Improved Separation of Vascular Territories in Vessel Encoded Pseudo-Continuous Arterial Spin Labeling

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Introduction

In vessel encoded ASL (1-3), two or more arteries of interest are cycled through tag and control conditions in an encoding scheme that allows for efficient mapping of vascular territories. In initial implementations, the tagging efficiency (α) was assumed to be uniform for all vessels and encoding cycles. When this is not the case, separation of the ASL signal into vascular territories is incomplete. We present here a simple method for measuring α from the vessel encoded data and using this information to improve the quality of vascular source separation.

Methods

Volunteers were scanned under IRB approval using a 3T GE scanner with an 8 channel head array. Vessel encoded ASL data were collected as described in (1). From subsets of the vessel encoded data, ASL images of the sum and difference of the two vessels of interest were constructed and are shown in the top two rows of **Figure 1**. After applying a threshold at 50% of the peak ASL signal, the difference images were divided by the sum images on a per-voxel basis, producing images of the α of the difference image relative to the sum image. A histogram of α is shown in **Figure 2**. The peaks in this histogram were fitted to Gaussian functions, and the centers of these Gaussians were taken to be the α of the corresponding vascular source and used to construct the encoding matrix. The pseudoinverse of this matrix was used to decode the data into vascular territories.

Results

The measured tagging efficiencies from the histogram of Figure 2 were 0.83 and 0.50 for the carotid and basilar territories, respectively. Ideal and empirical encoding matrices are shown to the right; columns are weightings for carotids, basilar, and static tissue, while rows are the 4 tagging cycles. Images of these vascular territories are shown in rows 3 and 4 of Figure 1 in the form of red and blue intensities in an RGB color scale. Rows 3 and 4 were reconstructed using ideal and measured α, respectively. The incomplete separation of territories in row 3 is most easily seen as a magenta hue in the posterior territory. These same data

$$A_{ideal} = \begin{bmatrix} -1 & -1 & 1 \\ 1 & 1 & 1 \\ -1 & 1 & 1 \\ 1 & -1 & 1 \end{bmatrix} \quad A_{meas} = \begin{bmatrix} -1 & -1 & 1 \\ 1 & 1 & 1 \\ -0.83 & 0.50 & 1 \\ 0.83 & -0.50 & 1 \end{bmatrix}$$
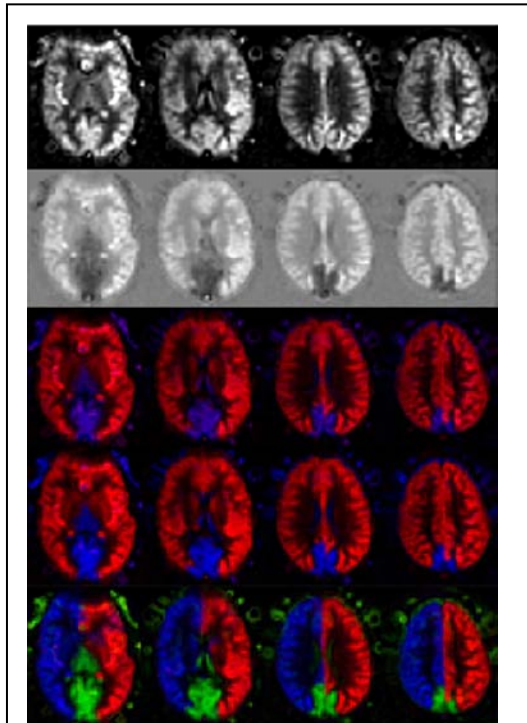
are shown as scatter plots of carotid versus basilar ASL signal in **Figure 3**. Blue and red circles are data reconstructed using ideal and measured values for α, respectively. Because most voxels are supplied by only one vascular source, the data should scatter primarily along the two axes. Note that the blue circles deviate away from the axes, incorrectly indicating that those voxels receive mixed blood supply. In this example, which is typical of 5 subjects examined, the assumption of ideal α rotates voxels so that pure carotid flow appears to be 8% basilar, and pure basilar flow appears to be 25% carotid. Direct extension of this method to 3 vessel encoding was used to produce the 3 territory maps in row 5 of Figure 1.

Conclusion

The use of measured tagging efficiencies, which are naturally present in vessel encoded data, can significantly improve the separation of vessel encoded ASL signals into independent vascular territories. This correction should allow for quantitative assessment of true mixing of vascular sources, such as through arterial anastomoses or in arterial border zones.

References

1. Wong et al, ISMRM 2006, p.668.
2. Zimine et al, MRM 2006, 56:1140
3. Gunther et al, MRM 2006, 56:671.

Figure 1. From top: Non-vessel-encoded ASL signal; ASL difference signal between anterior and posterior tagging; A/P territory maps calculated assuming ideal tagging efficiencies (α); A/P maps using measured α; three vessel separation using measured α
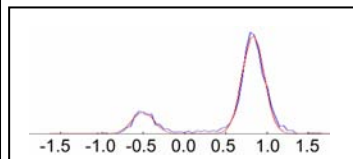

Figure 2. Histogram of tagging efficiencies for carotid (right peak) and basilar (left peak) arteries. The blue represents measured data, and the red line is a Gaussian fit.
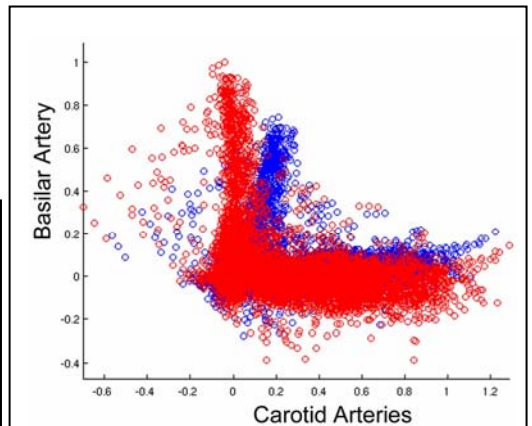

Figure 3. Scatter plot of ASL signal separated into carotid and basilar components using an ideal encoding matrix (blue); and measured tagging efficiencies (red).