Detecting cerebral perfusion territories and arterial source locations with minimal prior planning using harmonically encoded pseudocontinuous arterial spin labeling

Wen-Chau Wu[1,2]

[1]Graduate Institute of Oncology, National Taiwan University, Taipei, Taiwan, [2]Medical Imaging, National Taiwan University Hospital, Taipei, Taiwan

Introduction

Territorial arterial spin labeling (TASL) (1,2) has been known for its capability of noninvasively measuring regional blood flow supplied by a single or a subset of feeding arteries, which in the human brain is currently only achievable by using interventional digital subtraction angiography. The prior determination of target vessels for TASL demands familiarity of vascular anatomy and can be difficult when variations are caused by diseases. A few recent studies have shown the feasibility of pseudocontinuous ASL (PCASL) in mapping flow territory (3) with a caveat of tagging efficiency being susceptible to the off resonance induced by local field inhomogeneity. Here we propose to expand the use of PCASL and harmonic encoding (4) to detect flow territory, arterial source location, and off resonance with minimal prior planning.

Materials and Methods

PCASL-based TASL utilizes the property that pseudocontinuous tagging efficiency (α) is approximately a sinusoidal functional of the off resonance of tagging pulses with respect to the tagging plane. Vessel selectivity is thus achieved by spatially modulating α through application of gradients along the direction where multiple vessels are to be distinguished. With harmonic encoding, $\alpha(x) = \alpha_0\cos(k\pi x/L_x+\phi(x))$ [1], in which α_0 is the optimally achievable tagging efficiency, k is the number of tag/control contrast cycles in the encoding span L_x, x is the distance from the fixed tagging end, and $\phi(x)$ is the phase accrual originated from unwanted background gradient. In the original proposal (4), the two ends of L_x have to be placed exactly at the two vessels to be distinguished. In this study, the requirement is no longer necessary as long as L_x is large enough to cover the vessels to be separated and the number of vessels can be more than two (**Fig 1**). By varying k, multiple α's can be measured and fitted to equation [1] to extract x and $\phi(x)$. The Internal Review Board approved this study. Four healthy volunteers (F/M = 2/2, age = 22-30 yrs) were recruited and each provided written informed consent before participation. MR imaging was performed on a 3T MRI (Tim Trio, Siemens, Erlangen, Germany) using the body coil for transmission and a 12-channel phased-array head coil for reception. MR protocol included scout scans, 3D MPRAGE (for generation of gray matter masks), time-of-flight (TOF) imaging, and lastly a series of PCASL imaging. Harmonically encoded PCASL was performed with and without prior planning: TR = 3.5 s, TE = 18 ms, labeling duration = 1.5 s, post-labeling delay = 1 s, k = 1-4 along x and/or y directions for planned encoding, k = 4 along x and/or y directions for unplanned encoding, 10 control-tag pairs for each encoding step, single-shot 2D echo-planar readout (matrix size = 64x64, 5 axial slices, voxel size = 3.75x3.75x5 mm^3, inter-slice gap = 1 mm). PCASL was also performed (20 control-tag pairs) without spatial α modulation for calculation of relative tagging efficiency $\beta = \alpha(x)/\alpha_0$. After motion correction, difference between the control and tag images was computed and averaged for each encoding step, forming a feature dimension of the total number of encoding steps (e.g., 4 left-right steps + 4 anterior-posterior steps = 8). Independent component analysis and k-means clustering were applied successively to extract flow territories. For the results of unplanned encoding, average β's were calculated for separate flow territories, from which x and $\phi(x)$ were estimated and verified on the TOF images. All analysis was performed in the mentioned gray matter mask.

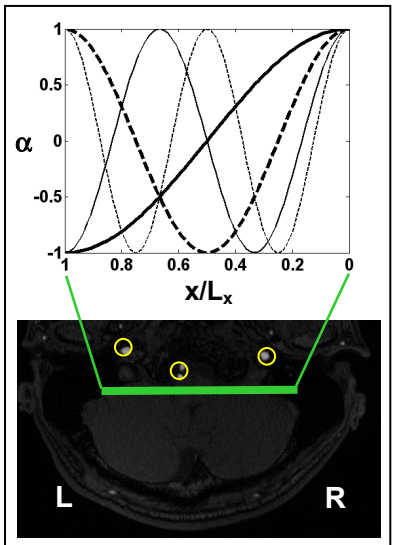

Fig 1. (A) Harmonic encoding layout. (B) TOF image of the tagging plane overlaid with detected arterial source locations (yellow circles).

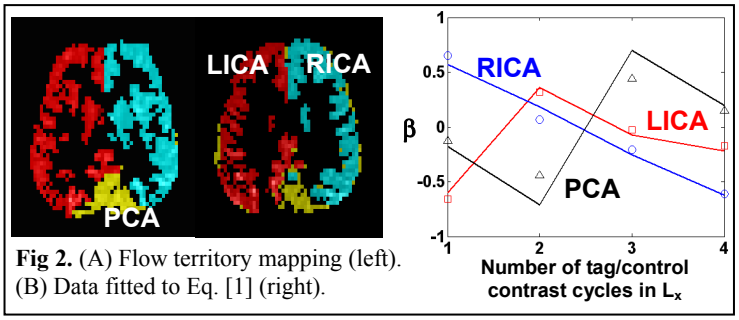

Fig 2. (A) Flow territory mapping (left). (B) Data fitted to Eq. [1] (right).

Results and Discussion

Fig 2A shows the flow territories detected using the unplanned method. **Fig 2B** shows the results of model fitting. The detected locations of arterial source are marked on the TOF image of the tagging plane shown in **Fig 1B**. The estimated locations closely match the actual locations: 17 vs. 19 mm for RICA, 62 vs. 60 mm for LICA, and 90 vs. 88 mm for the vertebral arteries. The estimated off resonance is -76 Hz for RICA, -29Hz for LICA, and 55Hz for the vertebral arteries (our RF spacing was 920 μs). The distance between the centroids of LICA/RICA/PCA territories measured with unplanned and planned (maps not shown) methods is within 5 mm. **Fig 3** shows an example with harmonic encoding applied above the circle of Willis. While left-right localization is accurate, anterior-posterior localization is off by several voxels. This could be due to vessel pulsatility (5) or because we had only sampled 4 points on the β-k curves, leading to suboptimal fitting results. The data shown here took a scan time of ~12 min. We are currently looking into possible improvement using increased k numbers and retrospective pulse oximetry gating.

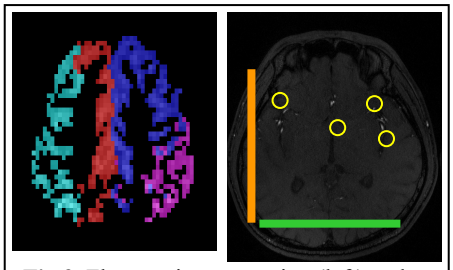

Fig 3. Flow territory mapping (left) and detected arterial source locations (right).

References

1. van Laar PJ, et al, Neuroimage 2006;29:136. 2. Werner R, et al, MRM 2004;52:1443.
3. Wong, MRM 2007;58:1086. 4. Wu, ISMRM 2011, p.295. 5. Wong and Guo, ISMRM 2011, p.294.