Phase Contrast MRA with Simultaneous Fat-Water Separation

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INTRODUCTION

The recent awareness of the link between NSF and Gd based contrast agents has brought renewed interest in non-contrast enhanced MR angiography (NCE MRA) methods, including phase contrast (PC) techniques. While PC MRA has traditionally suffered artifacts from cardiac pulsatility, intra-voxel dephasing, and lengthy imaging times, we have recently introduced PC VIPR [1], a 3D-radial undersampled phase contrast technique to virtually eliminate all of these shortcomings. However, in some cases with large signal contributions from fat, e.g. in abdominal exams of obese patients, chemical shift and signal aliasing related artifacts can lead to an overall degradation of image quality. To reduce the prevalence of fat related artifacts in PC, we propose a combined chemical shift and velocity encoding scheme to separate signals from fat and water that is insensitive to artifacts from B0 inhomogenity. This technique is applicable to any k-space trajectory, including Cartesian sampling; and will be usefully whenever chemical shift artifacts may occur (e.g. PC of coronaries, small peripheral vessels, renal arteries, etc).

THEORY

The IDEAL [2] fat/water separation technique is fully compatible with PC acquisitions and insensitive to off-resonance effects, but results in a tripled scan time. To reduce the scan time required and couple noise performance, we can combine velocity and time encoding for each voxel into a signal model: $S_n = \left(Fe^{i\omega_f t_n} + We^{i\gamma \vec{M}_n \cdot \vec{V}}\right)e^{i\psi t_n}$ where F is complex fat signal, ω_f is the chemical shift of fat, t_n is the echo time, W is the complex water signal, $\vec{M}$ is the first moment vector, $\vec{V}$ is the velocity vector, and ψ is the off-resonance. This signal model accounts for moving water protons and static fat protons, and contains 6 phase terms and 2 magnitude terms. At a minimum, 6 complex encodings are required to solve for the unknowns in the signal model, twice the number of encodings for simple fat-water separation but only 2 more than traditional phase contrast imaging. Ideally, images would be reconstructed using a cost minimizing iterative reconstruction, fitting all free parameters with respect to both the encoding at echo time and the spatial encoding gradient [3]; however, image domain point by point non-linear fitting of the signal from each echo time can be performed to reduce reconstruction time.

METHODS

All imaging was performed on a 3T clinical scanner (Excite HD, GE HealthCare, Milwaukee, WI). A respiratory gated, dual echo, undersampled 3D radial phase contrast sequences [1] was modified to acquire 4-velocity encodings at 4 distinct echo times, such that when accounting for both echoes, 8 total encodings were acquired with echo times evenly spaced between the 0 and 2π fat shift. To eliminate off-resonance and velocity encoding differences, projections were acquired with endpoints covering the entire sphere with staggering between dual-echoes, as shown in figure 1. Images from each echo and coil were first reconstructed at low resolution and fit on a coil to coil basis to the signal model using Newton's method with an L2 norm line search and Tikhonov regularization. High resolution images are then reconstructed using a multi-frequency reconstruction [4] using the low-resolution off-resonance map. Non-linear fitting is performed on the high resolution echo images using low resolution solution as an initial guess. Individual coil images are combined after the fitting procedure using magnitude squared weighting. To evaluate the sequence 3 volunteer exams were acquired without a contrast agent with (TR=13.1, TE1=3.9, ΔTE=0.3ms, α=10, BW=62.5kHz, FOV =32x32x16cm, resolution=1x1x1mm, 6000 projections/encoding, 50%respiratory efficient, 10min scan time). In the same session images were acquired with normal PC VIPR with the same scan time (TR=10.9, TE=3.9, α=10, BW=62.5, FOV=32x32x16cm, resolution=1x1x1mm, 7200 projections/echo, 50% respiratory efficiency) followed by a contrast enhanced breath held exam (clinical protocol, TR=3.5, TE=1.1,, α=30, BW=62.5kHz, FOV =34x34x30cm, resolution=1.3x1.3x1.3mm, 20s scan time, 20cc Multihance @3cc/s, parallel imaging). Images were compared for vessel conspicuity and presence of artifacts, across all three methods.

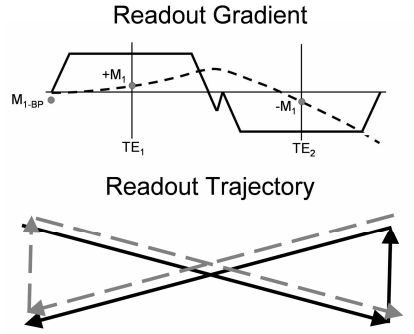

Figure 1. Readout gradient with minimized 1st moments and the corresponding trajectory for projections starting in the top (solid) and bottom (dashed) hemispheres.

RESULTS

Representative chemical shift/velocimetry imaging results are shown in Figure 2. Water images show excellent fat suppression, allowing a clear depiction of vessels on the magnitude images. Angiographic data derived from combining water and velocity information are able to depict smaller branches of the renal arteries that were not seen on the breathheld CE exams. In these healthy volunteers, angiographic image quality was comparable to PC VIPR images without fat/water separation.

DISCUSSION

Fat-water separation with mixed velocity encoding is very promising as a tool to reduce artifacts in PC exams, and possibly provide high resolution respiratory gated fat/water images at the same time. Further work is required to quantify fat/water signal behavior in obese patients and characterize SNR behavior in this method of processing. It also shows great promise for coronary flow measurements where chemically shifted fat disturbs flow quantification.

REFERENCES 1. Johnson *et Al* MRA Club 07 2. Reeder *et Al.* MRM 54(3):636 3.Samsonov *et Al* ISMRM 2007 #149 4. Man *et Al.* MRM 37:785

ACKNOWLEDGMENTS We gratefully acknowledge GE Healthcare for their assistance and support**.**

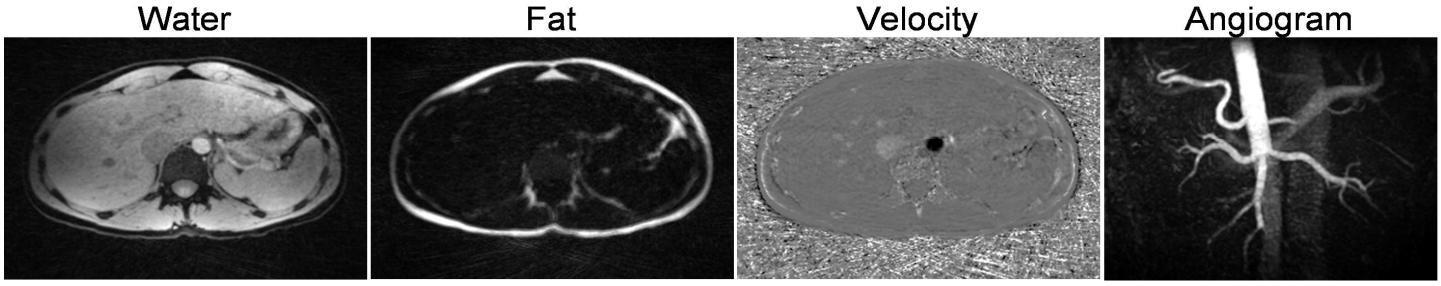

Figure 2. Representative images showing water, fat, velocity(S/I), and angiogram (MIP) of an abdominal PC VIPR scan with fat-water separation. Note the excellent fat/water separation across the large FOV and visibility of 2nd and 3rd order branch vessels not usually seen on CE exams.