Reduced specific absorption rate (SAR) pseudo-continuous arterial spin labeling

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Introduction: A reduced specific absorption rate (SAR) version of pseudo-continuous arterial spin labeling (pCASL) pulse sequence (1,2) is designed and implemented. Using a simulation study, a set of pCASL pulse sequence parameters is found that allows reducing the flip angle of pCASL radio frequency (RF) pulses (and consequently SAR) without losing the inversion efficiency. The proposed set of parameters employs smaller slice selective gradients which leads to less acoustic noise as well. This makes the pulse sequence more desirable, especially for functional MRI studies.

Methods: The behavior of the magnetization vector of an ensemble of moving spins (laminar flow with peak velocity = 100 cm/s, T1/T2=1600/250 ms) in the presence of a pCASL pulse sequence (Hanning-shaped RF of 500µs duration) was simulated using a numerical implementation of the Bloch equations. The area of the refocusing gradient was unbalanced by a variable amount to achieve a net average gradient (G_{av}). We measured the inversion efficiency for different amounts of average gradients and flip angles and repeated the simulation for different gradient amplitudes during RF pulse (G_{max}). A set of parameters providing high inversion efficiency (IE>90%) yet having the lowest SAR were found from the simulation results.

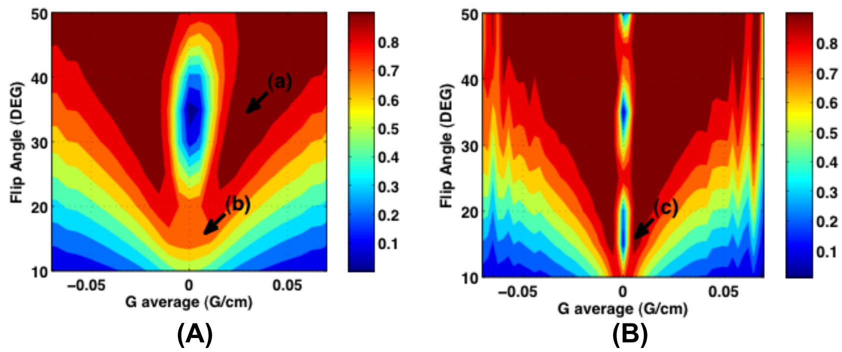

Fig. 1. Contour maps of simulated inversion efficiencies achieved using different amounts of average gradient (G_{av}) and Flip angles for **A)** gradient amplitude (G_{max})= 0.6 G/cm and **B)** G_{max}= 0.3 G/cm. Parameters used for the In-vivo study (Fig.2) are shown with arrows. Simulated inversion efficiencies for points a, b and c were 97%, 72% and 95% respectively.

We performed an In-vivo study to verify the results of our simulation study. The pCASL pulse sequence was implemented on a 3.0 T Signa Excite scanner (General Electric, Waukesha, WI). Three In-vivo perfusion studies (8 pairs of control-tag for each study) were performed using the parameters marked with arrows in Fig. 1: a) Standard pCASL b) Standard pCASL with low flip angle 3) Modified pCASL with low flip angle. Each experiment was also corrected for field inhomogeneity effects (3) to make sure that the highest possible efficiency is achieved.

A high resolution (256x256) T1-weighted anatomical image was also acquired using the same prescription used for perfusion images. A grey matter mask was created by segmentation of the T1-weighted image after co-registration to the perfusion images. Signal to noise ratio (SNR) of each perfusion experiment was calculated as the mean gray matter perfusion over the time course, divided by its temporal standard deviation.

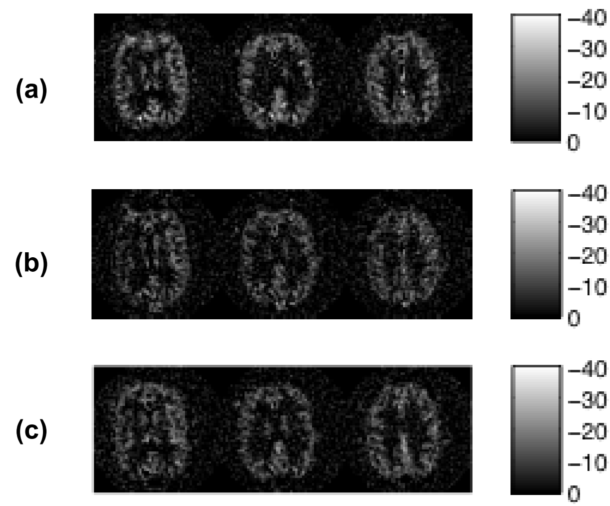

Fig. 2. Perfusion difference images acquired using: **a)** Flip angle = 35 (DEG), G_{max} =0.6 (G/cm) **b)** Flip angle = 15 (DEG), G_{max} =0.6 (G/cm) and **c)** Flip angle = 15 (DEG), G_{max} =0.3 (G/cm). Measured signal to noise ratio for these acquisitions are 8.22, 3.77 and 9.98 respectively.

Results: Simulation results obtained using different G_{max} values showed that using smaller G_{max} it is possible to use lower flip angles and still achieve high inversion efficiency (IE>90%). Fig.1. Shows simulated inversion efficiencies for G_{max} = 0.6 and 0.3 G/cm. Three slices of perfusion difference images acquired using the parameters marked in Fig.1 are shown in Fig.2. SNR values measured for these studies are: a) 8.22, b) 3.77 and c) 9.98.

Conclusion and Discussion: Decreasing the flip angle (and consequently SAR) of pCASL pulse sequence without changing other parameters compromises the inversion efficiency and SNR of the pCASL experiment. However by properly decreasing the gradient amplitude during the RF pulses (G_{max}), it is possible to use smaller flip angles without losing inversion efficiency. Decreasing G_{max} also reduces the acoustic noise of the pCASL pulse sequence. However, decreasing G_{max} increases the spatial width of the inversion plane, which may limit the choice of tagging plane location. The reduced SAR pulse will also be more sensitive to the gradient of the inhomogeneity at the tagging plane and correcting for it (3) will be critical for achieving high inversion efficiency.

Acknowledgements: This work is supported by the NIH grant EB004346.

References: [1] Wu *et al*, MRM 58:1020–1027, 2007. [2] Dai *et al*, MRM 60(6):1488-97, 2008. [3] Jahanian *et al*, ISMRM, 2009.