Measurement of Cerebral Metabolic Rate of Oxygen (CMRO2) using qBOLD Technique in Resting State

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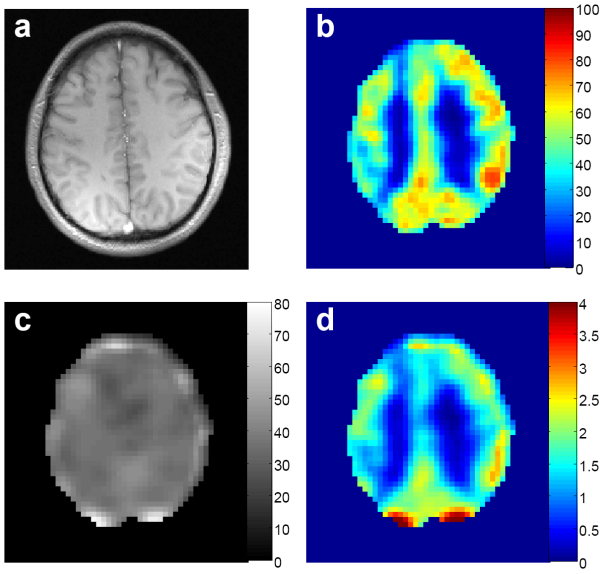
Introduction: Quantitative brain hemodynamic parameters, such as cerebral oxygen extraction fraction (OEF), cerebral blood flow (CBF), and cerebral metabolic rate of oxygen (CMRO2) in a baseline resting state or during functional activation, are essential for both understanding the biophysical processes underlying blood oxygenation level depend (BOLD) phenomenon (1,2) as well as for determining the consequences of neurological impairments associated with common brain diseases, such as stroke (3). It may also important for the quantification of tumor hypoxia. Previous studies developed (4) and validated (5) MRI-based quantitative BOLD (qBOLD) methods that allow for non-invasive regional measurement of OEF. In this study, we propose a new MR approach, ASL-qBOLD (arterial spin labeling qBOLD), to simultaneously measure both CBF and OEF, thereby providing quantitative CMRO2 mapping.

Methods: All experiments were performed on 3.0 T Siemens Trio scanner using a body transmit RF coil and 12 channel head receive coil. Perfusion sensitive preparation pulses (6) (slice selective and non-selective inversion recovery) were used to generate perfusion weighted GESSE (gradient echo sampling of spin echo) qBOLD images. QUIPSS II technique (7) was incorporated to shape the labeling bolus for a robust CBF quantification. Three studies were conducted on healthy volunteer subjects. The MR imaging parameters for the ASL-qBOLD were: TR = 3000 ms; total labeling time (TI) of 2000 ms; spin echo at 60 ms with 90 gradient echoes (15 echoes before spin echo); echo spacing of 1.5 ms; FOV of 256x192 mm^2 and voxel size of 4x4x8 mm^3. A 75% oversampling along phase encoding direction was adopted to reduce ghosting artifacts. The labeling and control k-space lines were acquired in an interleaved fashion. Total acquisition time was 500 s. To control the shape of labeling bolus, similar to QUIPSS II, the labeling area was saturated with periodic RF pulse train of 900 ms before GESSE data acquisition. The signal decay due to macroscopic field inhomogeneities was quantified from a high resolution field map acquired with a double echo 3D GRE sequence. The MRI parameters were T_R = 25 ms, TE = 4.92 and 12.3 ms with spatial resolution of 1x1x2 mm^3. To further compensate the B0 field changes (possibly due to respiration or scanner instability) during the data acquisition, 1D navigator was acquired for each line in k-space along the phase encoding direction.

After the correction for motion and Bo field, the averaged GESSE data between the labeling and control conditions was fitted by the qBOLD signal model (4) to estimate the absolute OEF maps. ASL signal corresponded to the averaged MR signal difference between labeling and control GESSE image for 10 echoes before the spin echo (limited by the progression of imaging artifacts along echo train). CBF was subsequently quantified by assuming T1 of GM, WM and blood to be 1200 ms, 800 ms and 1670 ms, respectively. The CMRO2 was determined by the product of OEF and CBF.



Results: Figure "a" depicts a typical case in point of a high resolution T1-weighted anatomy image from a healthy subject. The brain area was manually segmented. Areas close to the brain surface were masked out to avoid a possible contamination from large veins at the surface, reflected by the higher qBOLD fitting residue. Figure "b" is the estimated CBF map (in ml/100g/min), delineating the contrast between GM and WM. The mean CBF was 52±10 ml/100g/min in GM. Figure "c" illustrates the estimated OEF map, which is relatively uniform across the brain parenchyma with mean values of 38±9 %. Figure "d" shows the CMRO2 map (in μmol/g/min). Note that the CMRO2 was much higher in the cortical GM than the WM. The mean CMRO2 in GM area was 1.77±0.56 μmol/g/min, which is consistent with that measured by PET imaging (8).

Discussion: We have developed and implemented an ASL-qBOLD technique to determine quantitative MR-based in vivo absolute CMRO2 maps of the brain. The estimated CMRO2 was within a physiological range of those reported by PET imaging (the current in vivo gold standard). For a robust CBF estimation, it is essential to eliminate the effect of imaging artifacts caused by motion and Bo field drifting. However, since high SNR is required of OEF estimation in GESSE data, conventional ASL enhancement techniques (such as background suppression) cannot be applied. We demonstrated that imaging artifacts can be effectively minimized by incorporating over-sampling in phase encoding direction and navigator echoes. In addition, high SNR in CBF can be achieved by averaging the perfusion MR signal along the echo train. Application of these methods facilitates a robust estimation of absolute CMRO2 in the brain baseline state.

References: **1.** Ogawa, et al, PNAS 1990; 87:9868-72; **2.** Perlmutter, *et al.*, JCBFM;7:64-67; **3.** Derdeyn, *et al.*, Brain 2002; 125:595-607; **4.** He and Yablonskiy., MRM 2007; 57:115-126; **5.** He, *et al.*, MRM 2008; 60:882-888; **6.** Kim, *et al.*, MRM 1995; 34:293-301; **7.** Wong, *et al.*, MRM 1998; 39:702-708; **8.** Mintun, *et al.*, JNuclMed 1984; 25:177-187.