Improved reconstruction of partial Fourier 3D dual-echo Dixon images

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Introduction

Dual-echo in-phase (IP) and opposed-phase (OP) gradient echo images provide valuable information for characterization of liver disease. With the recent development of efficient, high SNR, dual-echo Dixon imaging, there is potential to replace the separate, multi-slice IP/OP scan in a liver exam with calculated IP/OP images from a Dixon acquisition (created by addition or subtraction of fat and water images when flexible echo times are used).[1] Moreover, exam time could be shortened by utilizing the pre-contrast dual-echo Dixon mask from the dynamic contrast enhanced (DCE) series, provided the calculated IP/OP images contain the necessary clinical information.[2,3] A complicating factor in this scenario is the need to use partial Fourier (PF) acquisitions to increase the resolution achievable within a patient-compatible breath hold duration. Typical homodyne reconstruction of PF scans exploits the Hermitian symmetry of k-space to maintain resolution, but removes the phase information. Unfortunately, Dixon reconstruction requires the phase information for separation of water and fat images. Alternatively, the missing PF data can be zero-filled or multiplied by a homodyne high-pass ("S-shaped") filter to maintain the phase information, but these cause blurring or unwanted phase errors. Others have described solutions for iterative Dixon reconstruction techniques.[4] Here, we present a solution that maintains the full resolution and can be applied to PF images utilizing analytical Dixon reconstruction.

Methods

The proposed reconstruction method estimates the missing portion of k-space P_{est} by,

$$P_{est}(k_x,k_y) = F\{p_{est}(x,y)\}, \text{ where}$$

$$p_{est}(x,y) = p^*(x,y)e^{j2\varphi(x,y)},$$

$$e^{j2\varphi(x,y)} = S\{p^2(x,y)\}/|S\{p^2(x,y)\}|, \text{ and}$$

p(x,y) is determined from the zero-padded k-space, p^* is the mirrored complex conjugate, F{} denotes Fourier transform, and S{} denotes a smoothing function. When this algorithm is applied to water, fat, IP, and OP images from dual-echo Dixon reconstruction, the full resolution is obtained similar to homodyne reconstruction. The advantage of this method for OP images is in the doubling of the phase term, removing 180° phase transitions at water-fat interfaces, thus allowing accurate estimation of the doubled-phase by the smoothing kernel method.[5]

The algorithm was tested on data from 4 normal volunteers. Both full Fourier and PF acquisitions were acquired for each volunteer. PF acquisitions were reconstructed with both a 1D (phase direction only) homodyne high pass filter without homodyne phase correction (S_filter) and the proposed alternative partial Fourier (APF) reconstructions. All data were acquired on a 1.5T whole body scanner with a digital receive coil array (Ingenia, Philips Healthcare, Best, the Netherlands). Both acquisitions were dual-echo 3D T1-FFE with FOV=350x300x230 mm^3 (FOV and scan time were increased for larger subjects), res=1.3x1.7x5 mm^3 (interpolated to 2.5 mm slices), FA=15 deg, SENSE: AP=2.5, FH=1.5. TR and scan time for full Fourier were 5.8 ms and 17.3 s, respectively. PF scans used halfscan (HS) factor 0.7 in the phase (AP) direction and 0.85 in the slice (FH) direction. For the PF scans, three different TE pairs were evaluated: TR(ms) / TE1(ms) / TE2(ms) / scan time(s) = 5.8 / 1.8 / 4.0 / 11.7; 5.6 / 1.7 / 3.8 / 11.3; and 6.4 / 2.3 / 4.6 / 12.9, to evaluate potential variations with flexible echo times. All images were evaluated for sharpness and chemical shift artifacts by an experienced body radiologist.

Results

Full acquisition and both PF reconstruction techniques produced images with good water-fat separation and sharp water-only images in all 4 volunteers. OP images produced with the S_filter algorithm displayed a chemical shift artifact in the phase-encode direction (most notable at tissue fat boundaries – Figure 1), whereas the APF algorithm did not show this artifact. Overall, the OP images from the APF algorithm had comparable image quality to the full acquisition images with the expected decrease in SNR due to the PF acquisition.

Discussion

The APF algorithm performed notably well at water-fat boundaries and may provide the opportunity to replace the standard multi-slice dual-echo T1-FFE liver scan with 3D PF dual-echo Dixon IP/OP images, thereby reducing liver MRI exam times. Further evaluation is required to ensure adequate clinical information is provided by the Dixon images.

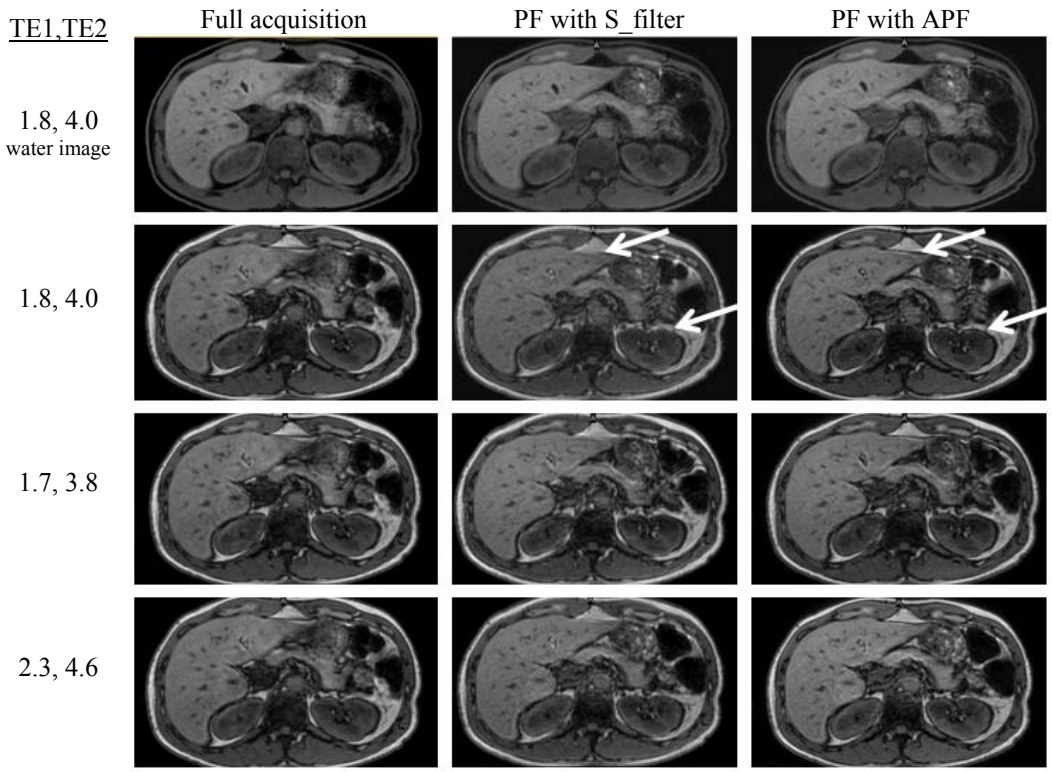

Figure 1. Comparison of full acquisition (left), partial Fourier (PF) with "S_filter" reconstruction (middle), and PF with APF reconstruction (right). Top row is water image. Three lower rows are calculated "opposed-phase" images for three different pairs of acquisition echo times (ms). APF reconstruction provided increased sharpness and reduction of chemical shift artifacts (arrows).

References

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