical Spectroscopies and Doppler Ultrasound

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Abstract: Diffuse correlation and optical spectroscopies are used to monitor cerebral blood flow and oxygenation in premature infants during changes in angular head-of-bed position. Subsequent transcranial Doppler ultrasound measurements corroborate our findings.

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1 Introduction

Preterm very-low-birthweight (VLBW) infants are at significant risk of brain injury, in part due to their limited ability to regulate cerebral blood flow (CBF). Two of the most common brain injuries affecting this patient group are intraventricular hemorrhage (IVH) and periventricular leukomalacia (PVL). The onsets of both IVH and PVL are highly dependent on changes in CBF. For example, in the case of IVH, a decrease in blood flow can cause injury to immature capillary vessels in the germinal matrix. This damage can lead to hemorrhage if flow increases in the future [4].

This study investigates whether diffuse correlation spectroscopy (DCS) can be used to measure blood flow changes in this delicate population. Because of the infants' fragile condition, there exist few available methods to evaluate their CBF and none of these techniques monitor continuously at the bedside. DCS and it has been well validated against other blood flow modalities such as arterial spin labeling perfusion MRI [1], [5]. It is portable, non-invasive, and relatively inexpensive, making it an ideal method to study this patient population. A hybrid diffuse optical spectroscopy (DOS) and DCS instrument is used to determine relative cerebral blood flow (rCBF) and blood oxygenation changes during changes in head-of-bed position. Subsequent validation measurements are also performed during head-of-bed angular changes by Doppler ultrasound. The results from the two modalities were compared.

Diffuse optical and correlation spectroscopies permit continuous monitoring of relative changes in oxy- and deoxy-hemoglobin concentrations and blood flow, respectively. In our setup, DOS is performed using a steady-state white light instrument that measures tissue absorbance over a wide range of wavelengths ($\lambda=650$ to 910 nm). Knowledge of the absorption spectrum and the semi-infinite photon diffusion approximation enables us to determine relative changes in tissue oxy- and deoxy-hemoglobin concentrations. For blood flow measurements, a narrowband cw laser (785 nm, 5mW), two photon-counting fast avalanche photodiodes, and a two-channel autocorrelator board are used [3]. Variations in the decay time of the temporal-autocorrelation function, g_2 , are related via solutions of the correlation diffusion equation to rCBF [6].

2 Procedure

Patients for this study are chosen based on their gestation age (<32 weeks) and birth weight (<1500g). They are only included in the study if they are declared in a stable clinical condition by the attending physician. A group of healthy full term infants is used as a control. Each patient undergoes a series of head-of-bed angle manipulations while a custom-made optical probe is secured on their forehead to continuously measure hemodynamics. The study, which lasts approximately 40 minutes, consists of a 5 minute measurement with the patient at 0°, followed by 5 more minutes at 15°. This measurement is repeated 3 times with an additional

baseline measurement taken at the end at 0° (see Figure 1). Critical vitals such as heart rate, blood pressure, respiration, and oxygen saturation are continuously monitored throughout the measurement. Control subjects undergo this procedure only once, while the preterm infants are measured a second time the following day. There are also 2 days of follow up measurements with the preterm infants once they reach 32 weeks of corrected gestation age.

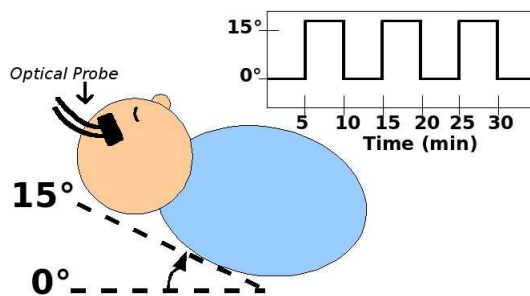


Fig. 1. Measurements are made on patients' foreheads for 5 minute intervals at 0° and 15° . This process is repeated three times followed by a final baseline measurement at 0° .

The optical probe used is specifically designed for this study and is customized to the special needs of premature infants. Because their skin is sensitive and not fully developed, we secure the probe using an elastic wrap that requires no adhesive. Two source-detector pairs, one for the white-light DOS system and the other for DCS, each 1.5 cm apart, are used. They are positioned perpendicular to one another to minimize crosstalk.

Transcranial Doppler ultrasonography (TCD) is also used on each of these patients. Measurements of peak systolic velocity and end diastolic velocity are made on the middle cerebral artery at 0° and 15° head-of-bed angles. TCD measures blood velocities of the macrovasculature as opposed to the microvascular flow sensitivity of DCS. Although these are two different quantities, they can certainly be coupled. It is our hypothesis that changes in macrovascular hemodynamics will be reflected in the microvasculature for this simple intervention.

3 Results

Preliminary data showed little or no change in CBF during head of bed manipulations in the majority of our patients. The DCS results shown on the left in Figure 2 are from a preterm infant who showed a common response. As is evident, there is very little variation in the temporal autocorrelation function, $g_2(\tau)$, when the bed is flat as compared to when it is elevated. This lack of variation indicates a relatively constant value of CBF. The bar plot at the bottom left of $\Delta rCBF$ normalized to the mean of the first 5 minute period at 0° shows a small drift in CBF over time, although no significant change is observed between bed positions.

A small group of patients exhibited some response during bed tilting. The right column of Figure 2 displays data from a unique patient who showed increased CBF at 15° as indicated by the decrease in decay time of the autocorrelation function. This increase is quantified in the bar plot on the bottom left. In adults it is more common for CBF to increase at lower head of bed angles. This infant's paradoxical response has also been shown to occur in a subsection of adults who have suffered a stroke [2]. Our group is currently in the process of investigating the underlying physiology of this response.

Preliminary results with transcranial Doppler ultrasound show results similar to DCS. On average, we see no significant changes in the majority of patients. Those that do show a response match the patients who showed a response using DCS.

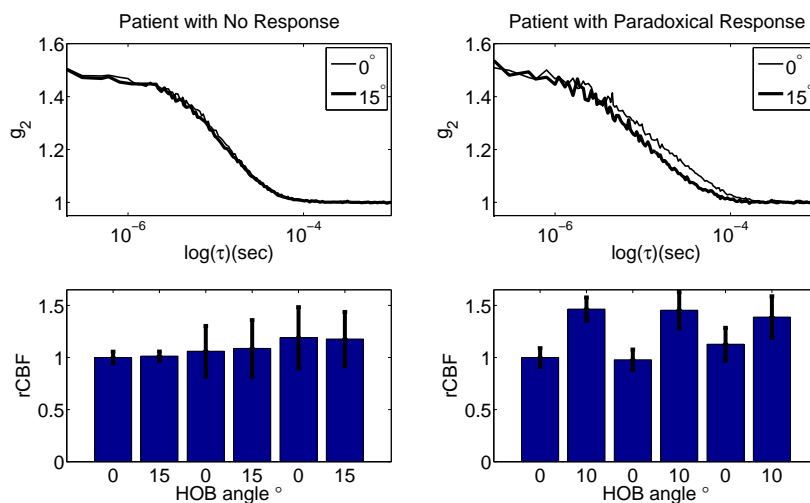


Fig. 2. The majority of patients showed little or no change with head-of-bed changes like the data on the left. However, a small group showed significant changes in rCBF as seen by the decrease in decay time of g_2 (example shown on right).

4 Conclusions

In conclusion, we have demonstrated the feasibility of using DCS to monitor the hemodynamics of VLBW preterm infants. We are in the process of recruiting new patients and analyzing data. The apparent agreement of DCS and TCD is encouraging. It is clear that further investigation is needed to increase the statistical significance of the results. In addition to head of bed manipulations, our future work will involve monitoring CBF on these infants during regular clinical treatments known to affect cerebral blood flow, such as indomethacin and caffeine.

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