Inferring evoked and baseline cerebral blood flow, volume, and oxygen metabolism from dynamic BOLD and ASL measurements

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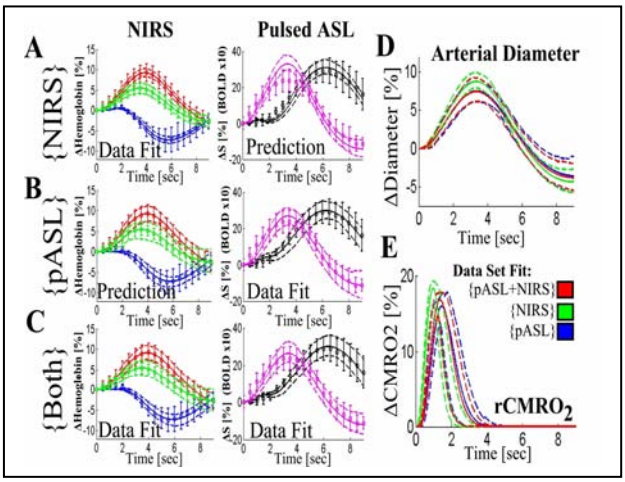
Variations in baseline cerebral blood flow, volume, and oxygen saturation determine the temporal characteristics of evoked hemo-physiological changes measured by functional MRI. Typical characteristics such as time-to-peak, temporal coherence, and temporal lag between components of the BOLD and blood flow response vary between subjects and sessions and can be altered by the modulation of baseline blood volume or flow through (i.e.) hyper/hypocapnia [1,2]. In this work, we present a physiologically motivated multi-compartment model of the cerebral vascular network to describe the basis of variability in the temporal dynamics of evoked signals and use this information to infer values of the underlying baseline and functional parameters [3]. We examined the posedness, accuracy, and precision of the presented model using numerical methods. We also applied our model to estimate the model parameters by numerically fitting pulsed-arterial spin labeling (pASL) data measured at high temporal resolution (2hz)[4] in the human motor-cortex. We demonstrate that this model can be used to indirectly infer the parameters that determine the flow-volume and flow-consumption relationship using the temporal characteristics of blood flow and oxygenation changes.



Our model of the vascular network is based on the multi-compartment extension of the Windkessel model described by [5]. The model estimates dynamically varying physiological states (arterial dilation and cerebral oxygen metabolism [$CMRO_2$]) as well as system parameters; including the mean vascular transit time, the Windkessel vascular reserve (β introduced in [5]) and the vascular volume fraction (*Vo* used in the BOLD signal equation [6]). We show that we can uniquely estimate relative $CMRO_2$, blood flow, and blood volume from BOLD and ASL measurements using non-linear minimization.

We cross-validate the two estimates by comparing them to values calculated by fitting the model parameters to independent measurements of blood volume, oxy- and deoxy-hemoglobin changes provided by near-infrared spectroscopy [NIRS]. The figure above shows model fit (dotted lines) to the functional responses measured by NIRS, pASL, or simultaneous (multimodal) imaging. Subplots D and E show the estimated arterial dilation and relative $CMRO_2$ changes from the fitting of each data set combination.

		{ASL, BOLD, NIRS}	{NIRS, BOLD}	{ASL, BOLD}	{NIRS}
Blood Volume	ml/100g	5.2 ± 0.2	4.3± 0.1	5.1 ± 0.2	5.2 ± 0.1
Total Hemoglobin	μM	100 ± 2	85 ± 2	100 ± 4	92 ± 2
Blood flow	ml/100g/min	82 ± 4	68 ± 2	84 ± 4	93 ± 3
Hemoglobin content	g Hg/dL	12.5 ± 0.1	12.8 ± 0.2	(12.5)	(12.5)
Oxygen delivery	ml O_2/100g/min	14.2 ± 0.6	12.1 ± 0.3	14.7± 0.8	14.8 ± 0.4
Oxygen extraction	[OEF]	0.37 ± 0.02	(0.37)	(0.37)	(0.37)
Baseline $CMRO_2$	ml O_2/100g/min	5.2 ± 0.2	4.4 ± 0.1	5.3 ± 0.3	5.4 ± 0.1

In addition, the values of the parameters estimated for volume fraction [Vo], transit time [τ], and baseline oxygen saturation, are used to calculate baseline flow and CMRO2 (i.e. $CBF_o = CBV_o / \tau$). The values for these baseline properties are shown (above) for the model parameters fit to the NIRS, pASL, or multimodal data sets. We find consistent parameter values for model fits for each data set.

Citations

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