VENTI: Venous Territory Imaging using Remote Sensing

Eric Wong[1] and Jia Guo[2]
[1]Radiology/Psychiatry, UC San Diego, La Jolla, CA, United States, [2]Bioengineering, UC San Diego, La Jolla, CA, United States

Introduction: In recent years, several methods have been introduced to map arterial vascular territories using arterial spin labeling. We explore here the use of spin labeling methods to map venous territories. Potential applications include the evaluation of venous strokes/thrombosis, and evaluation of venous drainage patterns in multiple sclerosis. We are interested in using venous territory maps to extend information on venous oxygenation from intravenous T_2 (1) or phase measurements (2) to the tissue that drains to these veins.

Methods: Our approach involves the following steps: 1) Spatial encoding of M_Z throughout the brain tissue; 2) A velocity selective pulse module to saturate flowing spins and thus remove intravenous spins from the encoding process; 3) a delay to allow for encoded M_Z to flow from tissue into the venous system; and 4) a rapid phase contrast angiographic readout to isolate intravascular signal. After several images are acquired with different tissue encodes, the data from each intravenous voxel is decoded into tissue sources. In our current implementation, step 1 was accomplished using a hard 90° pulse, a phase encoding gradient, and a hard -90° pulse, followed by a crusher gradient. This produces $M_Z=M_0\cos(k*r)$ encoding, while the addition of a 90° phase shift to the second 90° pulse produces $M_Z=M_0\sin(k*r)$ encoding. For step 2 a BIR-4 pulse, expanded in time with unipolar gradient pulses at the two $B_1=0$ points was used, generating a VENC of 2cm/s. A delay of 2s was inserted to allow for encoded M_Z to flow into the venous system. The phase contrast readout consisted of gradient echo interleaved spiral acquisitions, alternating between positive and negative flow moments, with a VENC of 5cm/s, and a variable flip angle schedule of $35°(0.4+0.6((i-1)/(N-1))^{1.5})$, where i is the interleaf number and N is the total number of interleaves. This schedule was found to minimize interleaving artifacts in this non-steady state acquisition. Parameters include TR=5s, 16 interleaves, FOV=20cm, matrix=192. Tissue magnetization was 2D Fourier encoded with matrix=8x8 and 2cm resolution. Two acquisitions were required for cos/sin components of each Fourier encode, for a total of 128 acquisitions in 640s. For each encoding step, images from positive and negative flow encodes were reconstructed and a complex subtraction yielded intravascular signal. Across encodes, the mean signal in each voxel arose from T_1 relaxation between tagging and image acquisition and was removed, and the remaining encoded cos/sin components were assembled into a complex signal and reconstructed into a source map by 2D FT. This produces a 4D dataset which maps 2D tissue space at the time of tagging to 2D image space at the time of image acquisition. One healthy subject was scanned in a GE MR750 3T scanner under an IRB approved protocol.

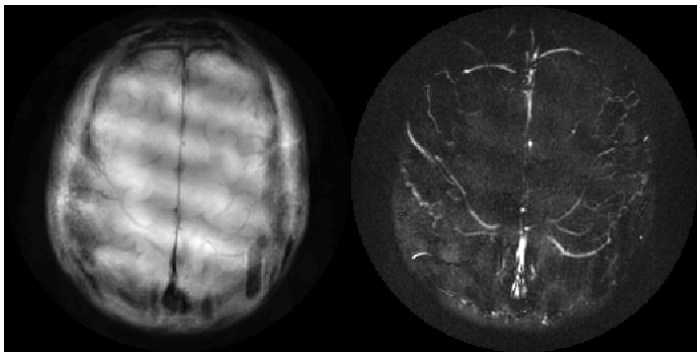

Figure 1: a) raw image; b) after complex subtraction of positive and negative flow encodes.

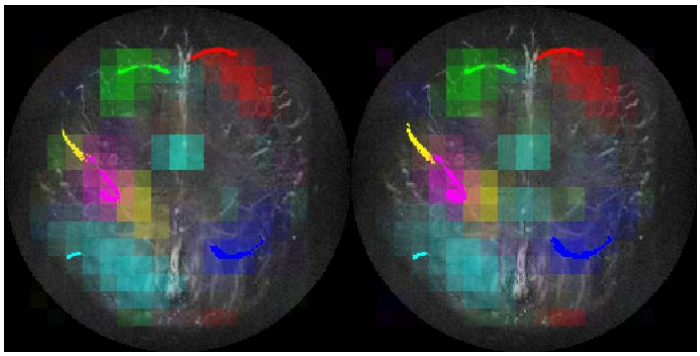

Figure 2: a) selected vessels shown in solid colors, and corresponding venous territories shown translucent; b) separate identical data set to demonstrate reproducibility.

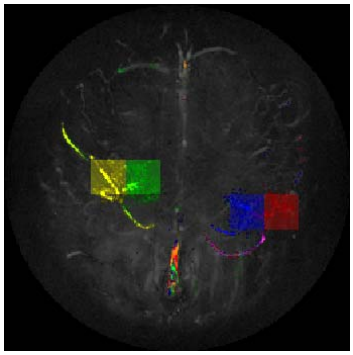

Figure 3: Selected tissue regions (translucent squares), and corresponding maps of venous drainage for each.

Results: A typical raw image is shown in **Figure 1a**. Residual modulation of the tissue is apparent, but after complex subtraction of the two flow encodes (**Figure 1b**), the signal is dominated by vessels. For several visible veins, the tissue draining into each vein is shown in color in **Figure 2a**. For some veins, (ie green, magenta, and blue) the venous territory is near the vein itself, while for others (red, yellow, and cyan) the territory is removed from the vein. **Figure 2b** shows a similar map from a second identical scan to demonstrate reproducibility. The data can also be querried in reverse, asking to what veins a particular region of tissue drains. This is shown for 4 tissue ROIs in **Figure 3**.

Discussion: This is a preliminary demonstration that magnetization can be spatially encoded in tissue, and measured and decoded in veins, following the principles of remote sensing NMR (3).

References

1. Lu et al, MRM Aug;60(2):357-63 2008
2. Fan et al, MRM Mar;67(3):669-78, 2012
3. Seeley et al, JMR 167(2):282-290, 2004