Statistical mapping of cerebral blood flow territories using multi-phase pseudo-continuous arterial spin labeling

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Introduction

Vessel-encoded pseudocontinuous arterial spin labeling (VE-PCASL) [1] is an MR imaging technique devised for territorial blood flow mapping. Depicting the primary flow territories of the brain is of clinical importance because collateral circulation is a common finding in patients with steno-occlusive disease. Based on VE-PCASL, several methods [2-4] have been proposed to distinguish the flow territories of the left/right internal carotid arteries (LICA/RICA) and vertebral arteries (VA). In this study, we tried to generate statistical maps of cerebral blood flow territories by using multi-phase VE-PCASL (MP-VE-PCASL) and the general linear model.

Theory

Fig 1 shows the original labeling scheme (black sinusoidal line) to separate LICA and RICA [1]. The target vessels are assigned with opposite labeling efficiencies (β) that can be approximated with a cosine function and is subject to the phase offset (ϕ_{bg}) induced by background field (see Eq [1] where L_x is the distance between the two vessels along x direction). With MP-VE-PCASL, phase ϕ_{mp} is introduced to the labeling module (see Eq [2] and gray lines in Fig 1). For a given location and thus a target vessel (i.e., different x for LICA/RICA/VA), β becomes a function of ϕ_{mp}, and $\beta(\phi_{mp})$ can be considered as an input function to the measured ASL signal. By using the general linear model, each voxel can be calculated for its statistical significance of being contributed by the input function (and of being supplied by the vessel).

$$\beta = cos\left(\frac{\pi x}{L_x} + \phi_{bg}\right) \qquad [1]$$

$$\beta = cos\left(\frac{\pi x}{L_x} + \phi_{bg} + \phi_{mp}\right) \qquad [2]$$

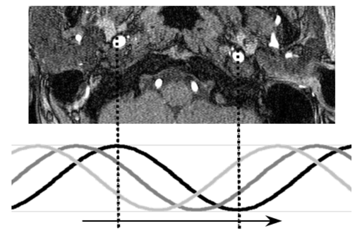
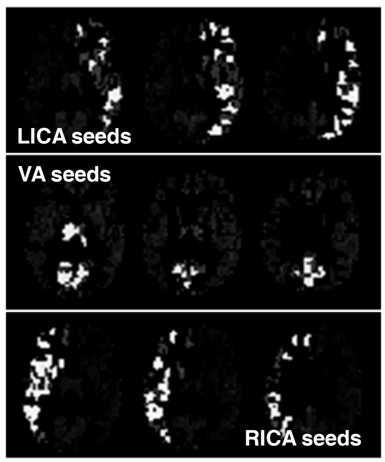


Fig 1.

Materials and Methods

The institutional review board approved this study. Five healthy volunteers were imaged after giving individual written informed consent. MR imaging was performed on a 3T clinical system (Tim Trio, Siemens). MP-VE-PCASL was performed based on the single-shot gradient-echo echo-planar readout and following parameters: FOV = 20 cm, matrix = 64x64, 15 slices, slice thickness = 5 mm, labeling duration = 2 s, post-labeling delay = 2 s, ϕ_{mp} = -180° –180° in steps of 30°, 2 pairs of tag and control measurements for each ϕ_{mp}. Vessel encoding was played out for left-right and anterior-posterior directions in separate scans. Time-of-flight images were obtained and used for labeling planning. Based on 3-class fuzzy clustering, voxels with the highest 80% memberships in each class were extracted as seeds and averaged separately to generate $\beta(\phi_{mp})$. To generate group territory maps, per-subject data were normalized to the MNI template followed by one-sample t test.



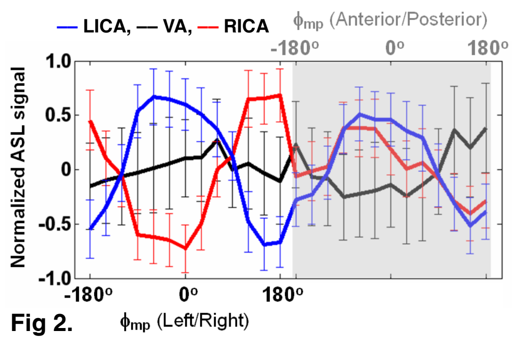
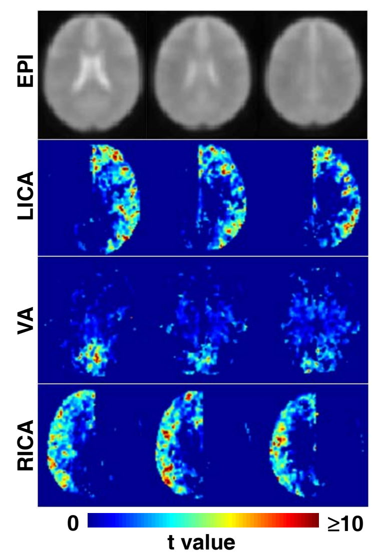


Fig 2.

Fig 3.



Results and Discussion

Fig 2 shows the $\beta(\phi_{mp})$ functions and their seeds obtained in a representative subject. Based on $\beta(\phi_{mp})$, ϕ_{bg} can be estimated by correlating the functions with a sinusoidal function. For example, the estimated ϕ_{bg} is ~30° for RICA and when necessary, can be used for calibrating labeling efficiency in perfusion quantification. Fig 3 shows the group territory maps in units of t values. In summary, the described method allows comparison between territories and/or subject populations to be carried out based on a statistical framework similar to that commonly adopted in functional MR imaging.

References 1. Wong, MRM 58:1086-1091, 2007. 2. Wong and Guo, MAGMA 25:95-101, 2012. 3. Wu. 19th ISMRM 295, 2011. 4. Jung, 20th ISMRM 581, 2012.