An Iterative Algorithm Method for T2 mapping

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Introduction

While it is considered more effective for diseases to evaluate matrix changes that exist prior to surface morphological changes, rapidly quantitative analysis is currently one of challenges for MR techniques. Cartilage structures changes or collagen fiber degeneration detection by T2 mapping techniques was reported several years ago [1]. In order to minimize scan time, a multi-slice, multi-echo spin echo sequence for T2 mapping is introduced, but the result is inaccurate because of stimulated echoes and magnetization transfer contrast (MTC) [2]. To reduce stimulated echoes effect, an optimized refocusing pulse profile with wider slice profile than excitation pulse is applied to improve the accuracy of T2 measurements [3]. But the wider slice profile refocusing pulse would result in increased slice-to-slice cross talk significantly. Also stimulated echo error generated from inaccurate 180^0 refocusing pulse is not considered.

Here we introduce an iterative algorithm method (IAM) for T2 mapping which aims at compensating the T2 estimation error caused by the inaccuracy of 180^0 refocusing pulse. We calculate the effective flip angle of refocusing pulse from imaging data for every pixel, then compensate the data to remove the error effects from stimulated echoes before fitting the data to T2 delay exponential function curve.

Methods

The method of IAM can be described in the following 6 steps (Fig 1):

1. Fit the amplitudes of echoes (S_1, S_2, … S_n) to produce an original T2 value ($T2_{e1}$) by least-mean-squares (LMS) method according to the T2 decay exponential function of "$S = M_0 * e^{-TE/T2}$", M_0 is the initial magnetization.
2. Normally T1 value is much longer than *esp* (echo spacing time): T1 >> *esp*, so assume T1 = +∞. Use S_1, S_2, … S_n and $T2_{e1}$ to calculate the flip angle of refocusing pulse (*RF2)* from Bloch function by LMS method. The simplest example is using the first two echoes to calculate *RF2* from the Bloch function: S_1/S_2 = [sin(*RF2*/2)^2*exp(-*esp*/T2)]/[sin(*RF2*/2)^4*exp(-2**esp*/T2)+sin(*RF2*)^2*exp(-*esp*/T1)*exp(-*esp*/T2)/2]. If T1 value can be gotten from other information, it can also be used in this step to improve the accuracy of T2 measurement. Take white matter in brain on 1.5T MR system for example, the T1 value is less than 1000 ms. RF field is known to be smoothly varying from pixel to pixel, so a low spatial filter can be applied on calculated *RF2* mapping to reduce noise effect.
3. Calculating the compensation factors f_1, f_2, … f_n by simulating Bloch function with *RF2, T1* and $T2_{e1}$ for every echo, S_1, S_2, … S_n, respectively.
4. Using f_1, f_2, … f_n to compensate S_1, S_2, … S_n. Produce S_{1c}, S_2c, … S_{nc}.
5. Fitting the compensated data: S_{1c}, S_2c, … S_{nc} to produce a new T2 value: $T2_{e2}$.
6. Repeat step2 to step5 until the new calculated T2 value is stable.

MR images are acquired from a 1.5T GE Healthcare Signa whole body system. A FSE sequence with CPMG 8-echo train was used to create 8 separate images with different echo times. 4 phantoms were used to test the efficacy of IAM by varying the amplitude of refocusing pulse from 100% to 92% and 84% to generate more stimulated echoes. The results were compared with over-exciting method: using different ratio of the slice gradient amplitudes for the refocusing pulses to the excitation pulse (gscale_rf2) [3]. The results of combing IAM and over-exciting method were also shown. The T2 value calculated from data acquired by single spin echo sequence with different TE was regarded as the gold standard.

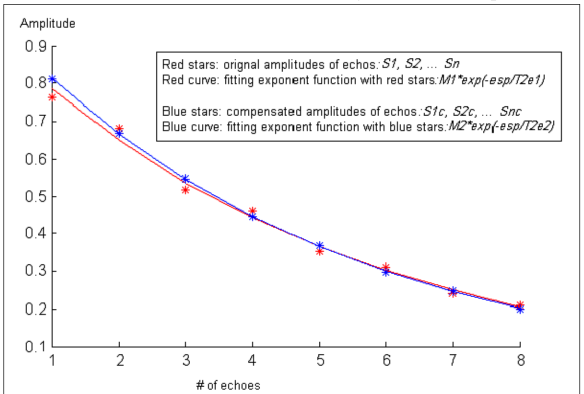

Fig 1. An example for the compensation of echoes amplitude before T2 fitting, which can reduce the error from the inaccuracy of refocusing pulse.

Results

T2 values of several different phantoms, gotten using above method, are listed in the table below. It shows improved T2 measurement for all except that of fat phantom. J-coupling existing in fat tissues affects the result of T2 measurement by FSE, which can't be corrected by IAM yet [4]. T1 = +∞ was used in compensation step.

Phantom/T1 (ms)	SE	100% refocusing pulse gscale_rf2 = 1		100% refocusing pulse gscale_rf2 = 0.56		92% refocusing pulse gscale_rf2 = 0.56		84% refocusing pulse gscale_rf2 = 0.56	
	T2 (ms)	Without IAM	With IAM	Without IAM	With IAM	Without IAM	With IAM	Without IAM	With IAM
1 ($NiCl_2$) / 137	117.7	128.8	118.4	119.9	116.8	120.6	117.8	121.6	115.8
2 (Agar) / 210	38.14	41.90	39.37	39.09	38.44	39.44	38.31	40.49	38.25
3 (Agar) / 1500	19.36	21.05	19.78	20.09	19.41	20.39	19.41	21.05	19.78
4 (Fat) / 234	42.25	/	/	85.14	83.77	89.89	87.92	98.72	93.88

Discussion

An iterative algorithm method (IAM) has been presented for FSE T2-mapping with minimal error caused by the inaccuracy of 180^0 refocusing pulse. The results of combining IAM with over-exciting method are more accurate than the results of single method used. The error can be reduced to about 1% even using 92% refocusing pulse (the flip angle of refocusing pulse is 165.6 degree). The error due to partial volume effect (different partial in one pixel excited by different flip angle of refocusing pulse) can be compensated about 90% by IAM, but can't be removed totally. Besides partial volume effect, the remained errors could come from inaccurate T1 value used in compensation step, MTC effect and image noise. Future improvements would be developing IAM to calculate T1-mapping, T2-mapping and RF2-mapping at the same time.

References

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