B_1 Self-Calibration for Artifact Removal in Radial Hyperpolarised ^{3}He Lung Imaging

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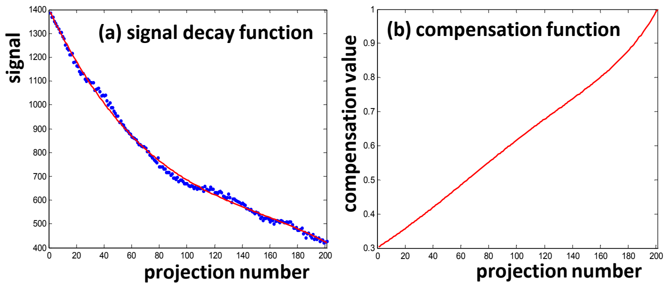
Introduction: In hyperpolarised gas (^{3}He/^{129}Xe) MRI there is finite longitudinal magnetisation. The transverse signal in a spoiled gradient echo (SPGR) sequence decays with each RF excitation according to the relation: $S_n = S_1(\cos\theta)^{n-1}$ (eq. 1), where S is signal, n is the excitation number and θ is the constant flip angle. This signal decay imposes a filter on the k-space data. In Cartesian sampling, the signal decay causes loss of effective spatial resolution for centric phase encoding and loss of signal to noise ratio (SNR) for sequential phase encoding [1]. A variable flip angle (constant transverse magnetisation) scheme has been introduced to counter this effect [2], but is difficult to implement in a robust fashion due to B_1 inhomogeneity and slice profile effects and is not commonly used at present [3]. Retrospective adaptive k-space filtering has been proposed to compensate for signal decay in a constant flip angle Cartesian acquisition, and was shown to slightly improve image quality [4]. Radial sampling offers potential benefits for hyperpolarised ^{3}He lung imaging [5-7]. In a radial acquisition the signal decay filter causes streaking, angular shading and loss of spatial resolution in the image. Sampling the centre of k-space (k=0) with every projection allows the signal decay to be tracked throughout the acquisition. The inverse of this decay function was used to retrospectively compensate the data for the signal loss incurred by RF depolarisation and T_1 decay. The k=0 data was also used to calculate the average flip angle applied to each slice, which varies from the specified value due to the inhomogeneous B_1 transmit field of the coil.

Methods: Experiments were conducted using a Philips 3T Intera system and data were processed in Matlab.

Decay compensation: A prototype Helmholtz coil (Pulseteq, UK) of 20cm diameter loops was used for linear T-R. ^{3}He was polarised to ~25% with a Helispin polariser (GE), and 300ml of hyperpolarised ^{3}He mixed with 700ml of N_2 was inhaled by a healthy volunteer. Axial radial images of the lungs (FOV = 380x380mm^2, matrix: 128x201 projections (meets Nyquist criterion), 15mm slices, full echo, TR/TE: 5.9/2.6ms) were acquired at breath-hold using a 2D SPGR sequence. For each slice, a polynomial was fitted to the decay of k=0 signal as a function of projection (fig 1a). The normalised inverse of the polynomial (fig 1b) was used as a compensation function. The data of each projection was multiplied by the compensation function value for that projection. The compensated k-space data were reconstructed using regridding.

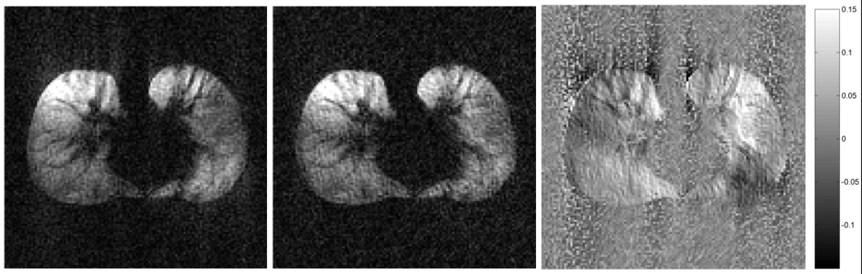
Calculation of average flip angle per slice: The average slice flip angle was calculated by plotting the k=0 signal of the radial data as $\ln(S_n/S_1)$ against n-1, the slope of which is $\ln(\cos\theta)$ (from eq. 1). This was done using all projection data and also using data from the first 25 projections only (where echo shifts due to an imperfect k-space trajectory were small). In order to produce conventional flip angle maps for comparison, Cartesian images (2D SPGR, matrix: 64x64, 3 dynamics, TR/TE: 4.6/1.9ms) of the same axial slices were acquired at breath-hold of hyperpolarised ^{3}He following the radial data acquisition. Flip angle maps were produced by fitting the signal decay in successive images to eq. 1 [3]. The maps were masked to exclude background noise, then the mean and standard deviation flip angle values were calculated for each slice.

Fig 1: Signal Decay Compensation Function Determination



(a) k=0 signal decay (blue) and the fitted polynomial decay function (red) with respect to projection number, and (b) the compensation function (normalised inverse of the polynomial in (a)) for the slice shown in fig 2.

Fig 2: Compensation of Radial Images



(a) uncompensated image (b) compensated image (c) normalised difference (b – a)

Results and Discussion: The proposed compensation method removes the streaking, blurring and angular shading introduced by the signal decay filter (fig 2). Figure 3 shows that the average slice flip angles calculated from the first 25 projections of radial data (green) correspond well to those calculated from conventional flip angle maps (blue). Using all radial projections in the calculation results in a lower estimate of the average slice flip angles (red, fig 3). This implies that k-space echo shifts, which can be seen in the raw k-space data (but are small for the first 25 projections), are introducing errors into the flip angle calculation. Future work will include the use of k-space trajectory mapping [8] to remove errors in the signal decay function and image reconstruction due to echo shifting.

Conclusions: The proposed retrospective compensation method gives an improvement in image quality. The oversampling of the centre of k-space inherent to radial acquisition provides a self-measure of the signal decay. This means that the effect on the decay of differences between the intended and delivered flip angle due to B_1 transmit inhomogeneity (which is not trivial for close coupled body transmit coils at high B_0) are taken into account by the compensation method. The ability to calculate average slice flip angle without an additional calibration scan may prove useful to compensate for B_1 inhomogeneity in the slice direction.

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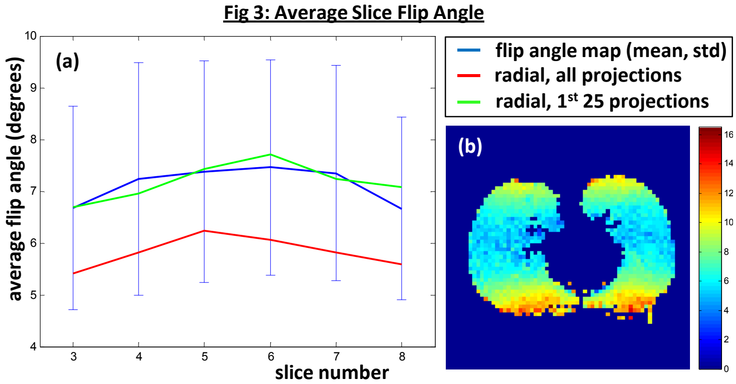
References: [1] Wild et al, MRM 47:687-695 (2002); [2] Zhao et al, J Magn Reson Series B 113:179-183 (1996); [3] Miller et al, MAGMA 16:218-226 (2004); [4] Cooper et al, proc ISMRM 2007 1821; [5] Wild et al, MRM 49:991-997 2003; [6] Wild et al, proc ISMRM non-Cartesian workshop 2007; [7] Holmes et al, MRM 59:1062-1071 (2008); [8] Duyn et al, JMR 132:150-153 (1998).

Fig 3: Average Slice Flip Angle



(a) average slice flip angle calculated; using a conventional flip angle mapping method (blue), from the k=0 signal of all 201 radial projections (red) and of only the first 25 radial projections (green). (b) conventional flip angle map for slice 6 .