Self-Referenced Flip Angle Mapping for Hyperpolarized Gas MRI

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Introduction

Hyperpolarized noble gas imaging is a novel form of non-equilibrium imaging where the gas magnetization is slowly depleted both by RF excitation and a reduced T_1 due to the presence of paramagnetic oxygen. When imaging is performed with constant flip angle excitations, artifacts are observed. To compensate for the decaying magnetization, Zhao, *et al.* described a variable increasing flip angle method to reduce these artifacts. [1] An additional source of artifacts are B_1 field inhomogeneities. To obtain a B_1 Flip Angle (FA) map, researchers typically perform an additional scan. Two consecutive images are acquired, $I_1(x,y)$ and $I_2(x,y)$, with N phase encodes between images and the FA map, $\alpha(x,y)$, may be calculated using:

$$\alpha(x,y) = \cos^{-1}\left(\left(\frac{I_2(x,y)}{I_1(x,y)}\right)^{1/N}\right) \qquad (1)$$

This method requires separate scans and additional gas and is therefore undesirable. To partially deal with this problem, researchers have increased acquisition speeds using both parallel coils and ultra-short TE sequences to obtain FA maps with a single acquisition. In this paper, we propose two methods to approximate the FA map without acquiring additional scans. These methods do not increase scan times significantly.

Methods

The method we propose is to split up the acquisition of k-space into two serially acquired components. To obtain a FA map, the part of k-space that is undersampled on each component acquisition, is estimated by interpolation from neighboring k-space data. The ratio of the voxel intensities from the serial images is then used in Equation 1. More importantly, these two components can also be recombined to yield a fully sampled image.

A Numerical Lung Phantom (NLP) was constructed (see Figure 1). The B_1 field profile was modeled using the equation: $B_1(r) = \exp(-r^2/(2\sigma^2))$ where σ is a falloff coefficient for the RF field and r is the radial distance from the center of the coil. This numerical phantom is displayed in Figure 1b. To simulate data acquisition, a set of ideal images is created using the expression:

$$I(x,y,i) = NLP(x,y)\sin(\alpha_0 \cdot B_1(x,y))\cos^{i-1}(\alpha_0 \cdot B_1(x,y))$$

where α_0 is the maximum flip angle and i denotes the image number within a set. Each image then is Radon or Fourier transformed into k-space and one column from the transformed image matrix is written to an acquisition matrix.

To approximate the field profiles, Figure 2 shows two different acquisition methods: Cartesian and radial gradient recalled echo sequences. The radial method uses an interleaved acquisition which effectively breaks up one image into two interleaved undersampled images while the Cartesian method uses two half Fourier images.

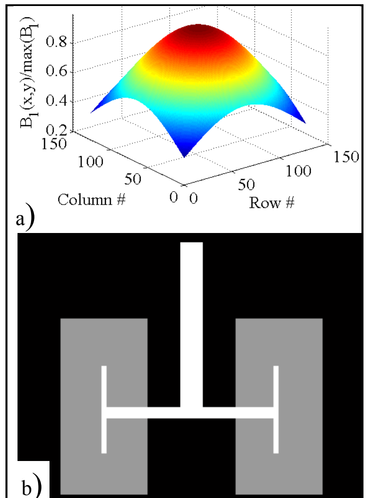

Figure 1. a) B_1 profile and b) the numerical phantom of the lungs.

Results

To determine the quality of the FA maps created with these methods, the estimated percent error is calculated using the equation:

$$\%Error(x,y) = \left(\frac{FA_{est}(x,y) - \alpha \cdot B_1(x,y)}{\alpha \cdot B_1(x,y)}\right) \cdot 100\%$$

The FA error maps for $\alpha = 9^o$ are shown in Figure 2d) and h) with $\mu = -0.5 \pm 1.8$ % and $\mu = -0.01 \pm 1.6$% for the radial and Cartesian acquisitions, respectively. The artifacts in Figure 2c) and g) may be reduced with k-space filtering. The accuracy of the FA maps, as determined by the standard deviation of the error maps, improves to less than 1% if only the central portion of k-space is used to estimate the FA map.

Discussion

We have demonstrated through our simulations that it is possible to split up the acquisition of k-space into two parts to obtain both a FA map and a fully sampled image. Theoretically, this technique works because the B_1 field profile is homogeneous and varies slowly over the sample of interest. Therefore, most of the information for determining FA maps is located in the central portion of k-space. Therefore, by breaking up the acquisition, k-space is acquired in an efficient manner that allows both imaging and estimation of a local FA map. These methods may not obviate the need for faster sequence design and the use of parallel coils for hyperpolarized gas imaging, but these methods obviate a separate scan for determining the FA map.

Acknowledgements

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References

1. Zhao L, Mulkern R, Tseng CH, Williamson D, Patz S, Kraft R, Walsworth RL, Jolesz FA, Albert MS. Gradient-echo imaging considerations for hyperpolarized ^{129}Xe MR. J Magn Reson B. 1996;113:179-83.

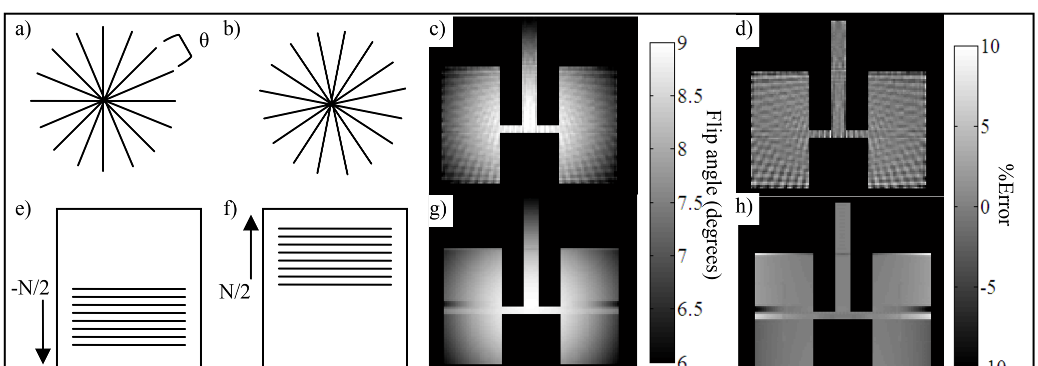

Figure 2. a) and b) are the interleaved radial projections used to created the FA map in c). e) and f) are the half Fourier acquired k-space data used to create the FA map in g).