# Retrospective adaptive k-space filtering for improved image quality in hyperpolarized gas MRI

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**Introduction** Spatial resolution and SNR in hyperpolarized gas MRI are largely constrained by the available magnetization. The current accepted standard for imaging are low flip angle spoiled gradient echo (SPGR) sequences. The depletion of magnetization from view to view with these sequences imposes a k-space filter $H(k_y)$ the shape of which is directly related to the phase encoding strategy. In this work we apply retrospective deconvolution in an attempt to recover the blurring imposed by PSF broadening in the $k_y$ dimension.

**Methods** $^3$He MRI was performed on a 1.5 T system (Philips, Eclipse) with T-R capabilities at 48.5 MHz. Gas was polarized to 30% with rubidium spin-exchange apparatus (GE). A low pass quadrature TR birdcage coil was used for all work. Gas phantom studies were conducted with a 300 ml glass sphere filled with 50 ml $^3$He and 250 ml $N_2$. A spherical phantom was used to generate a symmetric k-space to allow for comparison of noise distribution in the read ($k_x$) and phase ($k_y$) dimensions. A 2D SPGR sequence was programmed with TE/TR = 3.4/7 ms, 42 cm FOV, slice thickness 13 mm, BW = 31.25 kHz, $N_x$=128 samples and $N_y$=128 views. The flip angle was set as $\alpha = 8.7°$ representing a trade off between SNR and spatial resolution with the chosen centric encoding [1].

**Analysis** For centric encoding the magnetization decreases with cos($\alpha$) on successive views giving us an intrinsic k-space filter of the form $H(k_y) = (-1)^n.\cos(\alpha)^{n-1}$ where n = 1:128. This filter is responsible for the blurring in the y dimension of the image in Fig.1. We propose to remove some of the associated PSF blurring by deconvolution with the inverse filter function $H'(k_y)= [H(k_y)]^{-1}$, see blue line in Fig. 2. We write the measured signal profiles along central k-space in read and phase directions as $S_{read}=S(k_x)+\sigma(k_x)$ and $S_{phase}=H' S(k_y)+\sigma(k_y)$ where S() is the signal and σ() is the noise. Assuming a symmetric k-space and noise spectrum $S(k_x)=S(k_y)$ and $\sigma(k_x)= \sigma(k_y)$. Then $S_{read} - H' S_{phase} = (H'-1)\sigma$. Therefore the difference between $k_x$ and the filtered $k_y$ is approximately proportional to noise. We select a cut off where this difference becomes evident.

Fig. 1

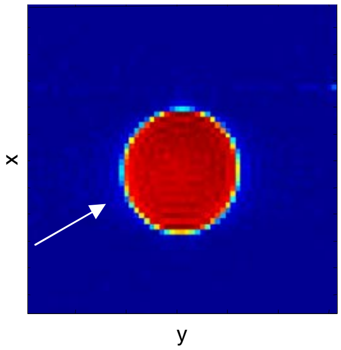

Fig. 2

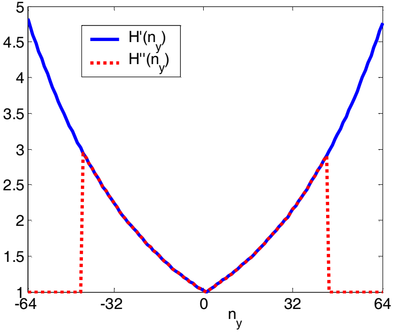

Fig. 3

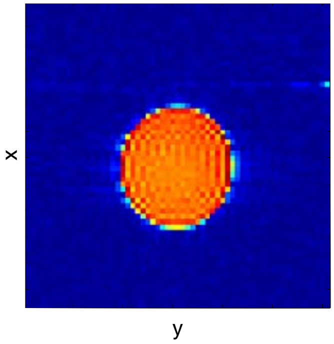

Fig. 1 shows the image of the spherical cell without any additional filtering. Note the blurring beyond the edges of the object (see arrow). Fig. 2 shows the filter applied in the $k_y$ dimension to recover the PSF broadening (blue line). The red line shows the crude adaptive filter [$H''(k_y)$] designed to cut out the high spatial frequency noise. Fig. 3 shows the image following deconvolution with $H'(k_y)$. Note the decreased blurring but with an increased visibility of background noise.

**Results and Discussion** The filter was applied in k-space using Matlab (Mathworks Inc, Natick), see the resulting image in Fig. 3. This shows reduced blurring in the y dimension with an increased level of background noise. Profiles were taken across the center of the deconvolved k-space in the x and y dimensions to visualize the SNR at the high spatial frequencies, see Fig. 4. Cut off frequencies were chosen for the definition of the bandpass of our basic adaptive filter $H''(k_y)$ based on the threshold of an amplification of noise at high spatial frequencies >1.5 times the noise in the unfiltered $k_x$ dimension, see red line in Fig. 2 and the resulting filtered image in Fig. 5.

Fig. 4

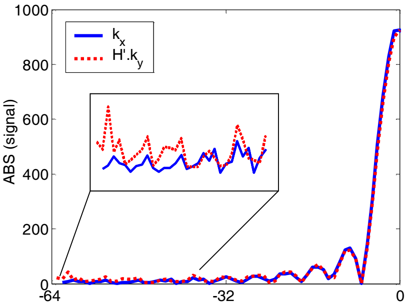

Fig. 5

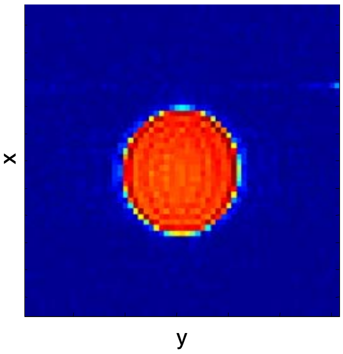

Fig. 4 shows the central $k_x$ (blue line) and filtered $k_y$ (red line) profiles. The noise in the $k_y$ dimension is magnified at the high spatial frequencies by $H'(k_y)$.

Fig. 5 shows the image following deconvolution with $H''(k_y)$. The image shows the desired reduction in blurring without rampant noise escalation.

**Discussion** In this preliminary work we have demonstrated that deconvolution in the $k_y$ dimension can retrospectively improve image quality of test phantoms in hyperpolarized gas MRI. The optimum filter configuration will be SNR dependent and could also depend on the object structure. Future work will involve adaptive design for structural phantoms and in-vivo lung images. In this work we have ignored the filter in the $k_x$ dimension due to gradient dephasing as the contribution is negligible in comparison. However, the same techniques could be applied in both dimensions.

**References** [1] Magn Res Med 2002;47:687-695

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