3D GRASE ASL using a modified refocusing pulse phase cycling scheme compatible with vascular crusher gradients

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Introduction

Recent developments in the labelling schemes and image acquisition techniques used for arterial spin labelling (ASL) have greatly improved the SNR of the method, enabling it to become a feasible clinical option. One such improvement is the use of background suppression combined with a 3D imaging approach, such as 3D GRASE (1). 3D GRASE consists of an RF-refocused train of 2D-encoded EPI acquisitions, each differently phase encoded along the third dimension. In order to achieve good immunity to B_1 inhomogeneity, the phase of the refocusing pulses relative to the excitation pulse is chosen to fulfil the CPMG condition (2). However, when vascular crusher gradients are used to reduce the intravascular signal, the CPMG condition can be violated (due to eddy currents and/or subject motion during the application of the gradient), leading to a second confounding source of signal decrease. A similar problem arises in diffusion-weighted FSE, and has been addressed by modifying the refocusing pulse train phasing (3, 4). In this work, we apply this principle to investigate the use of alternative refocusing pulse phasing schemes with 3D GRASE ASL, thus enabling the use of vascular crusher gradients with the technique and improving the accuracy of perfusion quantification.

Methods

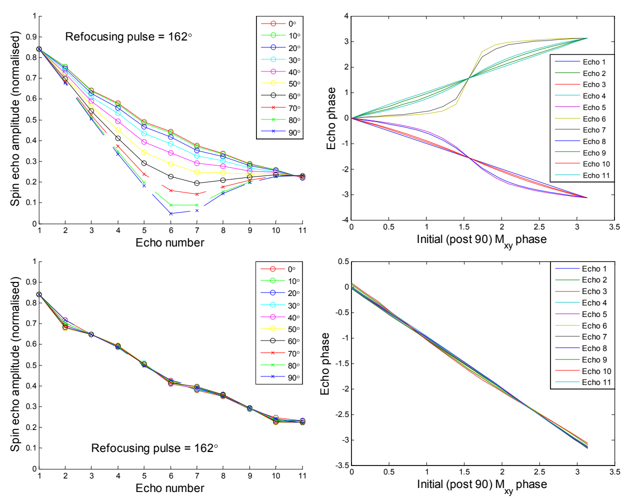
Simulations: computer simulations using the extended phase graph (EPG) algorithm (5) were performed in Matlab (The Mathworks Inc) to investigate the robustness of the RF refocusing pulse phase schemes to B_1 inhomogeneity and to the phase of the transverse magnetisation before the first refocusing pulse. The phasing schemes compared were: CPMG, XY-4 and XY-8 (6). The echo train length (ETL) was 11, to match the acquired data (see below). Other parameters used for the simulation were: half TE (time between 90 and first refocusing pulse) = 13.5ms; T_1=1500ms; T_2=200ms. For the XY-4 and XY-8 schemes, appropriate echo phases were reversed (*i.e.* multiplied by -1) and the complex conjugate of the even echoes was taken, as described in (3)).

MR acquisition: subjects were scanned on a 3T Magnetom TIM Trio scanner (Siemens Healthcare, Erlangen, Germany) using a background suppressed 3D GRASE pCASL sequence (7). The sequence parameters were: TE_{eff}=54ms; TR=3.5s; resolution = 4x4x6mm^3; 16 nominal partitions with 12.5% oversampling and 5/8 partial Fourier sampling, resulting in ETL=11; acquisition bandwidth 3004Hz/pixel. A balanced pCASL labelling pulse was used with duration 1.65s and a post-labelling delay of 1.5s. TI1/TI2 (time of inversion pulses prior to excitation) for the background suppression were 1.8s and 0.5s respectively. 32 averages were acquired giving a total scan time of 3min 51s. The XY-8 refocusing pulse phasing scheme was implemented, and images were acquired with and without vascular crushers along the partition encoding (head-foot) direction (V_{enc} ~ 5cm/s).

Results

(a) CPMG

(b) XY-8



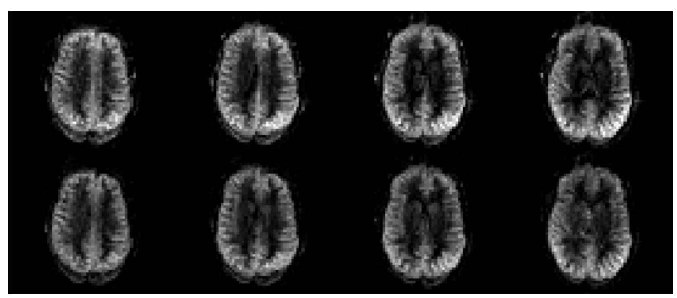


Figure 1 (left): left graphs show the variation of signal amplitude as a function of echo number for different initial M_{xy} phases. Right graphs show echo phase as a function of initial M_{xy} phase, plotted for each echo.

Figure 2 (above): example ASL difference images acquired with the 3D GRASE pCASL sequence using the XY-8 phasing scheme. Top row without vascular crushers, bottom row with V_{enc}=5cm/s

Figure 1 shows the 3D GRASE echo train amplitude and phase stability for a refocusing pulse flip angle of 162° and different initial M_{xy} phases. The key points are that for the CPMG phasing scheme, the echo train amplitude shows a strong dependence on the initial phase (particularly poor when the initial M_{xy} phase is 90° *i.e.* perpendicular to the refocusing pulse phase) and the echo phase differs between echoes depending on the initial (unknown) M_{xy} phase. Both these effects are absent when the XY-8 phasing scheme is used: the echo amplitude and phase are independent of the initial M_{xy} phase, confirming that this phasing scheme is compatible for use with vascular crusher gradients. Figure 2 shows an example of four slices from a volunteer, acquired using XY-8 phasing with and without vascular crushers. Overall, image artefacts do not increase when vascular crushing is applied, and the signal intensity in the grey matter decreases by ~10-20%, reflecting suppression of the intravascular signal.

Discussion

We have shown that it is possible to acquire 3D GRASE ASL data in a way that is compatible with the use of vascular crusher gradients. This approach avoids the issues associated with violation of the CPMG condition and therefore can be used to suppress intravascular signal in ASL. This should result in more accurate quantification of tissue perfusion, either by reducing large vessel contamination in the general kinetic model or by enabling model-free quantification (8). Future work will compare these different approaches to perfusion quantification using this technique.

References **(1)** Günther M *et al.* Magn Reson Med 2005;54(2):491-498. **(2)** Meiboom S & Gill D. Rev Sci Instrum 1958;29(8):688-691. **(3)** Pipe JG *et al.* Magn Reson Med 2002;47(1):42-52. **(4)** Sarlls JE & Pierpaoli C. Magn Reson Med 2008;60(2):270-276. **(5)** Hennig J. Concept Magn Reson 1991;3:125-143. **(6)** Gullion T *et al.* J Magn Reson 1990;89(3):479-484. **(7)** Fernandez-Seara MA *et al.* Magn Reson Med 2008;59(6):1467-1471. **(8)** Petersen *et al.* Magn Reson Med 2006; 55(2):219-232