Effect of labelling plane angulation on pCASL labelling efficiency – does it really matter?

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TARGET AUDIENCE: Researchers using pseudo-continuous arterial spin labeling for quantification of cerebral blood flow.

MOTIVATION: Pseudo-continuous Arterial Spin Labeling (ASL) (pCASL [1]) is emerging as a method of choice for the non-invasive measurement of tissue perfusion in research and clinical practice [2]. The labeling efficiency, knowledge of which is essential for accurate Cerebral Blood Flood (CBF) quantification, usually takes a value based on the idealistic model that assumes spins flowing perpendicularly to the labeling plane. In practice, it might not be always possible to meet this assumption for all feeding arteries at the same time, either due to anatomical variation, lack of appropriate anatomical scans or lack of angulation flexibility in the pCASL implementation. It is not clear, what the effect of such imperfect angulation and mis-placement will have on the labeling efficiency and consequently, on CBF estimation. Therefore this work aims to address this question by simulation and in vivo experiment and **quantitatively assess the effect of the angulation of the labeling plane on pCASL labeling efficiency**.

METHODS:

Simulations: The change of labeling efficiency α with the angulation of the labeling plane ξ (ξ = 0 represents flow perpendicular to the labeling plane) was investigated using Bloch Equation simulations. Angulation of the labeling plane was modeled by calculating the effective velocity that spins experience with respect to the vector perpendicular to the labeling plane (veff = v *cos ξ). ξ was varied from 0 to 80°; the input velocities ranged from 1 to 100 cm/s over a distance of 20 cm with a step size of 1 cm/s. Laminar flow was assumed [3]. The pCASL gradient (Gmax = 6mT/m, Gave = 0.6 mT/m) and RF pulse train (Hanning shaped RF pulses of 0.5ms/1ms duration/spacing, flip angle FA=18°) were matched to that implemented on our Philips 3T scanner. To provide predictions of the relative change in labeling efficiency large enough to be detectable in vivo, a pCASL train with FA=8° was also simulated. FA=8° was chosen based on the previous simulations (data not shown). T1/T2 of the blood was assumed to be 1.65s/0.2s.

In vivo experiments: Two healthy volunteers (1 female) underwent pCASL scans on a 3T Philips Achieva scanner. The pCASL labeling plane was carefully positioned using a vessel survey scan. In addition to the standard pCASL acquisition (ξ= 0°, FA=18°), two different angles were chosen for ξ: 30° and 60° with FA=18° (volunteer 1) and FA=8° (volunteer 2). The center of the labeling plane was positioned on the right carotid artery (CA) to keep the same distance between the labeling plane and the imaging slices. Each scan was repeated twice in a randomized fashion. pCASL protocol: 30 control/label pairs, labeling duration: 1.65s, post labeling delay: 1.8s, GE-EPI readout: FOV 240x240, acq. matrix 64x64 TR/TE 4000/15ms,BS, 20 slices. An M0 image was also acquired with the readout identical to that of pCASL but without background suppression.

Processing: All datasets were motion corrected (DT-ITK [4]), pairwise subtracted and averaged before correction for blood T1 relaxation and registration to a study template. M0 images were chosen to manually draw a mask in the cortex of the right hemisphere to minimize the effect of the saturation artifact caused by overlap of the labeling plane in the left hemisphere in the angulated cases. The mean perfusion weighted signal within the mask for a given ξ and labeling efficiency α, $\Delta S_{\xi,FA}$, was then used to estimate the labeling efficiency from the data: $\alpha_{\xi,FA} = \alpha_{0,18} * \Delta S_{\xi,FA} / \Delta S_{0,18}$, where $\Delta S_{0,18}$ is the mean perfusion weighted signal for the standard acquisition, i.e. ξ=0 and FA = 18, for which $\alpha_{0,18}$ was assumed to be 0.89, based on the simulation results for an average flow of 40cm/s. The ratios between $\alpha_{0,18}$ and $\alpha_{\xi,FA}$ were also compared to the results of simulations to find vmax that best explained the data. Additionally, cerebral blood flow (CBF) was calculated using a standard equation [3] using $\alpha_{0,18}$ in all cases to demonstrate potential CBF estimation error.

RESULTS:

The results of the Bloch Equation simulations for ξ values of 0°,15°, 30° and 60° and 2 flip angles plotted against the maximum velocity (vmax) of the laminar flow distribution are presented in Figure 1. For FA = 18°, ξ = 15° has a negligible effect on α, ξ = 30° has a very small negative effect only on efficiency of flows with vmax < 40cm/s, whereas ξ = 60° has significant negative effect on slow spins, but improves efficiency of the fastest spins. For FA = 8°, the angulation improves the labeling efficiency for velocities above 16 cm/s. Figure 2 A and B shows the measured and simulated labeling efficiencies for volunteer 1 and 2 respectively. In both cases, the $\Delta S_{\xi,FA} / \Delta S_{0,18}$ ratios, and therefore estimated $\alpha_{\xi,FA}$, follows the prediction of the simulations. CBF was measured at 54.6 (ξ=0°), 58.1 (ξ=30°) and 60.3 (ξ=60°) [ml/100g/min] for volunteer 1 and 21.7 (ξ=0, FA=8°), 22.6 (ξ=30°, FA=8°), 30.1 (ξ=60°,FA=8°) and , 41.5 (ξ=0°, FA=18°), [ml/100g/min] for volunteer 2.

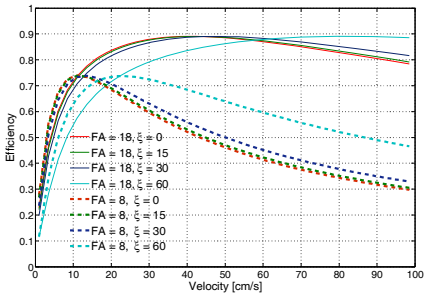

Figure 1. Results of Bloch Equation simulations for different ξ and flip angles (FA) for a range of vmax

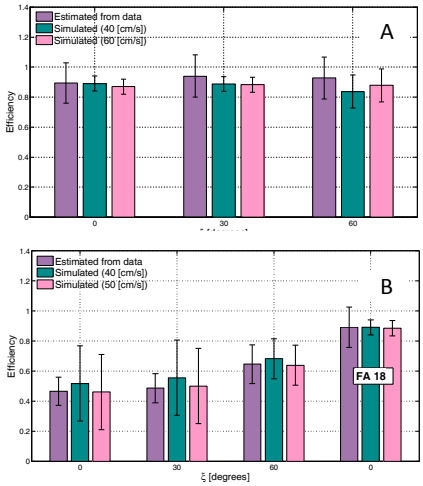

Figure 2. Results of measured and simulated labelling efficiency for different ξ and flip angles; A: for volunteer 1 (FA = 18°), B: for volunteer2 (FA = 8°)

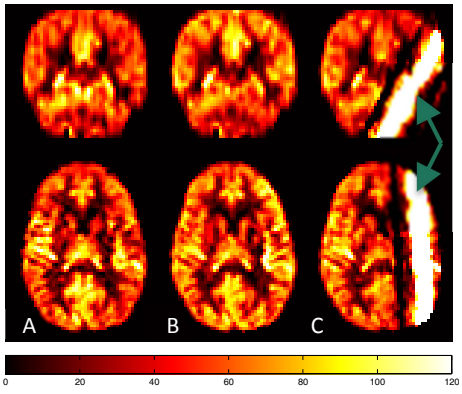

Figure 3. CBF maps computed for volunteer 1 acquired with A: ξ = 0°, B: ξ = 30° and C: ξ = 60°; top row – coronal view, bottom row - transverse view. Green arrows point to the artifact caused by the overlapping labeling plane. For analysis, only artifact free side was used

DISCUSSION & CONCLUSION

This study showed high robustness of the pCASL efficiency against the angulation of the labeling plane when using the standard 18° pulse train, as predicted by Bloch Equation simulations and confirmed in vivo in two healthy volunteers**.** Simulations based on a simple model of the labeling plane angulation by calculating the effective velocity described the data well.

FA=8° was used here to better demonstrate the agreement of the simulations with in-vivo data, as this predicts much larger changes, bearing in mind that this is not a part of a standard, recommended protocol. The improvement of efficiency for the fastest spins (Vmax > 55 cm/s) with angulation has the potential for improvement of the labeling efficiency where higher velocities are expected (i.e. descending aorta in renal pCASL) without changing the sequence parameters, which might not be available to a standard user. However, this is yet to be demonstrated.

In this study, the center of the labeling plane was positioned on the right CA for consistency. If centered in the mid-way between the carotid arteries, it would have caused a difference in the distance between the labeling plane and imaging slices of 3.6cm/10cm for ξ = 30°/60° and therefore introduce differences in the arterial transit time for left and right hemisphere. The real importance of this difference will be investigated in the future work.

In conclusion, pCASL is highly robust to mis-angulation of the labeling plane over a very broad range of velocities.

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