

Parallel Transmit Vessel Selective Arterial Spin Labelling: A proof of concept simulation

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Background

Vessel Selective arterial spin labelling (ASL) provides visualisation and quantification of the perfusion territory from a feeding set of arteries. Methods to selectively label blood include using pseudo-Continuous ASL with additional transverse gradients and phase cycling [1], CASL [4] with obliquely defined labelling planes by rotating the field of view [2] and the use of surface coils [3] to spatially confine the B_1 field to one side of the neck. The latter is advantageous as the confined field does not produce any magnetisation transfer (MT) [5] effects within the brain. However, the spatial profile of the surface coil extends across the neck, partially labelling the contralateral arteries. This work aims to reduce the amount of contralateral labelling by employing parallel transmission [6] techniques to vessel selective arterial spin labelling

Theory

Parallel transmission independently modulates the amplitude and phase of the driving current in multiple transmit antenna elements to spatially tailor the excitation pattern. Vessel selective CASL places only two requirements on the labelling field: a B_1 sufficiently high for efficient labelling of flowing spins over the arteries to be labelled, and a low B_1 over other arteries so that flowing spins are unperturbed. These two conditions can be mathematically written as a minimisation problem, where the B_1 field is minimised in a no label region, and constrained to a target value in the label region, and then solved as a constrained least squares optimisation problem (see equation 1).

Methods

A computer model of the carotid and vertebral arteries in the neck was constructed in Matlab (The Mathworks Inc., MA) using anatomic and physiological data obtained from time of flight and phase contrast MRI angiograms of a healthy 24-year-old volunteer (see figure 1). Three dimensional B_1 profiles of surface coils positioned around the neck were computed by integrating the Biot-Savart equation. Elliptical regions of interest (ROIs) were drawn around the right carotid (RCA) and vertebral (RVA) arteries to indicate a 'label' region, and around the left carotid (LCA) and vertebral (LVA) arteries to indicate a 'no label' region. Using these ROIs equation 1 was solved using CVX [8]. Complex coefficients and resultant B_1 fields were calculated for one, two and four circular surface coils (loop radius 22.5mm, field profiles normalised at $B_1=3.5\mu\text{T}$ at a depth of 5cm on axis), positioned on the neck at angles of 30° , 150° , 240° , and 300° to the x-axis respectively. Calculated fields were then used in a numerical Bloch equation simulation [7] of CASL. Flow velocity within each artery was dictated by a pulsatile temporal waveform, and parabolic cross-sectional velocity profile, as measured from a phase contrast angiogram of the volunteer. Typical human CASL parameters were chosen: $G_{\text{label}}=3\text{mT/m}$, and the labelling plane, z_{label} was positioned 19cm proximal to isocentre (the centre of the brain). Labelling was performed for 2 seconds and relaxation times were that of blood water at 3T: $T_1=2000\text{ms}$ and $T_2=300\text{ms}$.

Results

Figures 2a-c show the total B_1 field from one coil, two coils and four coils, all with the same colour scale (0 is dark blue and $3.5\mu\text{T}$ is dark red). Figures 3a-c are plots of z position and longitudinal magnetisation of a single spin isochromat as it travels through each artery. All three combinations of coils are able to produce a sufficient B_1 field at the RCA and RVA, reflected by a similar inversion efficiency in figures 3a-c. With one coil the B_1 magnitude at the centre of each artery and inversion efficiencies respectively are $0.39\mu\text{T}$ and 5.7% for the LCA and $0.52\mu\text{T}$ and 13.35% for the LVA. Using two coils to create a null over these arteries reduces it to $0.11\mu\text{T}$ and 0.4% for the LCA, and $0.33\mu\text{T}$ and 5.55% for the LVA. With four coils a very well defined null region is created over both the LCA and LVA, resulting in negligible B_1 fields and inversion efficiencies of $0.034\mu\text{T}$ and 0.05% for the LCA and $0.044\mu\text{T}$ and 0.15% for the LVA.

Discussion and Conclusion

Results show that selective labelling of the RCA and RVA with minimal labelling of the LCA and LVA is possible using parallel transmit methods to spatially localise the B_1 field. As the number of coils increases there is an improvement in the ability to tailor the shape and depth of the null region. Using the calculated fields in a simulation of the labelling procedure in the human carotid and vertebral arteries shows that the labelling efficiency on the RCA and RVA can be maintained when compared to the single coil case, whilst contralateral labelling is reduced by up to two orders of magnitude. Parallel transmit ASL could also be used to improve the repeatability of separate coil CASL as the B_1 fields produced at each artery no longer depend solely on coil positioning. Further work will be to extend the mathematical framework to include constraints for limiting power deposition, and to implement parallel transmit vessel selective arterial spin labelling in-vivo using a pair of independent transmit coils and parallel transmit system.

References [1] Wong, E. C. MRM 58:1086-1091 (2007). [2] Werner, R et al. MRM 53:1006-1012(2005). [3] Mildner et al. MRM 49:791-795 (2003). [4] Williams et al. PNAS 89:212-216 (1992). [5] Hernandez-Garcia et al. NMR in Biomedicine 20:733-742 (2007). [6] Ibrahim et al. MRI 18:733-42, (2000). [7] Bittoun et al. MRM 2:113-120 (1984). [8] CVX: Matlab software for disciplined convex programming, <http://cvxr.com/cvx>.

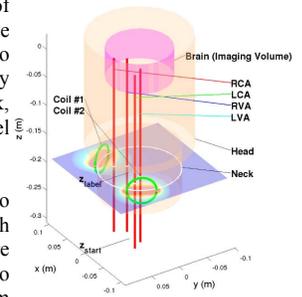


Fig. 1: Computer model of the neck and arteries

Equation 1:

$$\begin{aligned} & \text{minimise } \|\mathbf{S}_i \cdot \mathbf{c}\|, i \in \text{No Label Region} \\ & \text{subject to} \\ & \mathbf{S}_i \cdot \mathbf{c} = \mathbf{T}_i, i = \text{Centre of Label Region} \\ & |c| \leq 1 \end{aligned}$$

\mathbf{S} = coil sensitivity matrix

\mathbf{T} = target field

\mathbf{c} = vector of complex coefficients

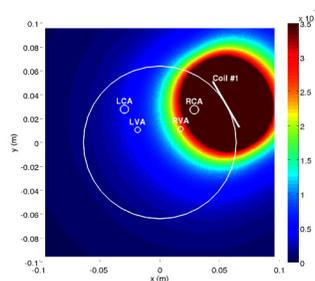


Fig. 2a: Field from one coil

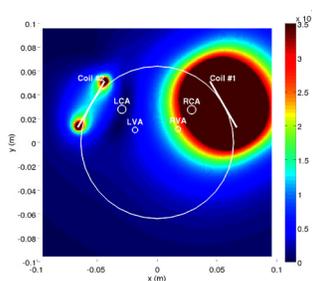


Fig. 2b: Field from two coils

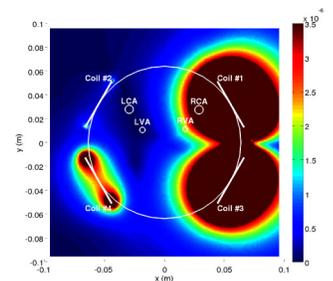


Fig. 2c: Field from four coils

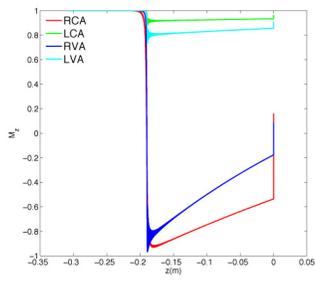


Fig. 3a: Longitudinal Magnetisation for one coil

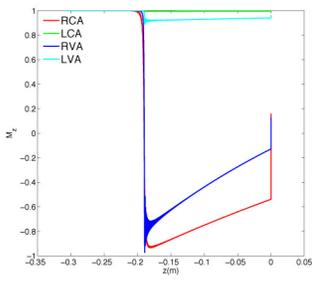


Fig. 3b: Longitudinal Magnetisation for two coils

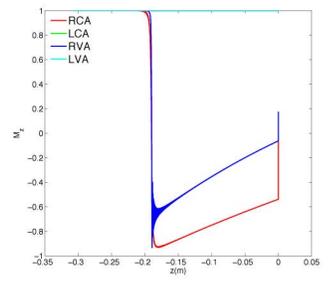


Fig. 3c: Longitudinal Magnetisation for four coils