Simultaneous Water-Fat and T2* Mapping with 3-Point Acquisitions

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Introduction

It is well known that separate water and fat images can be obtained with two or three acquisitions using either gradient-echo or spin-echo sequences with incremental echo shifts [1-4]. It is also known that similar pulse sequences can be used to obtain T_2* images that has applications for assessing iron depisition [5]. To separate effects of chemical shift and T_2*, a method fitting a "complex field map" using six or more acquisitions has been described [6]. In fact, with a 3-point method that samples water and fat vectors at three orthogonal phases (TOP), these two effects are natually decoupled and thus can be easily separated [4]. This work demonstrates how TOP sampling can be combined with a recently published phase correction algorithm of Regional Iterative Phasor Extraction (RIPE) to produce water-fat and T_2* images simultaneously with as few as three acquisitions.

Methods

Theory Using appropriate incremental echo shifts, three complex images can be acquired with water and fat vectors at (90°, 270°, 450°) angles, as described by Eqns(1-3), where W and F are non-negative real variables, P_0 and P_1 are phasors representing two types of phase errors. The three square brackets represent combined complex signal from both water and fat vectors. Since the two vectors remain orthogonal for all acquisitions, the three square brackets should have identical magnitude. In other words, any magnitude change of I_1, I_2, and I_3 is due to T_2* decay, and thus T_2* can be readily extracted from I_1, I_2, and I_3 by fitting their magnitude with respect to echo shift step Δt. After defining complex variables $X = WP_0 P_1$ and $Y = -iFP_0 P_1$, and magnitude normalization with respect to I_1, Eqns(4-6) can be written from which W and F can be respectively found as the magnitude of X and Y given in Eqns(7,8). According to their definitions, physically sensible (X, Y) solution between the two possibilities in Eqns(7,8) should be the one with X leading Y in phase by 90 degrees. This phase relation is robust for pixels containing both non-zero W and F vectors. For pixels with only a single peak, say water only, (X, Y) might be reversed and further processing is needed. The Regional Iterative Phasor Extraction (RIPE) algorithm [4] is used to determine and remove P_1 from Eqns(4-6), leading to W and F as 2nd pass linear solutions. Because P_1 is expressible in X and Y using either Eqns(4,5) or (5,6), an average P_1 can be defined by Eqn(9). Similar to that described in Ref [4], two possible phasor candidates for P_1 are defined as $P_u = \langle P_1 \rangle$ and $P_v = -\langle P_1 \rangle$, and the true P_1 is found through RIPE from (P_u, P_v) and an initial value P_0 that is defined as $\langle P_1 \rangle$ weighted by the smaller value between $|X|$ and $|Y|$. Finally, the true P_1 is smoothed and removed from Eqns(4-6), leading to (X, Y) as a least-squares solution, and thus $(W, F) = (|X|, |Y|)$. It can be shown that for both X and Y, the effective number of averages NSA* is 2.667, and by using a 3rd pass linear solution after phase correction of P_0 the NSA* for W and F can be further improved to be 3.0.

$$I_2 = [W + iF]P_0 \quad (1)$$

$$I_3 = [W - iF]P_0 P_1 \exp(-\Delta t / T_2^*) \quad (2)$$

$$I_3 = [W + iF]P_0 P_1^2 \exp(-2\Delta t / T_2^*) \quad (3)$$

$$J_1 = X - Y \quad (4)$$

$$J_2 = (X + Y)P_1 \quad (5)$$

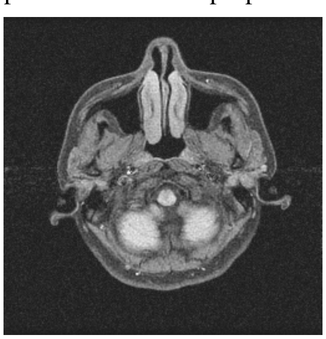
$$J_3 = (X - Y)P_1^2 \quad (6)$$

$$X = (J_2 \pm \sqrt{J_1 J_3})/2 \quad (7)$$

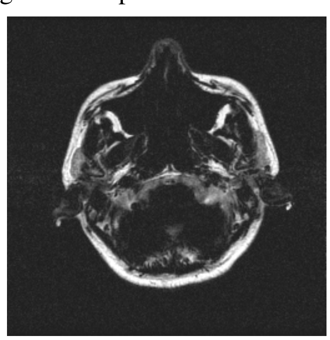
$$Y = (J_2 \mp \sqrt{J_1 J_3})/2 \quad (8)$$

$$\langle P_1 \rangle = \frac{1}{2}\left[\frac{J_2(X - Y)}{J_1(X + Y)} + \frac{J_3(X + Y)}{J_2(X - Y)}\right] \quad (9)$$

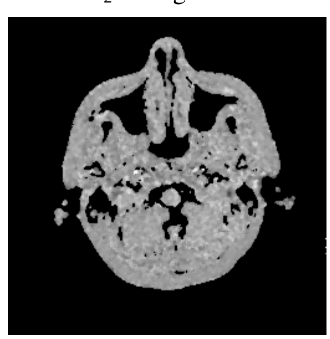
Experiments Complex images were acquired on a 1.5T clinical scanner with TOP sampling scheme (90°, 270°, 450°). They are processed with the proposed algorithm to produce water-fat as well as T_2* images.



(a) Water image



(b) Fat image



(c) T_2* image

Results

Figures (a), (b), and (c) are images of water, fat, and T_2* respectively, from a representative slice of an axial head scan, demonstrating the algorithm.

Discussion

TOP sampling combined with RIPE processing successfully separated chemical shift and T_2* effects, yielding images of water, fat, and T_2* simultanously from only 3 acquisitions.

References

[1] WT Dixon, Radiology, 153, 189-194, 1984 [2] GH Glover, JMRI,1,521-530, 1991 [3] QS Xiang and L An, JMRI, 7, 1002-1015, 1997 [4] QS Xiang, MRM, 56, 572-584, 2006 [5] LJ Anderson *et al*, Eur Heart J, 22, 2171-2179, 2001 [6] H Yu *et al*, JMRI, 26:1153-1161, 2007