Mapping Middle Cerebral Artery Branch Territories with Vessel Encoded Pseudo-Continuous ASL: Sine/Cosine Tag Modulation and Data Clustering in Tagging Efficiency Space

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Introduction

In vessel encoded pseudo-continuous ASL (VEPCASL) (1), two or more vessels flowing through the tagging plane are differentially tagged and encoded across image repetitions. In this and similar methods (2-3), Hadamard type encoding and a linear model are used to estimate the contribution of each vessel to the perfusion of each voxel. For some tagging planes, such as above the Circle of Willis, many arteries will pass through the tagging plane, and unique Hadamard encoding of each vessel is difficult or impossible. In this work, we exploit the continuous nature of the spatial modulation of tagging across the tagging plane in VEPCASL to identify multiple vascular territories with a small number of encoding steps. Branches of the M2 Segment of the MCA are mapped using two approaches.

Methods

In VEPCASL, the relative tagging efficiency β varies periodically and roughly sinusoidally across the tagging plane from +1 to -1 (1). In one approach, two A/P encoded images S and C are collected, with the tagging modulation shifted by one half cycle in the second, generating arterial magnetization $M_{zS} \propto \sin(2\pi y/Y)$ and $M_{zC} \propto \cos(2\pi y/Y)$, where Y is the spatial period of the modulation. At each voxel, the ASL signal is related to the location y of the source vessel by $y = Y \arctan(S/C)/2\pi$, and the y position of the vascular source can therefore be localized modulo Y. In a second approach, two or more vessel encoded images are acquired, and the relative tagging efficiency β is calculated for each voxel. For N vessel encoded images, β can be represented as a point in N dimensional space, and voxels with a common vascular source will cluster in that space. Conventional cluster analysis can then be used to identify clusters in β, and the centroid of each cluster used to estimate the position of the source vessel. Volunteers were scanned under IRB approval using a 3T GE scanner. Images were acquired using single shot spiral imaging at 64x64 matrix, 20cm FOV with 6mm slices. Vessel encoding was performed as described in (1). Total scan time was 8min for Figures 1 and 2AB, and 12min for Figure 2CD.

Results

The sin/cos modulation method is shown in **Figure 1**. In this example, A/P modulation of the tagging was performed with Y=54mm. **Figure 1A** shows the tagging plane, and the color scale shows the predicted phase angle arctan(S/C). **Figure 1B** has a pixel intensity proportional to the absolute ASL signal, but is colorized according to arctan(S/C), on the same color scale as in **Figure 1A**. Thus for each vascular territory, the y position of the vascular source can be identified by color. On both sides of the brain, three branches of the M2 segment of the MCA can be identified on both the angiogram and the vascular territory maps. The clustering method is shown in **Figure 2**. Using the same data as **Figure 1**, the clusters in two dimensional β space are shown in **Figure 2A**. Clusters were identified automatically using an Expectation Maximization Gaussian Mixture clustering routine in Matlab. Clusters were colorized, with the same colors transferred to the corresponding voxels in **Figure 2B**. Note that both methods identify the posterior branch of the MCA on the left and right sides as different, based only on slight differences in the A/P location of the arteries. In principle, the clusters in **Figure 2A** should fall along a circle, but do not because of inefficiencies in tagging due to variations in vessel curvature, flow velocities, B_1, and B_0. The phase angle in **Figure 1A** is the azimuthal angle in **Figure 2A**. For **Figures 2C and 2D**, a third data set containing L/R encoding was added to provide clean separation between left and right source vessels. The β space and clustering are 3 dimensional, and the clusters are shown in **Figure 2C**. While left/right encoding is not itself of use in this case, an additional axis can separate clusters that may otherwise partially overlap, and thereby improve the accuracy of the localization of the cluster centroids.

Discussion

Because VEPCASL provides a graded modulation of tagging efficiency across space, several vascular territories can be identified using a small number of encodings, limited only by the SNR of the measurement of β. At least 3 branches of each MCA can be separated at the M2 segment. The advantage of the sin/cos encoding method is that it does not depend on data fitting or clustering, and is fast and robust. The clustering based method allows for the inclusion of multiple dimensions of encoded data, which generally improves the separation of clusters. However, fully automated detection of clusters is not always robust.

References

1. Wong, "Vessel Encoded Arterial Spin Labeling Using Pseudo-Continuous Tagging"MRM 2007, epub ahead of print.
2. Zimine et al, MRM 2006, 56:1140
3. Gunther et al, MRM 2006, 56:671.

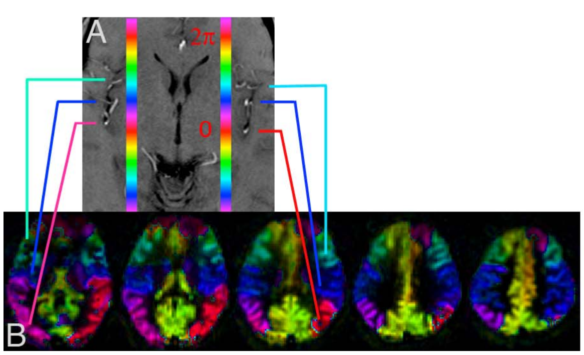

Figure 1: Sine/Cosine encoded localization.

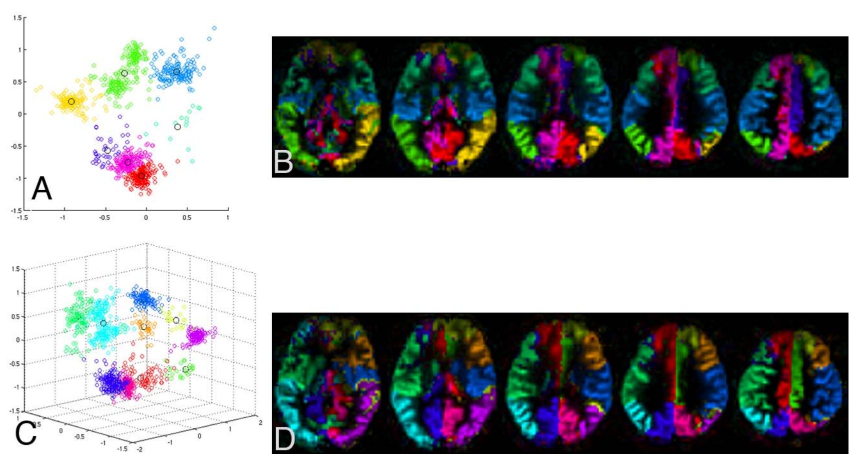

Figure 2: Territory mapping using two and three dimensional clustering.