A Fast Spiral Two-point Dixon (Spiral 2PD) Technique Using Block Regional Off-Resonance Correction (BRORC)

H. Moriguchi[1], J. S. Lewin[1], J. L. Duerk[1]

[1]University Hospitals of Cleveland / Case Western Reserve University, Cleveland, OH, United States

Introduction

Off-resonance blurring artifacts are a primary disadvantage of spiral imaging. The recently proposed Spiral two-point Dixon (Spiral 2PD) technique (i) does not require long duration spatial-spectral (SPSP) pulses, (ii) achieves unambiguous water-fat decomposition and (iii) performs effective de-blurring using only two data sets with different TEs [1]. However, since the B_0 inhomogeneity frequency field map cannot be directly derived from two data sets, off-resonance correction is achieved by testing multiple individual frequencies. Thus, the algorithm is very computationally intensive. In the recently proposed block regional off-resonance correction (BRORC) algorithm, off-resonance correction proceeds block by block through the reconstructed image [2]. BRORC is usually several times faster than frequency segmented off-resonance correction (FSORC) [3] with no perceptual difference between the images. In this study, we demonstrate that algorithms similar to BRORC can be advantageously used in Spiral 2PD techniques and that this newly developed technique (BRORC-Spiral 2PD technique) provides high computational efficiency when compared with other Spiral 2PD methods. Successful attainment of a rapid water-fat separation with off-resonance correction is a necessary step for future for real-time spiral applications.

Methods

In the Spiral 2PD technique, two data sets are acquired using normal spatially selective RF pulses [1]. The TE's of the first and second data sets are set to $n\tau$ and $(n+1)\tau$, respectively, where n is a positive integer and τ is the time during which fat spins precess by 180° out of phase with respect to water spins. With this condition, the signals in the reconstructed images (S_0 and S_1) can be expressed as: $S_0 = W' + F'$ [Eq.1], $S_1 = (W' - F')\exp(i\phi)$ [Eq.2], where W' is water signal blurred by local B_0 off-resonance frequency f (Hz), F' is fat signal blurred by local B_0 and chemical-shift frequencies $f + f_{fat}$ (Hz), and ϕ is the phase shift due to f during τ, i.e., $\phi = 2\pi f \cdot \tau$ [Eq.3].

The newly proposed BRORC-Spiral2PD technique consists of two steps: (a) block-based B_0 frequency estimation and (b) block-based signal decomposition with de-blurring. Figure 1 shows a flow chart of the B_0 frequency estimation method for a particular sub-image region. The sub-image matrices M_1 x M_1 ($M_1 = 2^x$, e.g., 16) are extracted from both S_0 and S_1 at the same location. Water-fat decomposition and de-blurring is performed using a guess frequency f_g. f_g is considered to be close to the true B_0 frequency f. In Fig.1, W_g and F_g are m_1 x m_1 low resolution water and fat sub-images, respectively. The central portions of W_g and F_g , W_{gc} and F_{gc}, are used to compute: $T_{gc} = ((W_{gc} + F_{gc})/(W_{gc} - F_{gc}))$ [Eq.4]. A local B_0 frequency is estimated as: $f_e = f_g - R \cdot f_d$ [Eq.5], where $f_d = \tan^{-1}((\mathrm{Im}(T_{gc})/\mathrm{Re}(T_{gc}))/(2\pi \cdot \tau)$ [Eq.6], and R is a regularization function to avoid inaccurate estimation of f_d which often occurs in water-fat tissue boundaries. Since B_0 inhomogeneity is usually smoothly varying across the FOV, f_g can be obtained from the neighboring blocks whose frequencies are already determined. In the estimated frequency field map, f_e is set to the central r_1M_1 x r_1M_1 pixels of the cropped M_1 x M_1 matrix location. Figure 2 shows a flow chart of water image reconstruction based on the computed frequency map. The sub-image matrices M_2 x M_2 ($M_2 = 2^x$, e.g., 32) are extracted from both S_0 and S_1 at the same location. Water signal separation and de-blurring are performed based on the mean frequency $\overline{F_e}$ of the selected sub-region. Since the outer region of the de-blurred sub-image W often exhibits artifacts, only the central r_2M_2 x r_2M_2 matrix is retained. The above procedures are repeated until the whole image or a particular region of interest (ROI) is processed.

Both Spiral2PD and the BRORC-Spiral2PD techniques were applied to in-vivo cardiac images acquired using spiral trajectories. TEs were set to 2.2/4.4ms. Images were reconstructed on 256 x 256 matrices. Both computational costs and image quality were compared between these techniques. In the Spiral 2PD technique, predetermined frequencies were set from –200Hz to 200Hz [1]. The total number of tested frequencies was set to 29 based on Eq.2 in ref.[2]. In BRORC-Spiral2PD technique, (M_1, m_1, r_1) = (16, 8, 0.25) and (M_2, r_2) = (32, 0.5).

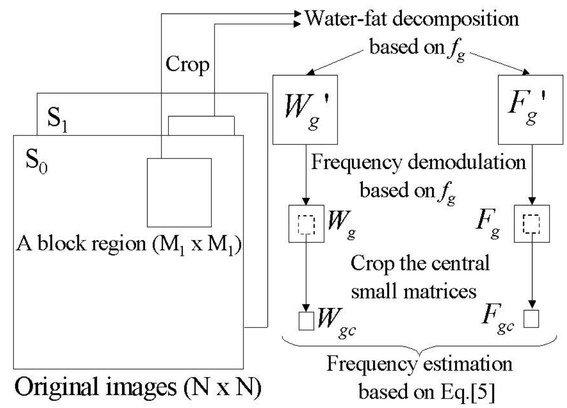

Fig.1. Flow chart of local B_0 frequency estimation

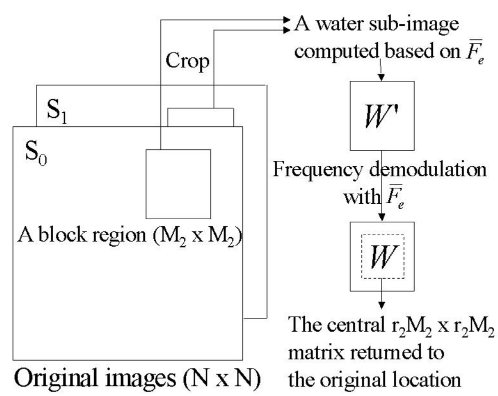

Fig.2. Flow chart of water image reconstruction

Results

Figure 3 shows the reconstructed images (a: one of the original images (TE=4.4ms); b: Spiral2PD technique; c: BRORC-Spiral2PD technique). The blurring artifacts observed in (a) are effectively reduced in (b) and (c). There are no observable differences in image quality between (b) and (c). The total number of complex multiplications required for reconstruction of (b) and (c) were 68.42×10^6 and 18.74×10^6, respectively. When the BRORC-Spiral2PD technique was applied to a 128 x 128 matrix region centered on the heart, the computational cost of (c) was further reduced to 9.18×10^6. This ROI based reconstruction was not possible with the Spiral 2PD technique (or conventional FSORC).

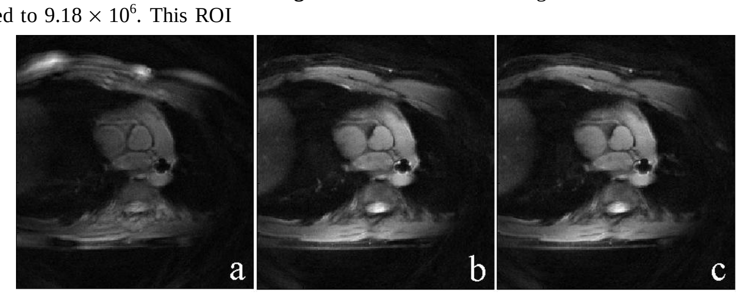

Fig.3. Reconstructed cardiac images. (a) the original image; (b) Spiral 2PD technique; (c) BRORC-Spiral2PD technique

Discussion and Conclusions

The BRORC-Spiral2PD technique requires significantly less computational demands than the original Spiral 2PD technique while retaining comparable image quality. Furthermore, the computational costs of the BRORC-Spiral2PD technique can be further reduced when the algorithm is applied to specific ROI's in the image. The newly proposed BRORC-Spiral2PD technique is a fast reconstruction technique for effective fat suppression with de-blurring from only two spiral data sets acquired without SPSP pulses. It is considered that the BRORC-Spiral2PD technique has a significant potential for real-time applications.

Acknowledgements

NIH/NCC Grants R01 CA81431 and R33 CA88144, Siemens Medical Solutions.

References [1] Moriguchi H, et al. MRM2003;50:In Press. [2] Moriguchi H, et al. MRM2003;50:643-648. [3] Noll DC. Ph.D. thesis, 1991.