Vascular Source Imaging

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Introduction

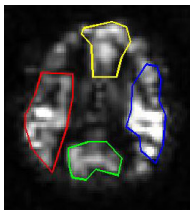
In remotely detected MRI[1], spins are spatially encoded in one location, and moved to another location where the signal from these spins is detected. We introduce here the combination of arterial spin labeling (ASL) and remote detection methods in vivo to form images of blood, encoded in one anatomical location, and detected after the blood is delivered by flow to another location. This method is termed vascular source imaging (VSI). Potential applications of this technique include mapping and quantification of normal vs collateral blood supplies, tumor blood supplies, likely targets for emboli from mural thrombi, and mixing of blood through AVMs or septal defects.

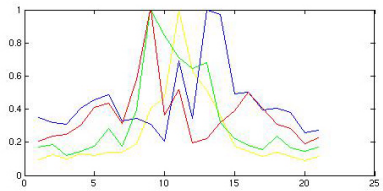
Methods

VSI can be though of as a generalization of ASL, with spatial encoding of the tagging region. In our initial implementation of VSI, a conventional ASL tagging pulse is preceded (it may also be followed) by a simple 90-grad-90 sequence to provide phase encoding of the longitudinal magnetization of the tagged blood. Since $T_2 << T_1$ for blood, typically only the longitudinal magnetization will survive to the imaging region. In order to implement full complex Fourier encoding, cos terms were generated using a 90_X-G-90_{-X} sequence, while sin components were generated using a 90_X-G-90_{-Y} sequence. Each VSI encoding step was repeated for both tag and control images of a conventional PICORE ASL tagging sequence, thus requiring 4 TRs for the collection of each phase encoding step. VSI encoding can be applied in any combination of directions. After FT across k-space and also across VSI encodes, VSI data can be up to 6 dimensional, up to 3 in conventional image space, and for each voxel, up to 3 spatial dimensions mapping the vascular sources for that voxel. Data shown here has 2 conventional imaging dimensions and one VSI encoding direction.

Axial images were collected from the brain of a normal volunteer on a GE 3T EXCITE system, using a single shot spin echo spiral at 64x64 resolution, and scan parameters: FOV=32cm x 10mm, cardiac gated using a pulse oximeter with TR=3x(R-R), TI=1600ms, an axial PICORE tagging slab of 100mm width, a 1-D VSI encoding matrix of 32 with 1cm resolution in the L/R direction, thus requiring 128 image acquisitions for a scan time of approximately 6min. Cardiac gating was found to greatly reduce artifacts in the VSI encoded space, presumably due to cardiac related variations in the delivery of tagged blood.

Results

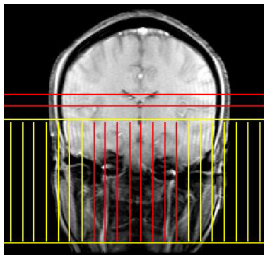




Because both the image and the source encoding domains are spatial, there are many possible ways to visualize VSI data. Two methods are shown here. In the Figure to the right, regions of interest are draw over ACA, MCA, and PCA territories on an averaged ASL image, and the VSI data averaged over these ROIs in the source encoding direction is shown color coded for each ROI in the accompanying graph (horizontal scale in cm). The peak in the VSI curve for the left MCA distribution (red) corresponds to the left/right location of the left carotid, and similarly for the MCA distribution on the right (blue), while the ACA and PCA territories receive blood from both sides. Shown below is a coronal image with the axial imaging slice shown in red, and the PICORE tagging slab shown in yellow. The vertical lines show the VSI encoding grid, and the accompanying images show the destination of blood encoded in the central 7 locations of the VSI encoding grid (red vertical lines). Note for example that the second image from the left shows perfusion of left MCA, as well as ACA and PCA territories, and the second vertical red line in the coronal image sits on the left carotid.

Discussion

VSI represents a new way of mapping vascular sources to their target tissues. Forms of spatial encoding of the tagging region other than Fourier are possible, including wavelet, hadamard, RIGR, and other methods that can improve encoding efficiency based on a priori information about the vascular geometry. VSI can be used with spatially selective forms of ASL, as in this study, to encode vascular contributions from specific regions, or with velocity selective ASL to encode vascular sources over all of space for a comprehensive image of all vascular sources for a tissue of interest. VSI can also be thought of as a generalization of vascular territory imaging, in which individual arteries are labeled and the delivery of blood is observed. With efficient encoding schemes, VSI can in principle image all vascular territories simultaneously, without loss of SNR efficiency relative to vascular territory imaging.



Reference

1. Seeley, J.A., S.-I. Han, and A. Pines, *Remotely detected high-field MRI of porous samples.* Journal of Magnetic Resonance, 2004. **167**(2): p. 282-290.