Deblurring of spiral images in the presence of fat and rapidly varying B_0

INTRODUCTION: Spiral imaging with long acquisition windows is efficient but suffers from severe blurring in the presence of off-resonance. Deblurring of these images is generally performed by making some assumption on the smoothness of the spatial B_0 field[1,2]. In practice, off-resonance can vary rapidly in regions of susceptibility differences and in the presence of fat. Iterative methods have been proposed [3,4] to relax the B_0 smoothness requirement but do not address the issue of fat and coil combination. One common way to deal with fat is to first perform a 3 point Dixon fat/water separation [5]. In the presence of blurring however, a fat region can blur onto a region of significantly different image phase. Therefore, typical phase correction cannot be performed adequately even in the presence of a perfectly known B_0 field map. This work proposes an iterative approach to deblurring with or without fat separation.

METHODS: This work presents a method to obtain the deblurred image f from the reconstructed blurred image g by solving the linear equation $g = Bf$ using a conjugate gradient approach. The 2D blurring operation $g = Bf$ and its complex conjugate transpose $h = B^H g$ being large, sparse and redundant are not explicitly written in matrix form but are computed as:

$$g(a,b) = \sum_i \sum_j k_{i,j}(i-a, j-b) f(i,j) \qquad [1]$$

$$h(i,j) = \sum_a \sum_b k^*_{a,b}(i-a, j-b) g(a,b) \qquad [2]$$

respectively, using the kernels k interpolated from a finite set tabulated *a priori*. To speed up computation, the field map is segmented in a region where the blurring operation is roughly Block Circulant with Circulant Blocks (BCCB), a region where it is not BCCB due to a rapidly varying field (including a suitable region of influence around it) and a region where there is no signal. In the BCCB region, the B and B^H operation are each be performed by a series of two 1D operations [6], which constitutes a significant speedup. Regions without significant signal are left untouched. Further speedup is achieved by performing coil combination prior to deblurring. This approximation assumes slowly varying coil sensitivity in the blurring area of a voxel. Our approach to deblurring in the presence of fat is to acquire images g at a minimum of 2 TEs (we used 3: 3.2, 3.9 and 4.7ms) and to solve the augmented linear system:

$$\tilde{B}^H \tilde{g} = \tilde{B}^H \tilde{B} \tilde{f} \qquad [3]$$

$$with\ \tilde{B} = \begin{bmatrix} BT_{1W} & FBT_{1F} \\ BT_{2W} & FBT_{2F} \\ BT_{3W} & FBT_{3F} \end{bmatrix}, \tilde{f} = \begin{bmatrix} f_{Water} \\ f_{Fat} \end{bmatrix}, and\ \tilde{g} = \begin{bmatrix} g_{TE1} \\ g_{TE2} \\ g_{TE3} \end{bmatrix}$$

The F operator is a modulation at the off-resonance of fat (-440Hz at 3T) which requires 2 FFT operations while the T operators constitute image space multiplication.

RESULTS: Images were acquired in a region of sharply varying B_0 on GE 3T Signa Excite scanner equipped with an 8 channel head coil. Scan parameters were: TR:150ms, flip angle:50^o, FOV:24x24cm^2, resolution: 0.1x0.1mm^2. A set of 3 images was acquired at the previously mentioned TEs with a long acquisition window of 17.5ms using 80 spiral arms and a readout bandwidth of 62.5 kHz and another set was acquired with a short acquisition window of 1.64 ms using 256 spiral arms and a readout bandwidth of 250kHz. A set of images with synthesized blurring was generated from the short acquisition set. For each voxel of each coil image, a synthesized readout was generated at the local off-resonance frequency following the k-space trajectory of the long acquisition window scan. These data were gridded together to form a blurred image. The deblurring of water-only synthesized data took ~100s on an AMD Turion X2 Dual-core 2.1 GHz laptop running Matlab and the results are shown in Figs 1a-d. Figs 1e-h show actual deblurring of a water image after fat/water separation. Our iterative fat/water separation and deblurring was then performed on synthesized data. The computation for these images was ~15min and details of the results are shown in Figs 1 i-p.

DISCUSSION: The improvements resulting from by the proposed methods are most significant in regions of rapid field variation. Discrepancies between deblurring performance on synthesized (Figs 1c) and actual data (Fig. 1g) are mainly due to the presence of fat, incorrect field map estimation and thru-slice dephasing.

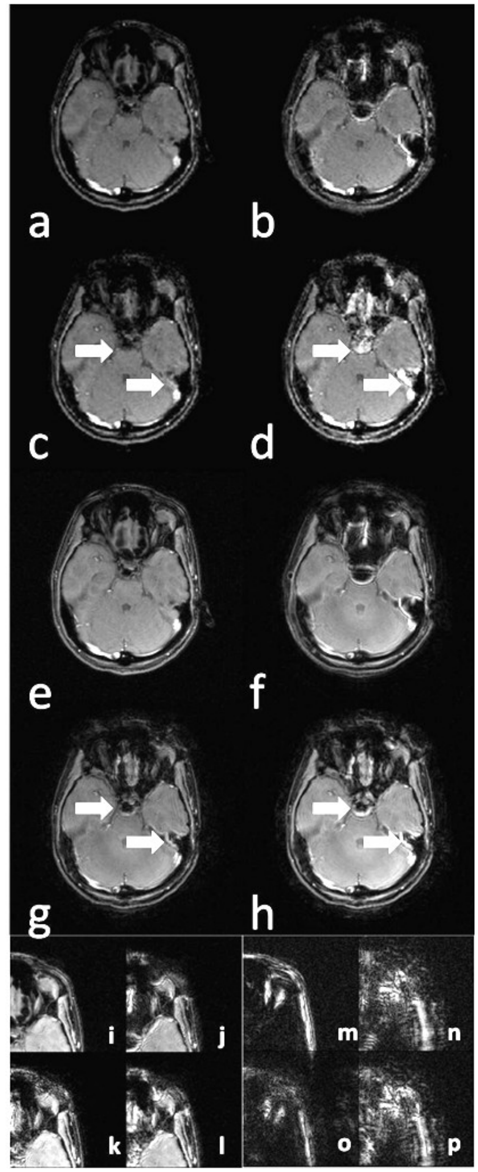

Fig 1. Water-only deblurring of synthesized data (a-d), water-only deblurring of real data(e-h), water image from the fat/water deblurring of synthesized data (i-l), fat image from the fat/water deblurring of synthesized data(m-p). Non-blurred images (a,e,i,m), blurred images (b,f,j,n) results from the proposed methods (c,g,k,o) and results non-iteratively deblurred by $B^H g$ (d,h,l,p). Arrows underscore regions where our methods perform better than the non-iterative alternatives.

REFERENCES: [1] Noll D. *et al.* MRM 25, 1992, [2] Börnert *et al.* JMRI, 32, 2000, [3] Makhijani M. K. *et al.* 2006 IEEE Biomedical Imaging Proc., [4]Fessler J. *et al.* IEEE J. SP 53,2005, [5] Dixon, T.W. Radiology, 153, 1984 [6] Ahunbay *et al.* MRM 44, 2000.