Validation of MR measured Oxygen Extraction Fraction

Y. Z. Lee[1], H. An[2], W. Lin[2]

[1]Radiology, University of North Carolina at Chapel Hill, Chapel Hill, NC, United States, [2]University of North Carolina at Chapel Hill, Chapel Hill, NC, United States

Introduction

Estimation of brain oxygen extraction fraction (OEF) is an essential component of CMRO2 measurement in evaluating tissue viability after stroke. Quantitative MR measurements of OEF have been previously demonstrated in normal and patient populations (1,2). While MR-OEF compared favorably to values obtained from other modalities, systematic and direct validation has not been performed. The goal of this study was to validate the MR measured OEF by inducing experimental hypoxia in rats and compare MR measured brain oxygenation to that obtained from blood gas samples.

Methods

The femoral artery and jugular vein were cannulated in ten Long Evans rats, 280-350 grams, providing arterial and cerebral venous access, respectively. Respiration gas (mixtures of air and nitrogen, 3 ratios) was supplied by a respirator through a tracheotomy. Animals were imaged on a Siemens 3.0T Allegra. Two multi-echo sequences were utilized, one with a SE (TE=10 msec) and 30 additional gradient echoes following the SE was used to acquire 31 images (SEFID), the other referred to as a, multi-echo gradient echo spin echo (MEGESE) acquired 18 gradient echoes prior to the SE, and 12 gradient echoes after the SE. OEF results were obtained by combining results from the two sequences: one to estimate CBV (λ) and the other for measuring local susceptibility.(3) Immediately before and after imaging, blood samples were drawn from the femoral artery and jugular vein, and blood gas parameters were obtained. Venous oxygen saturation (VOS, surrogate for MR-OEF) was calculated and plotted against jugular vein oxygenation.

A region of interest (ROI) encompassing both hemispheres in the cortical and subcortical area was drawn on the image slice from each animal. Images acquired using the SEFID were used to estimate λ. Based on the signal model, the blood volume fraction containing deoxyhemoglobin can be obtained by taking the difference between the log of the actual acquired SE signal and the log signal extrapolated from the R2* decay back to the time of the SE. In contrast, R2′ and R2 were estimated from the images acquired using the MEGESE sequence with the methods proposed by Ma and Wehrli (4) and modified by Yablonskiy and Haacke (5). Briefly, the gradient echo signal around the spin echo consists of a combination of R2 and R2′. Taking linear combinations of the linear fits of these sets of points allows the calculation of both R2 and R2′.

From these estimates of R2′ and λ, VOS can then be calculated

$$VOS = 1 - \frac{1}{\gamma \cdot \frac{4}{3} \cdot \pi \cdot \Delta\chi_0 \cdot Hct \cdot B_0} \cdot \frac{R2'}{\lambda}$$

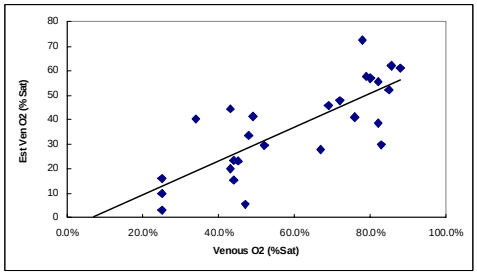
where $\Delta\chi_0$ represents the susceptibility measured to be 0.18 ppm. (6), Hct is the hematocrit, and B_0 is the field strength. However, since the arterial component also contributes to the deoxyhemoglobin pool under hypoxia, the MR measured R2′ can be written as $R2'_{total} = R2'_{arterial} + R2'_{venous}$. The arterial contribution to the total R2′ was removed through the forward calculation of the $R2'_{arterial}$ based on the arterial blood oxygenation obtained from the arterial blood draws. In addition, a 60:40 ratio between venous and arterial pools was assumed for this calculation, as the presence of deoxyhemoglobin under hypoxia contributes to changes in both λ and VOS. Finally, VOS can be calculated,

$$VOS = 1 - \frac{1}{\gamma \cdot \frac{4}{3} \cdot \pi \cdot \Delta\chi_0 \cdot Hct \cdot B_0} \cdot \frac{R2'_{ven}}{\lambda_{ven}}$$

where $\lambda_{ven}=0.6\lambda$.

Results

A highly linear relation between MR measured and blood draw VOS is shown in Fig. 1 (VenEst= 0.69 VenAct - 4.3 with an r-value of 0.78), suggesting that MR is capable of measuring OEF. Nevertheless, it appears that MR underestimates the "true" blood oxygenation obtained from the jugular blood samples.



Discussion/ Conclusion

Good agreement was demonstrated between the MR derived and blood gas values. An underestimate of VOS by the MR technique may be due to overestimation by the blood draw measurement through the extracranial contamination. Nevertheless, a highly linear relation between MR measures and that obtained through blood gas analysis, demonstrating the utility of the MR-OEF method for estimation of venous oxygen saturation at the tissue level in a hypoxia model.

1. Lee JM, Vo KD, An H, Celik A, Lee Y, Hsu CY, Lin W. Magnetic resonance cerebral metabolic rate of oxygen utilization in hyperacute stroke patients. Ann Neurol 2003;53(2):227-232.
2. An H, Lin W. Quantitative measurements of cerebral blood oxygen saturation using magnetic resonance imaging. Journal of Cerebral Blood Flow & Metabolism 2000;20(8):1225-1236.
3. An H, Lin W, Celik A, Lee YZ. Quantitative measurements of cerebral metabolic rate of oxygen utilization using MRI: a volunteer study. NMR in Biomedicine 2001;14(7-8):441-447.
4. Ma J, Wehrli FW. Method for image-based measurement of the reversible and irreversible contribution to the transverse-relaxation rate. J Magn Reson B 1996;111(1):61-69.
5. Yablonskiy DA, Reinus WR, Stark H, Haacke EM. Quantitation of T2' anisotropic effects on magnetic resonance bone mineral density measurement. Magn Reson Med 1997;37(2):214-221.
6. Weisskoff RM, Kiihne S. MRI susceptometry: image-based measurement of absolute susceptibility of MR contrast agents and human blood. Magnetic Resonance in Medicine 1992;24(2):375-383.