Assessing the Performance of Homodyne Combined with 2-point Dixon Reconstruction

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PURPOSE Two-point Dixon based fat-water separation is widely used due to its robustness to B_0 and B_1 heterogeneity and applicability to many imaging sequences[1,2], despite the need for acquisition of two echoes. This requirement limits the spatio-temporal resolution in applications such dynamic contrast enhanced (DCE) MRI for abdominal and breast imaging. The two-point Dixon method has been combined with half-Fourier acquisition with homodyne reconstruction[3], which has the potential to nearly halve the scan-time. Here, we assess the performance of the combined Homodyne-Dixon method in abdominal imaging at both the traditional and at phase-optimal echo times to determine the performance of the technique.

METHODS Without a known field map, both homodyne and two-point Dixon rely on the assumption of a smoothly varying phase to estimate a phase map from the k-space data alone[2,4]. Specifically, the two-point method assumes that the two given echoes represent time points where fat and water are exactly in and out-of-phase and any additional phase due to off-resonance is slowly varying. Homodyne also requires a slowly varying phase (without sudden polarity shifts) and assumes that the central, symmetrically sampled region in k-space is able to accurately represent the image phase. In order to satisfy the homodyne requirements, the Homodyne-Dixon method simply uses the central, symmetric part of k-space to perform a Dixon reconstruction and then uses the two Dixon phase maps (which should have all polarity shifts removed) as the phase maps for homodyne Reconstruction. The weighted, partial k-space data are then demodulated by these calculated phase-maps (similar to normal Dixon demodulation). The real part is then taken after the sum or difference of the demodulated data to produce homodyne fat-water images at full resolution. While this method works in theory, in practice the fat and water are generally not perfectly in and out-of-phase and off-resonance can vary abruptly, particularly at tissue interfaces.

EXPERIMENTS To explore this problem, abdominal images were acquired at the standard Dixon echo times of 1.1/2.2 ms and 2.2/3.3 ms. Images were also acquired at echo times of 1.2/2.4 ms and 2.4/3.5 ms to adhere more closely to the phase assumptions as Bloch simulations using a multi-peak fat model[5] show these echo-times to be the time points at which fat and water are nearly perfectly in and out-of-phase. All images were acquired in a single breath-hold (20-30 s) on a GE MR750 3T scanner using a 3D SPGR sequence and in accordance with IRB guidelines. Scan parameters were: Matrix size of 256x180x96 (for TE1/TE2 = 1.1/2.2 and 1.2/2.4 ms, implemented as a bipolar readout in the L/R direction) and 320x180x96 (for TE1/TE2 = 2.2/3.3 and 2.4/3.5 ms, implemented as a multi-TR readout in the L/R direction), with parallel imaging and 70% partial kz acquisition to reduce scan-time. The full extent of the k_x-k_y plane was acquired in order to retrospectively simulate partial acquisitions of 53%, 55%, 60%, and 70% in both the x and y directions. For image comparisons, ROIs were found for each partial acquisition value. The magnitude error between the fully sampled and homodyne water images were normalized to the fully sampled water images for each echo set and partial acquisition. In order to weight and see the effects of particularly bright regions, the sum-squared-error (SSE) was normalized to the SSE of the fully sampled water images.

RESULTS Figure 1 shows the normalized magnitude error and SSE for all echo combinations and partial fractions. In all cases, the images with improved echo times performed better than the corresponding traditional echo time. Additionally, it can be seen that in almost all cases a partial acquisition in the L/R-direction had a smaller error and SSE than the corresponding partial acquisition in the A/P-direction. A representative portion of the 60% homodyne acquisition is compared with the original and zero-filled images in Figure 2.

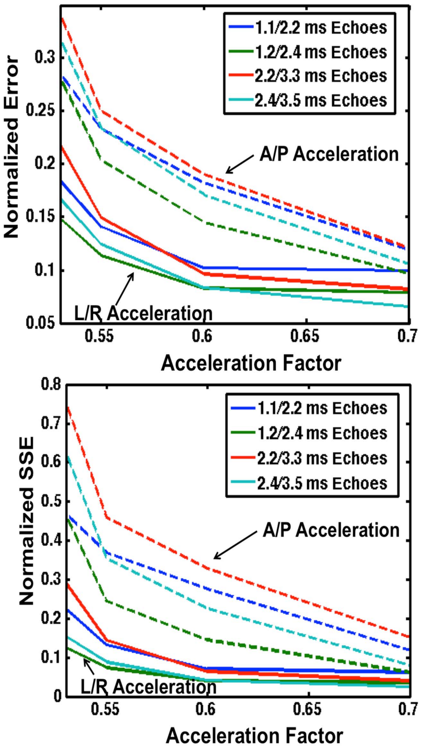

Figure 1: the normalized magnitude error and sum-squared-error (SSE) as a function of acceleration factor for all echo combinations in both the Frequency Encode (L/R) and Phase Encode (A/P) directions. Note that the optimized echo times perform better than the corresponding standard echo time for all acceleration factors.

DISCUSSION The errors in the phase-encoding direction (A/P) are far more pronounced than those in the Frequency encode direction (L/R). This is likely due to the fact that the orientation of the body presents pronounced fat-tissue interfaces tangential to the A/P direction and could also be complicated by respiratory motion. While the errors in the homodyne images from the L/R-direction are clearly visible in the difference images of Figure 2, the primary structure and resolution look virtually identical in the fully sampled and homodyne images, suggesting that this method can reasonably be used. Although the differences between the improved echo-times and the corresponding echo-times are subtle in the images shown, the error is much more noticeable in the error and SSE plots as seen in Figure 1. We note that our custom 2-point Dixon reconstruction occasionally had fat-water swaps when processing the low-pass/central, symmetrically sampled k-space data. This is likely due to the fact that the low-pass data inherently have slower phase variation, even at tissue boundaries, and can confuse the region growing reconstruction, which assumes that slow variations do not constitute tissue changes. This effect was far more prevalent when the symmetric data was very small. We believe that this could easily be corrected by either tuning the region growing parameters, or processing with a smaller matrix size and interpolating the phase after region growing. When fat-water swaps did occur, the ROIs used to calculate the plots in Figure 1 were modified to only cover the correct tissue type, and the ROI was constant across all echo pairs for a given acquisition factor and direction. We expect that this had little effect on the analysis because the data were normalized to the fully sampled water images using the same ROI.

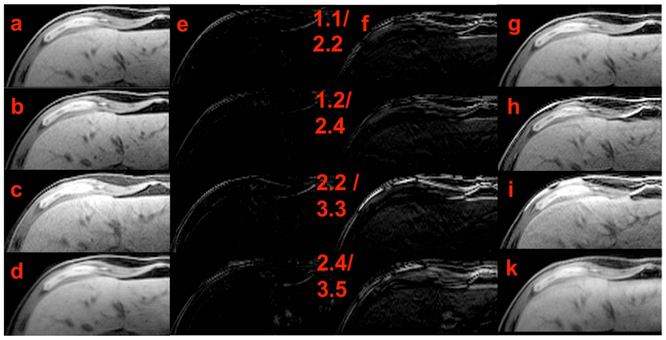

Figure 2: Representative Water images using 60% Acquisition Factor in the L/R direction (left images), and 60% Acquisition Factor in the A/P direction (right images). a,g are representative fully sampled images. b,h and c,d are representative homodyne water images for the 1.1/2.2 ms echo and 2.2/3.3 ms echo respectively, which are very similar to the 1.2/2.4 ms and 2.4/3.5 ms echoes. d,k are representative zero-filled images. e,f are the errors in the homodyne water image from the corresponding echo pairs.

CONCLUSION Different acquisition factors were compared and the normalized error and SSE were plotted as guidance on the error that one might expect when using this method. We have shown that the 2-point Dixon method combined with homodyne is feasible in vivo and that the performance can be noticeably improved by using echo times that align the data closer to the phase assumptions. Using partial-Fourier acquisition in conjunction with a 2-point Dixon acquisition can help alleviate the additional time constraints of the 2-point Dixon method. This time advantage can then be used to increase temporal or spatial resolution for DCEMRI.

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