A Novel Algorithm for Eddy Current Effect Elimination in Three Points Dixon Method

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Introduction

Dixon method has been well-known for its functionality of fat and water separation for many years. For three points Dixon method, time intervals between two echoes is as short as 2.38ms for out phase-in phase-out phase mode scanning on 1.5T MR system, which puts a high requirement for gradient performance. Commonly, bipolar gradient was adapted. Fig.1 gives the diagram of the "bipolar" three point Dixon sequence. However, the eddy current induced by alternating gradient quickly will result in k-space misalignment. The misalignment will leads to a linear phase discrepancy between different echo images. This phase discrepancy disrupts chemical-shift induced phase differences, causing failure in field map estimation and the subsequent water–fat separation [1]. Here a novel algorithm is presented to align three echoes in image space.

Methods

Negative-positive-negative gradients are applied in readout direction(Fig.1), considering the linear phase discrepancy between echoes induced by eddy current, and the phase caused by the field inhomogeneity, three image are expressed as following in image space (ignoring T2* effect):

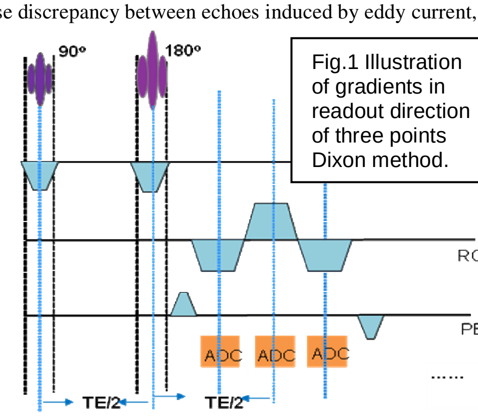

Fig.1 Illustration of gradients in readout direction of three points Dixon method.

$$S1=(W-F)e^{i(\phi_0-\Delta\phi+\varphi1)}$$
$$S2=(W+F)e^{i(\phi_0+\varphi2)} \qquad (1)$$
$$S3=(W-F)e^{i(\phi_0+\Delta\phi+\varphi3)}$$

W and F in the above equations represent water and fat image respectively. $\Delta\phi$ is the phase caused by field inhomogeneity, which changes with time. $\varphi1$, $\varphi2$ and $\varphi3$ are linear phases caused by eddy current. S1 and S3 were obtained when water and fat are opposed phase, and S2 at in-phase time. We know that multiplying S1*(*presents conjugate) with S3, then getting the phase of the product, $\psi31 = 2\Delta\phi + \psi3 - \psi1$, multiplying $e^{i\frac{\psi31}{2}}$ and $e^{-i\frac{\psi31}{2}}$ with S1 and S3 respectively, equation (1) can be transformed to be follows:

$$S1'=(W-F)e^{i(\phi_0+\frac{\varphi1+\varphi3}{2})}$$
$$S2=(W+F)e^{i(\phi_0+\varphi2)} \qquad (2)$$
$$S3'=(W-F)e^{i(\phi_0+\frac{\varphi1+\varphi3}{2})}$$

From (2), it's clear that field-inhomogeneity effect is eliminated. But for the existence of the discrepancy of phase induced by eddy current, the fat and water image can not be calculated directly.

Next come to the important idea for correction of the eddy-current-induced misalignment.

Similarly, get ting the phase of product $S32=(S3'\cdot(S2)^*)\cdot(S2\cdot(S1')^*)^*$,

$\phi_{ecc}=\frac{\varphi1+\varphi3}{2}-\varphi2-(\varphi2-\frac{\varphi1+\varphi3}{2})$. Multiplying S2 with $e^{i\frac{\phi_{ecc}}{2}}$, (2) is transformed as

$$S1'=(W-F)e^{i(\phi_0+\frac{\varphi1+\varphi3}{2})}$$
$$S2'=(W+F)e^{i(\phi_0+\frac{\varphi1+\varphi3}{2})} \qquad (3)$$
$$S3'=(W-F)e^{i(\phi_0+\frac{\varphi1+\varphi3}{2})}$$

Now, the phase is the same, k-space misalignment is corrected, eddy current effect is eliminated from the image, and more accurate water and fat images can be obtained from the above three formulas:

$$|W|=\left|(\frac{S1'+S3'}{2}+S2')/2\right|,|F|=\left|(S2'-\frac{S1'+S3'}{2})/2\right| \qquad (4)$$

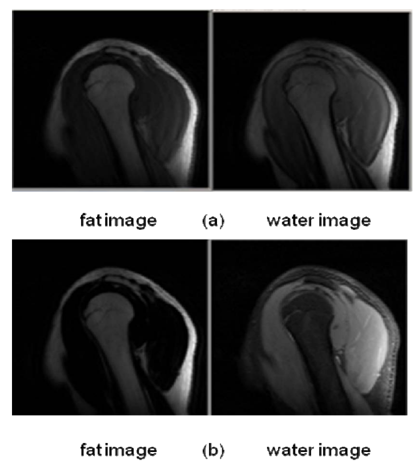

Fig.2 1.5T scanner (Siemens)
(a) Without eddy current correction.
(b) With eddy current correction.

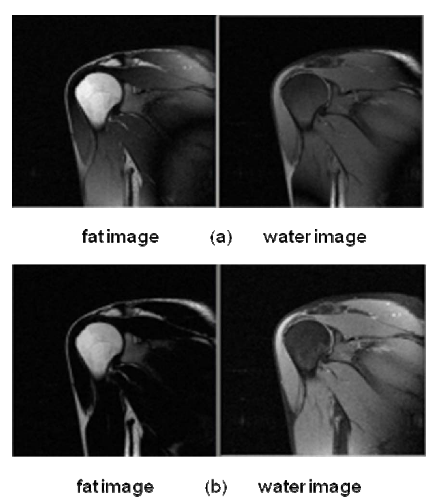

Fig.3 0.35T scanner (Siemens)
(a) Without eddy current correction
(b) With eddy current correction

Results

This novel algorithm removes the additional phase caused by eddy current and gets better water and fat separation image.

Discussion

1. The method is easily to be realized.
2. The eddy current effect in traditional Dixon methods could be largely reduced.
3. Quality of clinical images would be improved greatly (see Fig.2. and Fig.3.).

Reference

[1] Wenmiao Lu, Huanzhou Yu, et al, Water–Fat Separation with Bipolar Multiecho Sequences. Magnetic Resonance in Medicine 2008; 60:198–209