A Rapid Method for Deblurring Spiral MR Images

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Introduction

Spiral MRI in the presence of off-resonant frequencies results in blurring. Current methods for removing this blurring include an exact solution for linearly changing magnetic fields (1) and various methods for arbitrary field variations which involve unwrapping the phase of the signal in k-space(2, 3). The latter methods require several FFT's and represent the significant part of the computational time in image reconstruction. The proposed method is rapid and works for arbitrarily field variations. The solution is only an approximate one, but removes the majority of blurring; it can be used with the other methods if desired.

Method

The off-resonance induced phase ϕ in spiral imaging approximates a quadratic function in k-space

$$\phi(x,y,k_x,k_y) \approx c(x,y)\,(k_x^2 + k_x^2) \qquad [1]$$

This phase can be removed in the image by deconvolution with the kernel

$$\begin{aligned} \kappa(x,y) &= \mathrm{FFT}^{-1}\left[e^{ic(x,y)\left(k_x^2 + k_x^2\right)}\right] \\ &= \mathrm{FFT}^{-1}\left[e^{ic(x,y)k_x^2}e^{ic(x,y)k_y^2}\right] \\ &= \mathrm{FFT}^{-1}\left[e^{ic(x,y)k_x^2}\right]\mathrm{FFT}^{-1}\left[e^{ic(x,y)k_y^2}\right] \\ &= \kappa_x\,\kappa_y \end{aligned} \qquad [2]$$

Because the kernel in Equation [2] is seperable, one can perform this image space deconvolution as two separable one-dimensional deconvolutions. The kernels are compact in image space, and their size varies with c(x,y), which reflects the ADC time and the local off-resonance frequency. The kernel size can be adjusted dynamically according to the size of κ. Since the one-dimensional deblurring kernels are the same for all spiral trajectories, and are also the same in both the x and y directions, they can be calculated corresponding to a wide range of frequencies and stored, to be used in as a lookup table for all future deblurring operations. This deblurring is done after a single gridding and Fourier transformation are performed for each image. The compuational time for deblurring is much smaller than that for the gridding and FFT.

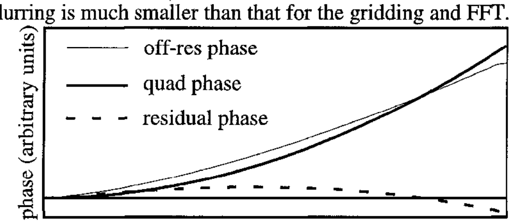

Fig. 1. Off-resonance phase for spiral vs. of k-space radius, quadratic phase removed by deblurring, and residual phase.

Results

The critical number for blurring is the product of the ADC time and the off-resonance frequency, referred to here as ϕ_0. The PSF's before and after deblurring were calculated for a range of ϕ_0, and are shown in Fig. 2. The method was also used to deblur a ToF based on spiral imaging with localized quadratic in-plane encoding(4) - the results are shown in Fig. 3.

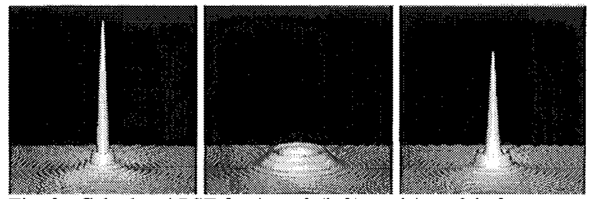

Fig. 2. Calculated PSF for $\phi_0 = 0$ (left), and $\phi_0 = 2$ before (middle) and after (right) deblurring.

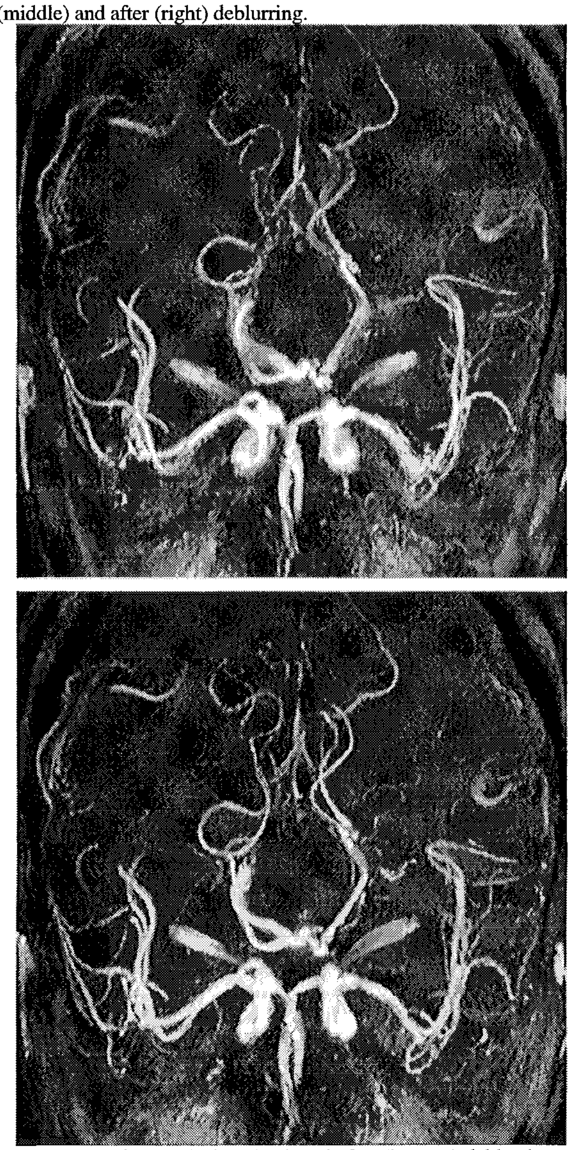

Fig. 3. MIP of MRA before (top) and after (bottom) deblurring.

References

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