A Closed-form Formula for Multipoint Water-Fat Imaging with Flexible Echo Increments

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Introduction: Fat suppression that uses 3-point techniques [1-3] has the advantage of being insensitive to the inhomogeneity of the main magnetic field. The standard 3-point Dixon's method [1] requires fixed echo time increments. Approaches have been developed to generalize the TE increments by direct phase encoding [2] or iterative least-squares estimation [3]. In this work, we propose a new closed-form multipoint water-fat reconstruction algorithm with flexible echo time increments. The feasibility of this approach is then demonstrated by an implementation with multi-coil spiral imaging.

Theory: Denote the signal of a pixel of an image at $TE = t_n$ as

$$S_n = \left(W + Fe^{i(2\pi\Delta f t_n + \phi)}\right)e^{i(\Delta B_0 t_n + \theta)} \quad (n = 1,2,...,N) \ . \qquad (1)$$

Real unknowns W , F and ΔB_0 are water, fat, and static magnetic inhomogeneity, respectively. Δf is the known chemical shift of fat. ϕ and θ are other unknown systematic phase errors. Let $\beta_n = \pi\Delta f\left(t_m + t_n\right), \psi_n = 2\pi\Delta f\left(t_m - t_n\right)$ and $A_n = \left|S_n\right|^2 - \left|S_m\right|^2$, in which $n = 1,2,...,N$ and $m = (n+1) \bmod N$. When $\sin\left(\psi_n / 2\right) \neq 0$, define $C_n = A_n / 4\sin\left(\psi_n / 2\right)$. If $\sum_{n=1}^{N} \sin\psi_n \neq 0$, with one possible choice of w_n ,

$$w_n = \sin\psi_n \Big/ \sum\nolimits_n \sin\psi_n \quad (N \geq 3) , \qquad (2)$$

WF and ϕ can be determined by

$$WFe^{-i\phi} = -2i\sum\nolimits_n w_n C_n e^{i\beta_n} \ . \qquad (3)$$

Furthermore, $\left(W - F\right)^2$ and $\left(W + F\right)^2$ can be calculated by

$$\left(W \pm F\right)^2 = \left|S_n\right|^2 - 2WF\left(\cos\left(2\pi\Delta f t_n + \phi\right) \mp 1\right). \qquad (4)$$

From (4), two sets of possible solutions for W , F and corresponding values of ΔB_0 and θ are determined. A critical step of the post-processing is to resolve the right solutions for each pixel.

Methods : Data were acquired by a 2D spiral GRE sequence on a GE Signa Excite 3T system using an 8 channel head coil. Two initial field maps of ΔB_0 were obtained from each receive channel under the assumption that $W > F$ for all pixels (Fig. 1 (b)) or vice versa (Fig. 1 (c)). Discontinuities exist at the boundaries of the regions where the true dominance of water or fat is opposite to the assumption. Water and fat were first classified by thresholding according to the histogram of the field maps. We then applied a region-growing algorithm guided by the local smoothness of the field map to correct the misclassified pixels in the previous step. A bilinear interpolation of the coil-combined field map was also utilized to further refine the determination of W, F and ΔB_0 for each channel. Finally, the values of W, F and ΔB_0 from 8 channels were combined according to sensitivity of each channel.

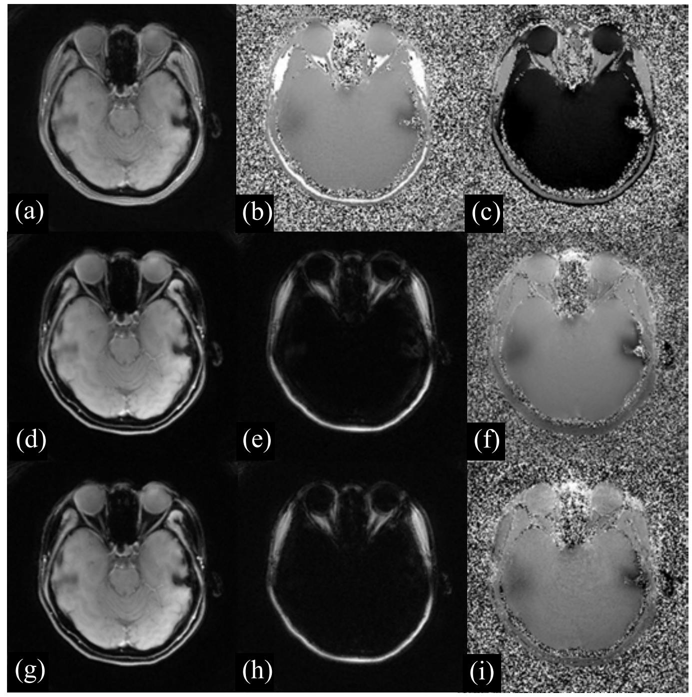

Fig.1 Illustration of the method: (a) the original image from one echo; (b) ΔB_0 ((-440 440) Hz) assuming $W > F$ for one coil; (c) ΔB_0 assuming $W < F$; (d, g) water; (e, h) fat; (f, i) Final ΔB_0 ((-220 330) Hz). (b-f) TE={3.7, 4.5, 5.3} ms; (g-i) TE={4.5, 5.3, 5.6} ms. Some parameters: FOV=22 cm, slice thickness = 5 mm, resolution =1 mm, ADC=3.7 ms, TR = 400 ms.

Results and Discussion : The 3-point form of the algorithm has been successfully applied with both equal TE increments as well as unequal TE increments (Fig.1). An optimal SNR can be achieved when the relative phase between water and fat is uniformly distributed within a 2π cycle using equal TE increments ($\Delta TE \approx 0.75$ ms at 3T) [1]. While the SNR is lower when the relative phase is nonuniform with unequal TE increments (e.g. $\Delta TE = \{0.4, 1.1\}$ ms) for the same total TE increments, aliasing of ΔB_0 becomes easier to solve. Since iterative procedures are not required, the proposed method potentially has high computational efficiency.

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References: [1] G. H. Glover, J Magn. Reson. Imaging 1991: 1:521-530. [2] Q .S. Xiang, et al. , J Magn. Reson. Imaging 1997: 7:1002-1015. [3] S. B. Reeder, et al. , Magn. Reson. Med. 2004:51:35-45.