Cerebral Blood Volume Contribution to the Functional T1ρ in the Human Brain

Hye-Young Heo[1], Casey P Johnson[1], Daniel R Thedens[1], John A Wemmie[2,3], and Vincent A Magnotta[1,3]

[1]*Department of Radiology, University of Iowa, Iowa City, Iowa, United States,* [2]*Department of Neurosurgery, University of Iowa, Iowa, United States,* [3]*Department of Psychiatry, University of Iowa, Iowa, United States*

Introduction

Functional $T_{1\rho}$ mapping is a recently proposed method to detect metabolic changes in the brain [1-3]. $T_{1\rho}$ signal reflects water-protein interaction in tissue, which has been shown to be sensitive to pH, concentrations of metabolites such as glucose and glutamate, and cerebral blood volume [1,2,4-6]. The contribution of these various components to the functional $T_{1\rho}$ response is unknown. In this study, we propose to further investigate the blood volume contribution to the functional $T_{1\rho}$ signal in human brain. Two imaging experiments were designed to determine the efficiency of using spatial presaturation pulses to suppress the intravascular signal and to assess the influence of cerebral blood volume on the functional $T_{1\rho}$ signal.

Methods

For both experiments, MR imaging was conducted on a 3T Siemens TIM Trio scanner (Siemens Medical Solutions, Erlangen, Germany) after informed consent was obtain in accordance with the Institutional Review Board at the University of Iowa. In order to evaluate the labeling efficiency of the spatial presaturation pulse (preSAT), single slice $T_{1\rho}$ imaging was performed using an echo-planar spin-echo sequence with an additional $T_{1\rho}$ spin-lock encoding pulse. The sequence parameters were TR=2000ms, TE=12ms, FOV=220x220mm, matrix size=64x64, bandwidth=1954Hz/pixel, and slice thickness=5.0mm. Two spin-lock pulses were used (10 and 40ms) with a spin-lock frequency of 350Hz. Data was acquired with and without a spatial preSAT pulse. The location (5 and 30mm) and slab thickness (3,10,70, and 110mm) of the SAT pulse was varied. For $T_{1\rho}$ data, two-dimensional motion correction was performed using AFNI. Each pair of spin-lock images were then analyzed using MATLAB to generate $T_{1\rho}$ relaxation times using a log-linear regression of the voxel signal intensity with the spin-lock time. The difference between the images collected with and without the preSAT pulse were calculated. This information was used to determine the efficiency of the spatial preSAT pulse.

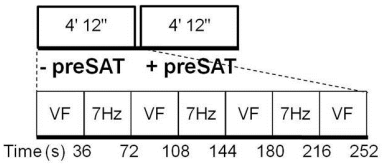

Fig 1. flashing checkerboard paradigms. Functional $T_{1\rho}$ imaging without a spatial presaturation pulse (-preSAT) and with the presatruation pulse (+preSAT). VF=visual fixation.

In the second experiment, three subjects were recruited into a visual functional activation study. A visual checkerboard was presented with the block design of 18 scans "OFF" and 18 scans "ON" following the first 2 dummy scans as shown in Fig 1. Each experiment included 2 phases, $T_{1\rho}$ imaging with preSAT and without preSAT. The same imaging parameters and analysis strategies used in the first experiment were used in this study. The preSAT pulse was applied with a 5mm offset from the slice with a 110mm slab thickness. The $T_{1\rho}$ relaxation maps were spatially smoothed using a Gaussian filter (6mm FWHM). The smoothed $T_{1\rho}$ relaxation maps were analyzed using linear regression where the relationship between the $T_{1\rho}$ relaxation times and the experimental design was estimated. The resulting functional maps were thresholded at $p<0.01$, uncorrected. The overlap between the voxels found to be activated at the selected threshold level were computed and overlaid on the mean functional image. The average percent signal change was calculated within the union of the activated voxels identified during each of the runs (-preSAT and preSAT).

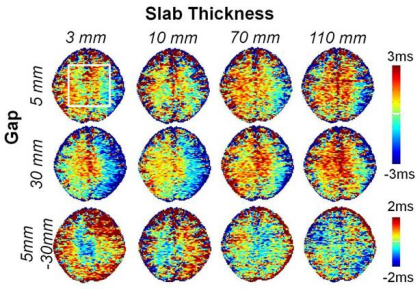

Fig 2. Labeling efficiency. $T_{1\rho}$ experiments with varying thickness of slab-selective inversion presaturation pulse and gap between the inversion band and the imaging slice.

Results

Fig 2 shows the subtracted $T_{1\rho}$ maps between without preSAT and with preSAT. The $T_{1\rho}$ experiment with varying thickness of the preSAT showed that the difference significantly increased with the slab thickness of 70mm and 110mm relative to the thickness of 3mm and 10mm. However, there was no significant difference in the gap of 5mm and 30mm when more than 70mm in thickness was applied. Functional $T_{1\rho}$ activation was observed in the primary visual cortex for imaging with and without preSAT as shown in Fig 3. The activated voxels with a significant activation ($p<0.01$, uncorrected) are shown. Area of the $T_{1\rho}$ activation with the preSAT were similar with those of the $T_{1\rho}$ activation without preSAT. However, the percent signal change in the union between the two activated regions was decreased when the preSAT was applied. It was found that the mean blood volume contribution to activity-evoked $T_{1\rho}$ signal change was 27% (34.8%, 24.1%, and 22.8% for the three subjects).

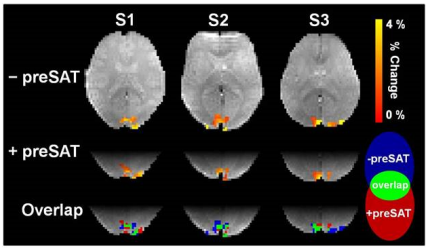

Fig 3. $T_{1\rho}$ functional activation maps with/without the spatial presaturation RF pulse for three subjects in response to a full field flashing checkerboard (7Hz).

Discussion and Conclusions

Our study suggests that a majority of $T_{1\rho}$ signal likely comes from the tissue compartment. Previous studies suggested that a local change of cerebral blood volume mainly affects functional $T_{1\rho}$ signal because of longer $T_{1\rho}$ of blood relative to tissue [2,6]. In order to suppress the intravascular signal, a spatial presaturation RF pulse was applied inferior to the imaging slice to minimize the blood contribution to the observed signal intensity. Our result shows the vascular contribution to $T_{1\rho}$ signal is about 27% in the brain. Therefore, the use of spatial presaturation in conjunction with $T_{1\rho}$ imaging is an effective and efficient way to minimize the blood volume contribution to the functional $T_{1\rho}$ signal.

References

[1] Magnotta, VA et al., PNAS (2012). [2] Jin, T and Kim, SG, Neuroimage (2013). [3] Magnotta VA et al., Biol Psychiatry (epub). [4] Kettunen, MI et al., Magn Reson Med (2002). [5] Jin, T et al., Magn Reson Med (2011). [6] Hulvershorn, J et al., Magn Reson Med (2005).