Dual Flyback Echo-Planar Imaging for Separation of Water and Fat

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Introduction: Numerous applications require rapid imaging with fat suppression. Dixon based techniques are able to offer excellent fat suppression with a cost of scan time [1,2]. Recently, dual-echo Dixon techniques have shown great promise for very rapid imaging and robust separation, owing to careful phase correction algorithms [3,4]. Here, we extend this work using a dual flyback echo-planar imaging (EPI) sequence [5] to further speed the acquisition of data. The reconstruction is augmented to include correction for a relative phase-direction shift of fat and water. We demonstrate the full technique for abdominal imaging, where high temporal resolution and robust fat suppression are essential.

Theory: The pulse sequence (Fig 1a) is a standard segmented EPI sequence, with blip gradients only after the negative readout, with timing such that all positive readouts acquire images with fat/water in-phase (dark gray), and negative readouts acquire out-of-phase images (light gray). Standard echo time-shifting is used to ensure smooth phase variation in k_y. Fat accrues a phase of 2π per positive/negative echo, and this phase accrual causes a spatial shift of fat tissue with respect to water. This shift occurs along the y direction, and the number of pixel shifts is the number of echoes per readout (ETL). Considering water (W) and shifted fat (F_s), the signals in the in-phase (S_0) and opposed phase (S_1) images can be described as:

$$S_0 = (W + F_s e^{j\alpha_0}) \cdot e^{j\varphi_0} = M_0\, e^{j\beta_0},$$

$$S_1 = (W - F_s e^{j\alpha_1}) \cdot e^{j\varphi_1} = M_1\, e^{j\beta_1}.$$

Where $\alpha_{1,2}$ are the additional phases due to shifted fat, $\beta_{1,2}$ are the apparent phases of the images, and $\varphi_{1,2}$ are the original phase of the images. Fig 2 illustrates the phase behavior of water and shifted fat in the in-phase and out-of-phase signal model.

Methods: The proposed phase correction algorithm is as follows: **(A)** Make a low resolution image (subsample by a factor of 2·ETL) along the y direction (e.g. 256 × 32 when ETL = 4). **(B)** Estimate $\Delta\beta(x,y)$ ($=\beta_1 - \beta_0$) using the region growing method [1,6] from the low resolution images. The amount of the shift then becomes a half pixel, and it is possible to approximate $\Delta\varphi(x,y)$ ($=\varphi_1 - \varphi_0$) by $\Delta\beta(x,y)$. **(C)** Interpolate $\Delta\varphi(x,y)$ to the full resolution (e.g. 256 × 256), and estimate $\alpha_0(x,y)$ and $\alpha_1(x,y)$. The estimation can be performed as: $\alpha_0(x,y) = \Delta\varphi(x,y+ETL) - \Delta\varphi(x,y)$ and $\alpha_1(x,y) = 2\alpha_0(x,y)$. **(D)** Compute S (small) and B (big), as described in [4], based on α_0, α_1, M_0, and M_1 using the "cosine theorem". **(E)** Compute the phase difference between $\Delta\varphi$ and $\Delta\varphi_u/\Delta\varphi_v$ where $\Delta\varphi_u$ is an estimate of $\Delta\varphi$ based on S=W and B=F_s, and $\Delta\varphi_v$ is an estimate of $\Delta\varphi$ based on B=W and S=F_s. **(F)** Determine water and fat signals based on the phase difference (e.g. choose W=S and F_s=B when $|\Delta\varphi_u - \Delta\varphi|^2 < |\Delta\varphi_v - \Delta\varphi|^2$).

Results: The dual flyback EPI sequence was implemented on a GE 1.5T scanner. The imaging parameters were: matrix=256×256, TE1/TE2=5.7/8.0ms, TR=200ms, BW=±125kHz, slice thickness=5mm, and FOV=34cm. Fig 3 contains a representative result of water/fat separation from an abdominal scan. The in-phase and out-of-phase images contain the shifted fat (along A/P direction), and the water and fat images were well separated using the proposed phase correction algorithm.

Discussion: Based on promising recent works in two-point Dixon imaging [3,4,6], we have proposed to use positive and negative EPI echoes for a highly efficient fat/water separated acquisition, which is unaffected by EPI ghosting artifacts. The method is dependent upon careful consideration of background phase, as well as the k_y-direction shift between fat and water in source images. Some tissue boundaries may require an additional extrapolation and smoothing to improve the accuracy of the $\alpha_{0,1}$ estimation. The acquisition can be easily extended to 3D by adding z-direction phase encoding, and partial Fourier in k_y to reduce the echo time [7]. Overall, dual flyback-EPI provides a highly efficient method for acquiring 2-point Dixon data, with the same uniform fat/water separation experienced with other multipoint separation methods.

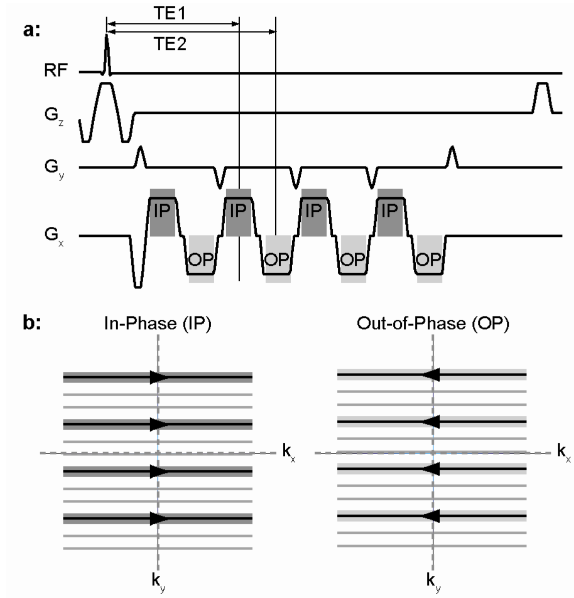

Fig 1: (a) Pulse sequence diagram, and (b) its corresponding k-space trajectories. A dual flyback EPI sequence acquires positive (left-right) and negative (right-left) echoes simultaneously per readout.

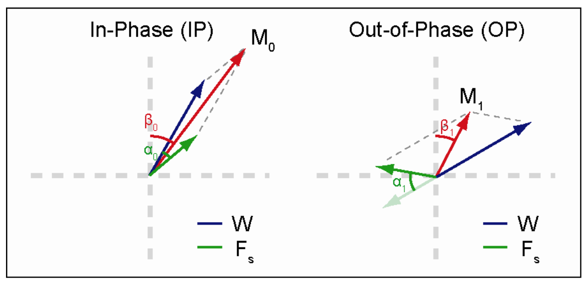

Fig 2: Phase diagram for in-phase and out-of-phase signals.

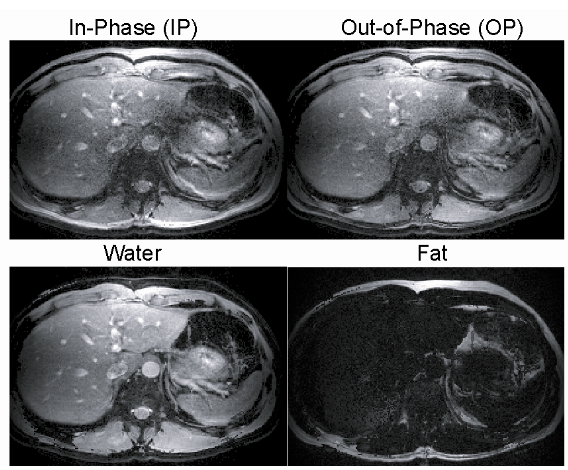

Fig 3: *In vivo* water/fat separation using the proposed phase estimation method.

References: [1] Dixon WT. Radiology 1984, [2] Glover GH. MRM 1991, [3] Ma J. MRM 2004, [4] Xiang Q-S. MRM 2006, [5] Feinberg DA, et al. MRM 1990, [6] Ma J et al. MRM 2008, [7] Reeder SB, et al. MRM 2005.