Perfusion quantification using pseudo-continuous Arterial Spin Labelling: the impact of labelling efficiency estimation

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Purpose: To assess the impact of labelling efficiency estimation on perfusion quantification in pseudo-continuous ASL

Background: The quantification of cerebral blood flow (CBF) plays an important role in disease diagnosis and treatment monitoring in neurological conditions (1). Arterial Spin Labelling (ASL) is a non-invasive method allowing quantitative measurement of CBF. The technique works by imaging the distribution of an endogenous tracer introduced by magnetically labelling water protons in the arteries. Pseudo-continuous ASL (pCASL) (2) is considered one of the best ASL techniques due to its high SNR. However, the accurate and reproducible CBF quantification using this technique can be challenging (3), because the labelling efficiency of the protons (α), which measures the effectiveness of the magnetic labelling of spins, depends on a number of subject-specific factors. Since labelling in pCASL is flow driven, its efficiency is affected by factors such as blood velocity and B0 homogeneity in the labelling plane, which can be variable between patients, patient groups or different scanners. This is particularly important in certain patient populations, such as infants, in which the blood velocities can vary from 8-27 cm/s compared to healthy adults where the range is 40-60 cm/s. Therefore there is a recognised need for estimating α on an individual basis in this patient population. On the other hand, however, the method that requires the minimum scan time would be preferred. The aim of this study was to compare different methods of labelling efficiency estimation of pCASL and evaluate error distribution on perfusion quantification resulting from α.

Methods: Three main methods estimating labelling efficiency were investigated: A) based on Bloch equation simulations (4) (based on velocities measured with phase contrast sequence (PC), with and without cardiac gating), B) based on comparing whole brain ASL with the rate of blood delivery via the carotid and vertebral arteries, as measured by phase contrast MRI (3) (with and without cardiac gating), and C) direct imaging of intra-arterial magnetisation superior to the labelling plane similarly to (5) with GE efficiency sequence. All sequences involved parameters are summarised in Table 1. Scans were performed on Philips 3T system during a single session on a healthy volunteer. Time of flight (TOF) was used for positioning of labelling plane as well as PC and GEefficiency slice. Blood velocity was measured with a PC sequence (with and without cardiac triggering) in RICA, RVA, LICA, LVA. The area of each artery was manually segmented for each cardiac phase and mean velocity within the segmented area determined.

Name	3D MPRAGE	TOF	PC non-gated	PC gated	pCASL	M0	GE efficiency
TE/TR [ms]	3 / 7	4.6 / 22	5.1 / 8.8	5.1 / 8.8	9.8 / 5000	9.8 / 9000	5.7 / 397
FOV [mm^2]	279 x 252	160 x 132	140x140	140x140	240 x 240	240 x 240	240 x 240
Flip angle	9		10	10	90	90	60
Slices	179	90	1	1	20	20	1
size[mm^3]	1.x1.x1.2	0.3x0.3x1	1x0.1x4	1x0.1x4	3x3x5	3x3x5	1x1x5
Acq matrix	244 x 227	160 x 132	140 x 140	140 x 140	64 x 64	64 x 64	140 x 140
Averages	1	1	20	1	1	3	1
Total time	5.34	1.49	0.5	2.21	5.1	0.36	1.28

Table 1. Parameters for sequences used

Method A: Bloch equation simulations (with identical design of pCASL as used in experiment) were then performed to calculate theoretical efficiency for maximum velocities assuming laminar flow. To better mimic the physiology of blood delivery to the brain, i.e., the fact that the highest volume of the blood is delivered to the brain in systolic phase (when the velocity and artery area are the highest) a weighting strategy was incorporated. The weight was constructed based on the flux (area times velocity) so that the calculated efficiencies during systole were emphasised. Next, all weighted efficiencies were integrated over one full cardiac cycle. Similarly, the data from non-gated PC were analysed. The uncertainties of velocity calculations with the PC method were accounted for by repeating simulations for +/- 10% of maximum blood velocity. Method B: the above segmentations and velocities were combined to calculate flux: total flow in mL per minute and divided by brain volume (derived from T1 image segmentation) and density (1.06 g/ml) to obtain total blood flow per 100g of brain tissue per minute. This was then equated to average perfusion within brain tissue (M0 images were skull stripped and segmented to provide the mask) to estimate efficiency, on the assumption that both methods of calculating perfusion should be equivalent (3). Method C: direct measurement of labelling efficiency was obtained. This was achieved by performing pCASL labelling for 300ms and acquiring images with GEefficiency readout without any delay. The imaging plane was positioned 2cm superior to the labelling plane.

Results: Results of labelling efficiency estimation for each method and mean CBF computed based α on are shown in Figure 1 and Figure 2, respectively. Efficiency calculated using Bloch Equations was the highest and ranged between 0.86 to 0.92 with or without gating, indicating that non-gated PC is sufficient to achieve a good estimation of labelling efficiency. Method B showed the lowest efficiency estimation from all 3 methods. The reason for this could be that this method requires the highest number processing steps and therefore errors may accumulate. Direct measurement gives intermediate results. This method also provides efficiency of each artery separately.

Discussion: 3 methods of estimation of labelling efficiency of pCASL were compared. Bloch equation simulation can give a good guidance optimisation of pCASL protocol, however theoretical values might not be achieved in reality, even when a careful mimic of physiology is used. Empirical methods are preferred, however additional scans and post processing might not be practical. In this respect, measure of efficiency with gradient echo readout is the most suitable. It is also the easiest to perform. The main downside of this method is the positioning of the imaging plane as well as relaxation of labelled protons between the labelling and imaging plane, which can lead to underestimation of alpha. However, the later can be corrected if velocity of blood is known.

Conclusion: Labelling efficiency estimation with gradient echo readout is a promising candidate because it has the least complicated protocol and processing involved. Further investigation and optimisation of this method will be performed as the next step of this project.

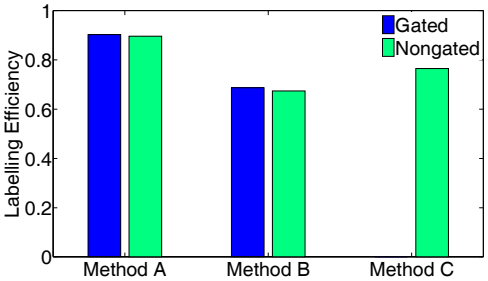

Figure1. Labelling efficiency for methods A, B and C

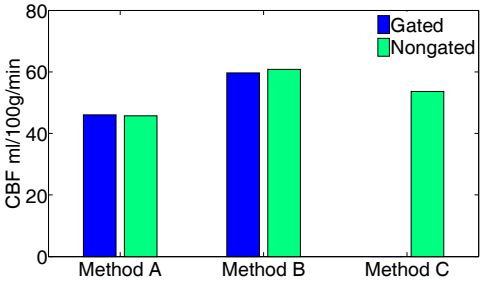

Figure2. CBF results for methods A B, and C

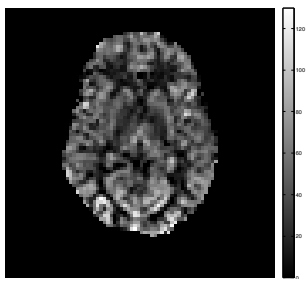

Figure 3. CBF map acquired with pCASL

References: 1. Petersen et al. The British Journal of Radiology, 79 (2006), 688–701, 2. Dai et al. MRM 60:1488–1497 (2008) 3. Aslan et al. MRM 63:765–771 (2010), 4. RL. O'Gorman et al. MRM 55 (2006) 1291–1297 5. H. Jahanian et al NMR Biomed. (2011); 24: 1202–1209.