Title: Developing a Hybrid Optical System for Studying the Dynamic Regulation of Blood Flow/Metabolism in the Human Brain

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Structured Abstract:

Introduction: The brain relies on cerebral blood flow (CBF) for a continuous supply of oxygen and energy substrates. Subtle changes in CBF regulation have been postulated to contribute to age-related neurological diseases. This link remains speculative due to the lack of non-invasive methods to study dynamic regulation of blood flow and tissue oxygenation (StO2) in the human brain. Combining non-invasive optical techniques can provide measurements of StO2 (near-infrared spectroscopy, NIRS) and CBF (diffuse correlation spectroscopy, DCS), which together can determine oxidative metabolism. One of the main challenges with these optical methods is signal contamination due to light absorption in extracerebral tissues (scalp and skull). The aims of this study were to assess the magnitude of scalp contributions to the NIRS and DCS signals and investigate approaches from removing this signal contamination.

Hypothesis: Scalp signal contamination can be significantly reduced for both NIRS and DCS by enhancing depth sensitivity: time resolved (TR) detection for NIRS – light that interrogates the brain must travel farther than light that only interrogates the scalp – and multi-distance measurements for DCS since depth sensitivity increases with source-detector distances (SDD).

Methods: Experiments were conducted on healthy volunteers, and a computerized gas control system generated 5-min hypercapnic challenges to increase CBF and StO2. MD-DCS and TR-NIRS data were acquired on the forehead at SDD of 1 and 3 cm. Each participant performed the experiment twice with a head cuff on the 2nd trial to eliminate scalp blood flow.

Results: CBF data from DCS were acquired from 7 subjects, and StO2 measurements for TR-NIRS were acquired from 5. With the head cuff inflated, blood flow and StO2 responses at SDD = 1 cm were eliminated, demonstrating that the cuff effectively blocked scalp blood flow. The scalp contamination at SDD = 3 cm was assessed by comparing CBF and StO2 responses with and without the cuff inflated. For NIRS based solely on changes in light absorption, scalp contamination was 74 ± 25%; however, this was reduced to 16 ± 29% using TR detection to select late-arriving light. For DCS, contamination at SSD = 3 cm was 31 ± 47%. This magnitude is less than expected from light absorption measurements due to the higher blood flow in brain relative to scalp.

Discussion: These experiments demonstrated the magnitude of signal contamination for NIRS and DCS measurements aimed at monitoring CBF and cerebral StO2. For NIRS, TR acquisition is an effective means of enhancing depth sensitivity. This approach is currently not suitable for DCS; however, acquiring data at multiple SDDs is likely an effective approach as the DCS data acquired at SDD = 1 cm, which represents scalp blood flow, can be as a regressor in the analysis of data acquired at SDD = 3 cm.