Chemical Shift Artifact Correction in MREIT using Iterative Least Square Estimation Method

Z J Meng, A S Minhas, Y Q Han, W C Jeong, Y T Kim, H J Kim and E J Woo
Department of Biomedical Engineering, Kyung Hee University, Korea
E-mail: ejwoo@khu.ac.kr

Abstract. Human and animal imaging in magnetic resonance electrical impedance tomography (MREIT) demands high signal-to-noise ratio (SNR) data. We therefore perform MREIT experiments with a higher bandwidth per pixel. This leads to bigger chemical shift artifacts in MR images from fat regions. We may correct such artifacts in MREIT using a recently proposed method based on the three-point Dixon technique. This method is however not suitable for fast imaging pulse sequences. It has a poor SNR and also sometimes leads to swapping of water and fat signals in certain pixels when the field inhomogeneity phase unwrapping algorithm fails. This work demonstrates a new chemical shift artifact correction method in MREIT using a least square estimation method. Iterative separations of water and fat complex images obviate the phase unwrapping step. We present the separated water and fat images using the conventional and also the least square method. These two algorithms are compared in terms of the SNR and their water-fat separation capability. We propose the new method for future studies of fast MREIT imaging experiments.

1. Introduction
Magnetic resonance electrical impedance tomography (MREIT) enables us to perform high-resolution conductivity imaging of body tissues. MREIT data has to be collected with a high signal-to-noise ratio (SNR) for better accuracy of reconstructed conductivity images. This necessitates MR data acquisition with a high bandwidth per pixel. However, such setting may produce bigger chemical shift artifacts in MR images when we image animal or human subjects containing fatty tissues. The artifact creates misalignment of certain pixels in a fatty region. Reconstructed conductivity images in such regions are noisy and inaccurate.

Recently, few researchers proposed chemical shift artifact correction method in MREIT based on the three-point Dixon technique [1, 2]. The basic idea was to separate an MRI image into water and fat images, correct pixel misalignments in the fat image and then add the water and corrected fat images to produce an artifact-free MR image data. Reconstructed conductivity images from such corrected data are free from artifacts. However, using this method to separate water-fat images may lead to water-fat swapping in certain pixels if the unwrapping of the field inhomogeneity phase fails at those pixels. Besides, it is not suitable for fast imaging pulse sequences due to its longer time shift requirements to acquire Dixon’s data [3].

In this work, we demonstrate the performance of a recently proposed iterative least square estimation method for water-fat separation and subsequently chemical shift artifact correction in MREIT. The algorithm obviates the phase unwrapping step by using an iterative algorithm...
with a parametric estimation of the phase due to field inhomogeneity. The separated water-fat images have a higher SNR. This method is suitable for fast pulse sequences like balanced steady state free precession (b-SSFP), which Minhas et al proposed to be useful in MREIT [4]. In this paper, we compare corrected images using the least square method and the Dixon method in terms of SNR and swapping of water-fat pixels. Future MREIT experiments using a fast imaging pulse sequence would utilize the proposed technique for chemical shift artifact corrections.

Figure 1. Multislice separated magnitude images of (a) water $W$ and (b) fat $F$ using the three-point Dixon method.

Figure 2. Multislice separated magnitude images of (a) water $W$ and (b) fat $F$ using the iterative least square method.

2. Methods

2.1. Water-fat separation using three Dixon data sets

We assume an imaging object containing a fatty region. The MR signal at every pixel is assumed to be a linear combination of water and fat signals. Three $k$-space Dixon data sets with the read gradient shift of $\tau = (0, +1.14, -1.14)$ ms were collected. This makes a phase shift of $\phi = (0, +\pi, -\pi)$ between water and fat signals. Using conventional post-processing method proposed by Glover et al [3], we estimate the field inhomogeneity phase from these data sets and cancels its effect from each data set. A simple addition and substraction of these new data sets provide us with separated water and fat images.

Another approach to post-process the Dixon data sets is the iterative least squares method proposed by Reeder et al [5]. Here, the water $W$ and fat $F$ signals are assumed to be complex and have a chemical shift of $\Delta f_{wf}$ (Hz) between them. The signal acquired at an echo time $t_n$ is then given by,

$$S_n = (W + Fe^{j2\pi \Delta f_{wf} t_n})e^{j2\pi \psi t_n}$$

where $\psi$ is the field inhomogeneity induced phase. An iterative least square algorithm is used to estimate three parameters $W$, $F$ and $\psi$ at each pixel from $n$ data sets collected at different echo times $t_n$. The data sets need not necessarily have the phase shift of $\pm m\pi$, ($m = 0, 1, \ldots$) between them.
2.2. Imaging experiment
We used a swine leg from a local grocery store as an imaging object with fatty tissues. Four carbon-hydrogel electrodes with adhesive (60 × 60 × 5 mm$^3$) were attached around the leg for current injections. Current of 10 mA was sequentially injected in two mutually orthogonal directions. Using our 3 T MRI scanner (Medinus, Korea), we scanned the leg with a spin echo based multi-echo data acquisition method. We collected three Dixon data sets with read gradient shifts of $\tau = (0, +1.14, -1.14)$ ms with respect to the echo time $TE$. Eight slices in the central region were scanned with field-of-view of 150 × 150 mm$^2$, slice thickness of 4 mm, image size of 128 × 128 and an averaging of 10 cycles.

2.3. Chemical shift artifact correction
We set the bandwidth per pixel as 62.5 kHz, which produced one pixel shift in fatty tissues. We separated the water-fat images using the two techniques described in section 2.2. The fat images were shifted by one pixel from the bottom to top (frequency-encoding direction). These shifted fat images and water images were added to produce corrected data [1]. The $z$-component of current injection induced magnetic flux density $B_z$ was then obtained from this corrected data.

![Figure 3. Multi-slice magnitude images (a) before and (b) after corrections using the three-point Dixon method.](image)

![Figure 4. Multi-slice magnetic flux density $B_z$ images for vertical current injection (a) before and (b) after corrections using the three-point Dixon method.](image)

![Figure 5. Multi-slice magnitude images (a) before and (b) after corrections using the iterative least square method.](image)
3. Results
Figure 1 and 2 show the results of separated water \( W \) and fat \( F \) images using the three-point Dixon method and the least square method, respectively. Both methods could separate water and fat images in a similar way. Figure 3 shows the original and corrected magnitude images in upper and lower rows, respectively using the three-point Dixon method. Figure 4 shows the corresponding phase images. Arrows in the upper row of figure 3 indicate the position of chemical shift near electrodes. Arrows in the lower row indicate corrections. Chemical shift is also observed in internal fatty regions of the swine leg. Corrected magnitude and phase images show better image contrast. Similar results for the least square method are shown in figures 5 and 6. With a quantitative measurement over a small region, a 10-15 % SNR improvement over the three-point Dixon method was observed in magnitude images using the least square method.

4. Discussion and Conclusion
We performed a comparative study of the three-point Dixon method and the least square method in MREIT for chemical shift artifact corrections. The results show that for a water-fat phase shift of \( \pm \pi \), two methods give similar results in terms of the separation quality of water-fat images. However, the least square method provides a better SNR. Since we could not separate water and fat images properly using the least square method when the data was noisy, we speculate that it is sensitive to noise. This may be attributed to the failure in estimation of a proper field inhomogeneity phase. An improved field inhomogeneity phase estimation method suggested by Yu et al [6] may provide better results. We suggest using the least square method to correct chemical shift artifact in future MREIT studies using a fast pulse sequence.

Acknowledgments
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References
[1] Minhas A S, Kim Y T, Jeong W C, Kim H J, Lee S Y and Woo E J 2009 Chemical shift artifact correction in MREIT J. Biomed. Eng. Res. 30 461-8
[2] Hamamura M J, Nalcioglu O and Muftuler L T 2009 Correction of chemical shift artifacts in magnetic resonance electrical impedance tomography Proc. Intl. Soc. Mag. Reson. Med. Conf., Honolulu, Hawaii, USA April 18-24 17 4658
[3] Glover G H and Schneider E 1991 Three-point dixon technique for true water/fat decomposition with \( B_0 \) inhomogeneity correction Mag. Res. Med. 18 371-83
[4] Minhas A S, Woo E J and Lee S Y 2009 Magnetic flux density measurement with balanced steady state free precession pulse sequence for MREIT: a simulation study Proc. IEEE EMBC09 (Minneapolis, MN, USA) 2276-8
[5] Reeder S B, Wen Z, Yu H, Pineda A R, Gold G E, Markl M and Pelc N J 2004 Multicoil Dixon chemical species separation with an iterative Least-Squares estimation method Mag. Res. Med. 51 35-45
[6] Yu H, Reeder S B, Shimakawa A, Brittain J H and Pelc N J 2005 Field map estimation with a region growing scheme for iterative 3-point water-fat decomposition Mag. Res. Med. 54 1032-9