MRI Estimation of Global Brain Oxygen Consumption Rate

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Introduction

Measuring the cerebral metabolic rate of oxygen ($CMRO_2$) is a valuable tool for monitoring acute, severely brain injured patients[1]. Measurement of blood oxygen saturation (HbO_2) and flow in the major cerebral inflow and outflow vessels can provide a global estimate of $CMRO_2$. The internal jugular veins (IJV) are the major vessels for cerebral venous drainage while internal carotid (ICA) and vertebral arteries are the predominant inflow vessels. The current gold standard for quantifying $CMRO_2$ is by internal jugular bulb oximetry involving catheterization which is invasive, prone to complications such as thrombosis, infection, jugular vein occlusion and is not practical for non-emergency patients. Furthermore, the accuracy of the method is highly dependent on the catheter position and the simultaneous measurement of both the left and right sides is impractical but important due to asymmetric venous drainage. We demonstrate MRI-based $CMRO_2$ quantification by measuring blood oxygenation difference between IJVs and ICAs with MR susceptometry-based oximetry and average blood inflow rate with gated phase-contrast (PC)-MRI. The total blood inflow through the carotid and vertebral arteries was preferred over venous drainage to quantify flow as studies have shown that accessory drainage pathways (such as the vertebral venous plexi) in addition to IJVs might contribute to venous drainage [2].

Methods

MR-susceptometry based oximetry [3,4] relies on relative magnetic susceptibility $\Delta\chi$ of intravascular blood and surrounding tissue the latter serving as a calibration-free reference. If the blood vessel is modeled as a long paramagnetic cylinder an exact expression for the relative incremental field ΔB can be derived as $\Delta B = \frac{1}{2}\Delta\chi B_o(\cos^2\theta - 1/3)$. ΔB is measured with a phase difference image $\Delta\phi = \gamma\Delta B \cdot \Delta TE$, where ΔTE is the echo-spacing between two successive gradient echoes. For whole blood $\Delta\chi = \Delta\chi_{do} Hct \cdot (1 - HbO_2)$ (in SI units), where $\Delta\chi_{do} = 4\pi \cdot (0.27$ ppm) [4] is the susceptibility difference in SI units between fully deoxygenated and fully oxygenated erythrocytes, HbO_2 is the fraction of the oxygenated hemoglobin, hematocrit (Hct) is the volume fraction of the packed erythrocytes in the whole blood and θ is the tilt angle of the vessel with respect to the main field B_o. For HbO_2 estimation images were acquired with a velocity-compensated multi-echo RF-spoiled GRE sequence with fat suppression programmed with SequenceTree™ [6]. In order to avoid phase wrapping while measuring oxygen saturation, an interleaved acquisition scheme was used reducing the effective ΔTE to 1.16ms. Scan parameters: FOV = 176x176 mm^2, voxel size = 1 x 1 x 5 mm^3, dwell time = 15 μs and flip angle = 20°, total scan time = 26s with four interleaves (see Figure 1). In order to reduce the effect of low spatial frequency static field inhomogeneity a least squares fit to a quadratic polynomial was implemented. Pulse-triggered phase-contrast MRI was used to measure flow velocity during the cardiac cycle with a temporal resolution of 20ms and the acquisition window was set to 120% of the average R-R interval. The average flow velocity over a single cardiac cycle and the vessel cross sectional area were used to obtain the average inflow measurement (mL/min). The $CMRO_2$ value was derived as a product of arterial-venous difference in oxygen content ($ADVO_2$ in mL/100mL of blood) and cerebral blood flow (CBF in mL/100g/min). All experiments were performed on a 3T Siemens Trio with a head/neck coil. Written informed consent was obtained prior to all human studies following an institutional review board-approved protocol.

Results and Discussion

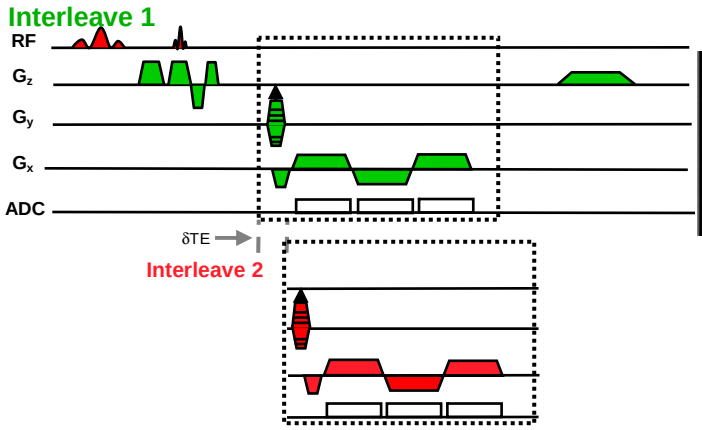

Figure 1:*Multi-echo spoiled GRE sequence with fat saturation and flow compensation along the slice direction. Phase difference images were constructed between successive interleaved echoes separated by δTE = 1.16 ms*

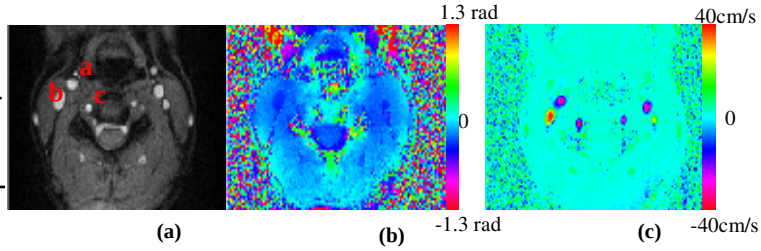

Figure 2: *(a) Representative axial magnitude image (a= right internal carotid artery, b= right internal jugular vein, c= right vertebral artery) along with the corresponding (b) phase image used for estimating oxygen saturation levels and (c) velocity image.*

Preliminary results obtained in two healthy human subjects, a 36 year old male and a 23 old female, are consistent with literature [7,8]. The total measured arterial inflow and the estimated global $CMRO_2$ was 720mL/min and 3.9 mL/100g/min , respectively for the male volunteer and 780ml/min and 2.4mL/100g/min for the female volunteer. The above $CMRO_2$ values lie within the range of 2.9-4.9mL/100g/min for males and 1.9-3.9mL/100g/min for females as cited in literature.

Conclusions

MR susceptometry-based oximetry can be used to estimate $CMRO_2$ .Further development of the method's potential requires larger sample size and further measurements analyzing the precision and reproducibility of measurements.

References

[1] Jaggi et al. Crit Care Med 23: 66-70; **[2]** Milan Rufz et al. AJNR 23:1500-1508 (2002);**[3]** Haacke et al. Human Brain Mapping 5:341-346 (1997); **[4]** Fernandez-Seara et al. MRM 55:967–973 (2006); **[5]** Spees et al MRM 45: 533 – 542 (2001); **[6]** Magland et al., Seattle, WA. Proc.ISMRM 2006, p 578 ; **[7]** Bateman et al., Am J Radiol 29: 98-102 (2008); **[8]** De Deyne et al.Acta Anaesth 49:21-31 (1998)