Background suppression in multi slice arterial spin labeling

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Introduction

In brain perfusion measurements with Arterial Spin Labeling (ASL), blood is used as an endogenous tracer by inversion of the longitudinal magnetization of spins in blood. Because typical perfusion signal is low (1-2%) as compared to background signal, alternate images are acquired with and without labeling rendering perfusion images after subtraction. However, subtraction does not render complete cancellation of the background signal due to physiological noise that fluctuates over time. To counter this problem, a background suppression (BS) scheme can be added to the scan sequence, commonly consisting of a saturation pulse that precedes labeling and one or two inversion pulses during the waiting period between labeling and imaging. In BS, timing needs to be configured such that signals of all tissues have equal sign during acquisition of a slice (or volume), to prevent artifacts due to sign changes over time or due to intra voxel cancellation when tissues have signals of opposite sign. When timing is optimized, BS may result in improvement of perfusion SNR of up to 100 % [1]. Whereas for single shot 3D GRASE sequences BS can be made optimal for the complete acquisition volume, in multi slice 2D imaging the BS is only ideal for the first slice, while background signal will regrow for subsequent slices. However, multi slice 2D imaging has the advantage of higher in-plane resolutions and the possibilities of large coverage, due to the limitations of total read-out duration in single shot 3D acquisitions. In the present study we investigated the effectiveness of an extended BS scheme with inter-slice inversion pulses during image acquisition. To evaluate detrimental effect on the label, efficiency of BS inversion pulses was investigated first and secondly the relation between the amount of background suppression and SNR was established. This allowed for computer simulations of 2D acquisition with different BS inter-slice inversion schemes that subsequently were tested in vivo.

Materials and methods

Three healthy volunteers (2 male, 1 female) were scanned on a 3T, clinical scanner (Philips Healthcare, Best, The Netherlands). Pseudo continuous ASL was applied with a labeling duration of 1650 ms, a delay before imaging of 1525 ms while the imaging module consisted of a multi slice 2D, single shot EPI sequence with TR/TE = 825/12 ms and in plane resolution of 3 x 3 mm^2. The BS scheme comprised a saturation pulse before labeling at t = 0 and the first inversion pulse at t = 1680 ms. Duration of the acquisition of a single slice was 35 ms. To investigate how the SNR of the ASL scan depends on the amount of background suppression, timing of the second inversion pulse was varied from t = 1750 – 3150 ms in 9 steps. All control images within a sequence were averaged to measure the amount of background signal and relative BS (%) was calculated by taking the relative difference with the signal in a PD image that was acquired separately. For all sequences, the average gray matter perfusion was calculated at the level of the centre semi ovale and perfusion SNR was calculated as perfusion signal / SD. Subsequently, the dependency of perfusion SNR on BS timing was modeled and simulations of different BS schemes were performed. Herein perfusion SNR was calculated with the first two BS inversion pulses set at t = 1680 and 2830 ms while no, 1 or 2 inversion pulses were played during imaging, at different positions within a stack of 17 or 25 slices. Resulting schemes were subsequently tested in vivo. For inversion, volume selective hyperbolic secant pulses were applied followed by spoiler gradients. In case of multiple inter-slice pulses the sign of these gradients was alternated between pulses. During single inter-slice inversion, the pulse was played preceding the 10^{th} or 16^{th} slice for 17 and 25 slice acquisition respectively. With two inter-slice pulses timing was before slice 10 and 16 for both sets of slices.

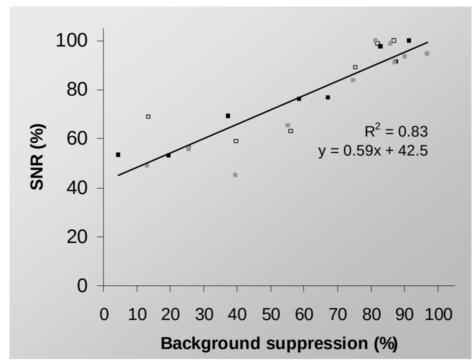

Figure 1. Relation between BS efficiency and SNR of the perfusion images. Color of dots refers to different subjects.

Results and Discussion

The efficiency of the employed inversion pulses was found to be 91%. Evaluation of BS with different timing of the second inversion pulse showed a linear relationship between perfusion SNR and BS efficiency (see Figure 1). Computer simulations predicted that, with the first two inversion pulses optimally set, addition of inter-slice inversion pulses could improve perfusion SNR up to 10% for subsequently acquired slices, even when 91% inversion efficiency is taken into account. Figure 2 shows an example of two scans with 17 slices. In the modulus control images, the return of the inverted signal back to zero is clearly visible.

Application of inversion pulses had marginal influence on both perfusion signal and SNR. This can be explained by inefficiency of the inversion pulses that decreased the label with an estimated 9% thereby counteracting the positive effect of improved background suppression. In vivo pilots yielded artifacts from the perfusion signal of the retina that became visible in slices that were acquired later in time. This problem was overcome by adding crusher gradients after the inversion pulses. The use of non-selective inversion pulses yielded loss of perfusion signal, probably due to their effect on spins that are labeled during the next dynamic.

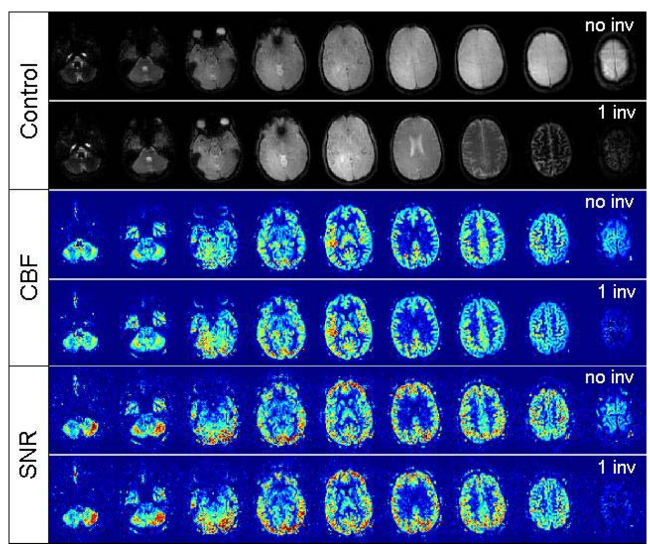

Figure 2. Comparison of two 17 slice ASL acquisitions without and with an additional inversion pulse for BS respectively. The inversion pulse is played after acquisition of the 9^{th} slice. In the second row return of background signal to zero following the inversion pulse is clearly visible. (NB: images are modulus)

Conclusion.

When multi slice 2D imaging is applied in BS-ASL, addition of inversion pulses in between acquisition of slices is feasible and has the potential of improving SNR of the perfusion signal due to improved background suppression in the later acquired slices. However, the introduction of these inversion pulses leads to loss of label due to imperfection of the inversion pulses, limiting the benefit of this approach. Design of inversion pulses with higher efficiency would be helpful for this approach. In that case, improvement of SNR of the perfusion signal can be anticipated. With the current inversion pulses with 91% efficiency, the addition of inversion pulses during image acquisition will only result in appreciably higher SNRs when the acquisition window is relatively long, for example when using spin echo EPI.

References. 1. Garcia DM, Magn Reson Med, 54(2): 366-72; 2005.