Simultaneous BOLD and NIRS Signal Correlation During Hypoxia

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Introduction: Near infrared spectroscopy (NIRS) is a non-invasive method that can be used to directly measure both oxyhemoglobin (oHb) and deoxyhemoglobin (hHb) concentrations non-invasively. In contrast to blood oxygen level dependent (BOLD) MR imaging, NIRS is more portable, has superior temporal resolution, and measures both oHb and hHb directly. On the other hand it is limited in its penetration depths. We performed simultaneous NIRS and BOLD studies in healthy subjects under normoxic and hypoxic conditions to determine the correlation of cortical NIRS measurements with BOLD changes in various brain regions. The hypoxic challenge (HC) caused the fraction of inhaled oxygen to decrease, which is associated with a signal change in NIRS and fMRI[2].

Methods: Three healthy adult volunteers were studied with a 3T Philips Achieva scanner and SENSE head coil. A gradient echo EPI sequence with TE50/TR3000 FOV 160x160x159mm, 32 slices was used. The matrices were 72x70 and 160x160 for acquisition and reconstruction matrices.

A Hammatasu NIRO-200 Near Infrared Spectroscopy unit with two pairs of MR compatible optodes was used. Optodes were placed on the right and left of the forehead. Optode location was marked with MR compatible markers affixed to the optode holder. The optodes ran outside the MR suite to the NIRO-200 adjacent to the MR console. The volunteers were connected to a Medrad Veris™ physiological monitor device. Blood oxygen saturation levels (SPO2), end tidal CO2 concentration (ETCO2), heart rate (HR), blood pressure (BP), and the respiration rate were recorded. NIRS and physiological data were captured simultaneous using a laptop with HyperTerminal™.

A Mapelson D breathing circuit with a two liter reservoir was connected to the volunteers and a gas delivery line ran outside the MR suite to compressed gassed adjacent to the MR console. The mask was customized to allow it to fit into the head coil. Medical grade breathing gasses were connected to the gas delivery line via a Y fitting. A 12% O2, ~88% N2 hypoxia mixture and a ~22%O2, ~78% N2 normoxia mixture were used. During the BOLD sequences the experimental paradigm was to allow one minute of normoxia, two minutes of hypoxia, followed by four minutes of normoxia (**Fig. 2.1**). Switching was performed manually using the regulators. Gases were set to flow at least 6 liters per minute.

Data processing was performed using SPM8[3], the re-sliced/re-aligned images were imported[1], and then processed using the investigators' software. This software performed a cross correlation to synchronize the NIRS and the physiological data with the ROI intensity curves and then calculated correlation coefficients between the ROI, and the parameters.

Results: MR signal changes were analyzed in three areas (**Fig. 1**). During the two minute HC, BOLD signal, NIRS-measured hHb, oHb, and SpO2 significantly changed followed by a recovery toward baseline for the remainder of the sequence (**Fig. 2**). BOLD and NIRS signals correlated well in the whole slice (ROI1) and in frontal areas (ROI2) while the correlation in white matter (ROI3) was poor (**Table 1**).

Discussion and Speculation: Limited data is available on simultaneous acquisition of NIRS data and BOLD images human subjects during HC[2]. Our findings demonstrate a good correlation between BOLD signal and NIRS-measured hHb and oHb in healthy subjects during HC. The higher correlation in the gray matter compared to the white matter could be due to the higher blood volume (BV) and perfusion and/or the higher O2 extraction in the gray matter. Future studies will include arterial spin labeling to allow direct comparison of quantitative cerebral BV measurements by NIRS and MR followed by studying the preterm neonate where cerebral blood flow autoregulation is limited.

Variable	ROI1	ROI2	ROI3	rHb	oHb	tHb
ROI1	-					
ROI2	.80	-				
ROI3	.62	.06	-			
hHb	-.85	-.82	-.38	-		
oHb	.87	.82	.39	-.94	-	
tHb	-.54	-.57	-.22	.76	-.58	-

Table 1 describes the correlation coefficients between the NIRS and BOLD signals shown in **Fig. 2.** Coefficients for NIRS are for both channels averaged.

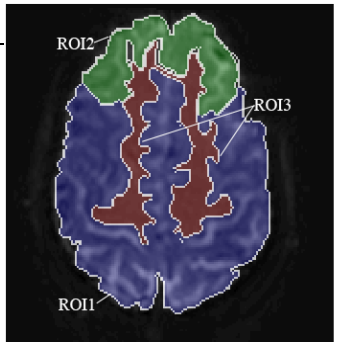

Fig. 1. Example BOLD image with ROIs for the whole slice (ROI1), frontal cortex (ROI2) and gray matter (ROI3)

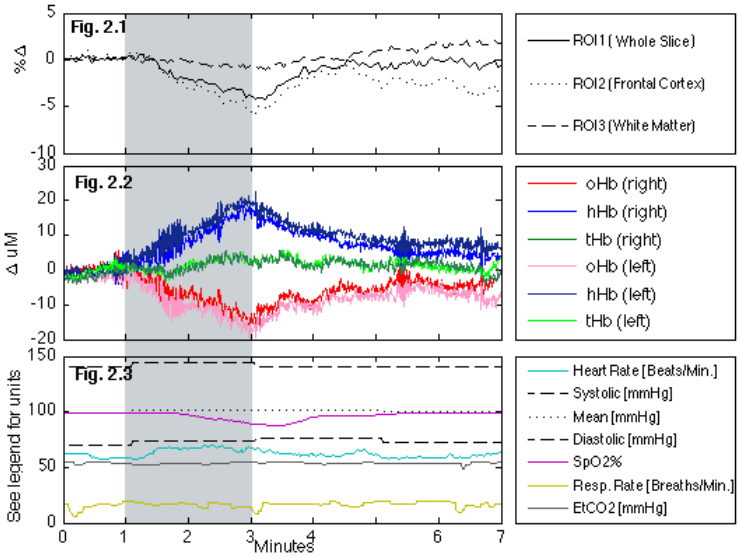

Fig. 2. Signal intensities of the frontal cortex adjacent to the optodes (ROI2), whole slice (ROI1), and white matter (ROI3) are shown together with the NIRS signal and physiological data. Changes in intensity of the ROIs (2.1) and the NIRS-measured hHb, oHb and calculated tHb (2.2) are changes relative to time=0; physiological signals (2.3) are also depicted. HC occurs within the gray window.

References

1. Jimmy Shen, Rotman Research Institute, NIFTI Toolbox
2. Klassen, L and R Menon. Proc. 13th ISMRM (2002)
3. Wellcome Trust Centre for Neuroimaging, SPM8

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