Accurate perfusion quantification using pulsed arterial spin labeling: Choosing appropriate sequence parameters

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Introduction

Pulsed arterial spin labeling (PASL) techniques can provide non-invasive quantitative measurements of both resting and functional cerebral blood flow (CBF). To achieve accurate quantification of CBF, a QUIPSS II saturation pulse is typically applied to minimize errors due to variations in transit delays and bolus widths [1]. Although previous studies [1,2,3] have addressed the optimal choice of QUIPSS II PASL parameters, these studies have typically focused on a specific set of experimental conditions. In the present study, we show that optimal PASL scan parameters show a strong dependence on experimental conditions (e.g. tag angle, brain region) and must therefore be tailored to specific study conditions rather than employing a universal approach or adopting literature values. Data from the visual cortex and hippocampus are presented to illustrate the impact of tag angle and brain region and to demonstrate how appropriate parameters can be chosen.

Theory

For a PASL sequence the QUIPSS II conditions are: (i) TI1 < Δ and (ii) TI2-TI1 > δ, where TI1 and TI2 are saturation and inversion times, respectively, Δ is the natural width of the bolus of tagged blood, and δ is the transit time from the tag region to the imaging region [1]. These conditions ensure full delivery of a well-defined bolus of blood to each voxel. A third condition, (iii) TR-TI1 > Δ, must also be met to ensure full refreshment of the tag region before application of the next tag. In addition, SNR and/or temporal resolution requirements may influence the optimal choice of parameters, e.g. for functional studies, temporal resolution is typically critical and minimisation of TR within the confines of the three conditions may be desired. However, reduction of TI1 will reduce SNR, and there is clearly a trade off between these parameters. If the specified conditions are not met, it is likely that baseline CBF will be underestimated, and functional CBF changes overestimated.

The values of Δ and δ for a particular experiment can depend upon the following factors: (a) **Tagging geometry**. The tagging pulse is typically applied parallel to the imaging slices. Its anatomical extent will depend on the thickness and angle of the tagging slab. It may also be limited by the extent of the RF transmit coil. (b) The **brain region** being imaged, since different regions have different vascular supplies. (c) The **physiological state** of the subject (blood velocities and vascular structure), which will depend upon many factors such as age, disease, drugs, and may be modified by functional activation, administration of CO2, etc.

Methods

Sequence parameters were optimised for the collection of CBF data in the visual cortex and hippocampus with the aim of minimizing TR (e.g. for use in rapid event-related fMRI studies). Data were acquired on a 3T GE Signa system, using a body coil for transmit and an 8 channel head coil for receive on several healthy subjects. For the visual cortex, four 7mm slices were positioned ~45° counter-clockwise from horizontal, aligned with the calarine sulcus. For the hippocampus, five 6mm slices were positioned ~20° clockwise from horizontal, aligned with the hippocampus. The tagging band was positioned parallel to and 10mm from the most inferior slice.

Data were acquired using a PICORE sequence with multiple TI times and fitted for δ and Δ on a pixelwise basis (since spatial heterogeneity is expected) within the visual cortex (for 10cm and 20cm tags) and hippocampal regions (for 20cm tag). These measurements are inherently very noisy, making robust pixelwise fitting difficult [4]. Typically a range of δ and Δ values are found within each brain region, making it difficult to decide upon the best parameters to use. The results were therefore used to set approximate sequence parameters, and further optimisation was performed by acquiring data with a PICORE QUIPSS II sequence, using a range of TI1, TI2 and TR values close to the estimated values. For each scan, CBF was quantified using CSF as a signal intensity reference [1,5]. CBF values within the region of interest were then compared between sets of parameters, and if a medium to large effect size (ES >0.2) [6] was found, the parameters for which the mean CBF was maximised were adopted. A specific example of this process is described below.

Results

Multi-TI data: In the visual cortex, a 20cm tag resulted in δ~500-800ms and Δ~1500-1700ms, requiring a long TR for satisfaction of condition (iii). With a tag of 10cm, the values were δ~500-800ms and Δ~1100-1300ms. Variability between pixels is due to heterogeneity in the vascular supply across each slice. Note that these values for Δ are longer than those reported in [1], likely due to the use of axial slices in that study and therefore a different tagging geometry. In the hippocampus, a 20cm tag produced δ~300-500ms and Δ~700-1000ms. Bearing in mind our specific aim of keeping TR to a minimum, these suggest initial estimates for optimal parameter values of: visual cortex: tag=10cm, TI1~700ms, TI2~1500ms, TR~2s. For hippocampus: tag=20cm, TI1~700ms, TI2~1300ms, TR~2s.

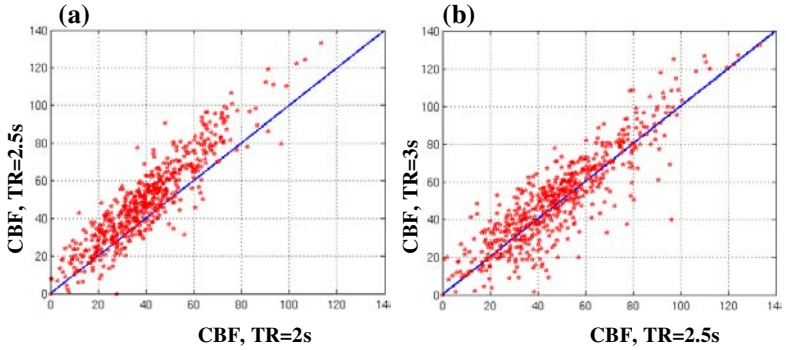

Fig. 1. Scatter plot of hippocampal CBF values (ml/100ml/min) for TI1=700ms, TI2=1400ms, 20cm tag, with varying TR values.

PICORE QUIPSS II data: Data acquired with a range of parameters were compared. In general, parameters for which the baseline CBF values were maximised, whilst minimising TR and maximising TI1, were chosen as optimal. An example of parameter selection is given in Figure 1, where optimisation of TR (with TI1/TI2 = 700/1400ms) for the hippocampal studies is investigated. A comparison of TR=2s and TR=2.5s (Fig 1(a)) reveals a significant difference between the CBF values ($p<0.001$), with a medium effect size of 0.37, indicating that TR must be increased to 2.5s for the parameters used. Increasing TR from 2.5s to 3s (Fig 1(b)), still shows a significant CBF increase ($p<0.001$) for the longer TR, but the effect size is small (0.07). In the interests of keeping TR to a minimum, TR is set to 2.5s for the hippocampus. This is longer than the initial estimate, perhaps indicating that there are more voxels with large Δ and therefore slow refreshment than could be reliably identified by the multi-TI data. The optimal parameters determined in this way are: visual cortex: tag=10cm, TI1=600ms, TI2=1500ms, TR=2s. Hippocampus, tag=20cm, TI1=700ms, TI2=1400ms, TR=2.5s.

Discussion

The difference in optimal parameters for PASL imaging of the visual cortex and the hippocampus most likely reflects the following two factors. Firstly, the steeper angle of the tagging slab means that the posterior vessels are tagged lower for the visual cortex. Secondly, the visual cortex is supplied primarily by the posterior vertebral arteries, whereas the hippocampus is supplied by both the posterior vertebral arteries and the internal carotid arteries. The carotids are larger diameter vessels with higher blood flow than the vertebrals, leading to shorter bolus widths and faster refreshment of the tag region for the hippocampus compared to the visual cortex.

Ultimately, the appropriate scan parameters for achieving accurate CBF values will depend upon the region of the brain under investigation, the subject group and the nature of the study. Rather than taking values from the literature, parameters should be optimised for each study. This can be done by measuring Δ and δ in the brain regions of interest using multi-TI ASL data, estimating the appropriate QUIPSS II parameters using these results, then testing these parameters using a PASL sequence with QUIPSS II.

References

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