Optimal TE_1 and Echo Time Shift Combination for R_2* Estimation using T_2* IDEAL

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Introduction

Chemical shift based multi-point water-fat separation techniques can not only accurately quantitate fat percentage but also be used to calculate T_2* map, which is an important indication of iron accumulation in the tissue [1]. The noise performance of complex-fitting method is greatly affected by the selection of echo time combination [1, 2]. Cramer-Rao Bound theory has been used to find optimal echo time combination for high number of signals (NSA) for fat and water seperation [3]. However, the influence of R_2* to fat quantification has not been investigated comprehensively. Besides, the ideal echo time combination for T_2* and fat/water separation are usually different. Thus the optimal protocol for fat quantification may not suitable for the R_2* estimation .The purpose of this work is to evaluate the noise performance of R_2* estimation based on the complex-fitting approach. Preliminary results show that it is sensitive to echo times and it's necessary to use optimal protocols when the R_2* values are more interested, such as iron load studies. Besides, the effectiveness of Cramer-Rao Bound theory on searching the optimal echo combination for R_2* estimation is studied.

Methods

Three methods were used in this work: 1) NSA analysis based on Cramer-Rao bound. Fisher matrixes were built up using the method introduced by Pineda et al [2] with additional R_2* considered. 2) Monte Carlo simulation. Computer simulations were carried out to investigate the noise performance of R_2* estimation using T_2*-IDEAL algorithm with pre-calibrated multi-peak fat model using six equally spaced echoes [6]. Both TE_1 (1^{st} echo time) and ΔTE (echo time shift) increased with a step of 0.02 ms from 0ms to 2ms (water and fat are approximately in phase). The water/fat source signal was generated based on the six-peak fat spectrum model [4]. The T_2*-IDEAL algorithm with pre-calibrated multi-peak fat model was used to process the data. The fat ratio ranges from 0 to 80% with 1% increment. Two sets of different R_2* values for water and fat were assumed, $R^*_{2water}=52s^{-1}$, $R^*_{2fat}=64s^{-1}$ to simulate the ordinary conditions; and $R^*_{2water}=120s^{-1}$, $R^*_{2fat}=200s^{-1}$ to simulate the iron overload conditions. Complex Gaussian distributed noise was added to the source signal with SNR of 100dB. Since the NSA of R_2* from simulation is not as meaningful as fat/water magnitude, only the variance of R_2* was calculated here. 3) Phantom study. Seven emulsified water-fat phantom were built using a procedure described in [5] with with fat-fractions of 0%, 10%, 20%, 30%, 40%, 60%, 100%.TE_1=1.89ms and seven different ΔTEs (0.38ms, 0.7ms, 0.9ms, 1.1ms, 1.36ms, 1.6ms, 1.9ms) were repeated 60 times on a 3T scanner (Achieva, Philips Medical System) using a birdcage RF coil. Other imaging parameters: FOV 240mm×198mm, image matrix=160×160. The computation algorithm and parameters were the same as the Monte Carlo simulation.

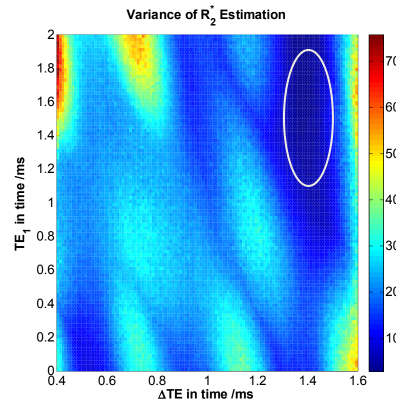

Fig.1 The simulation result of R^*_2 variance when $R^*_{2water}=52s^{-1}$, $R^*_{2fat}=64s^{-1}$, the circled area indicate the ideal protocol of echo shift combination when R^*_2 is interested.

Results

Fig.1 only showed Monte Carlo simulations for the condition when $R^*_{2water}=52s^{-1}$, $R^*_{2fat}=64s^{-1}$. Different conditions, [$R^*_{2water}=52s^{-1}$, $R^*_{2fat}=64s^{-1}$] or [$R^*_{2water}=120s^{-1}$, $R^*_{2fat}=200s^{-1}$], had no significant difference in R_2* variance pattern. Every point in this figure represents the highest R_2* variance estimation among the fat ratio from 0% to 80%. Only the result of 0.4ms<ΔTE<1.6ms was shown here since when 0ms<ΔTE<0.4ms and 1.6ms<ΔTE<2ms , the variance of R^*_2 is too big. It is shown that when $TE_1 \in (1.4ms, 2ms)$ and $\Delta TE \in (1.3ms, 1.5ms)$ (circled area), the R^*_2estimation has the lowest variance and thus is the optimal choice for stable R^*_2 calculation. The results from the phantom experiments in Fig. 2 show that when ΔTE=1.36ms and 1.6ms the R^*_2 variance is more stable than other ΔTE choices. When, $\Delta TE \le 0.6ms \;\; and \;\; > 1.6ms$, R^*_2 variance is much bigger. This is consistent with the Monte Carlo simulation results. However, the NSA results based on Cramer-Rao theory in Fig.3 are not consistent with the Monte Carlo simulations as well as phantom experiments.

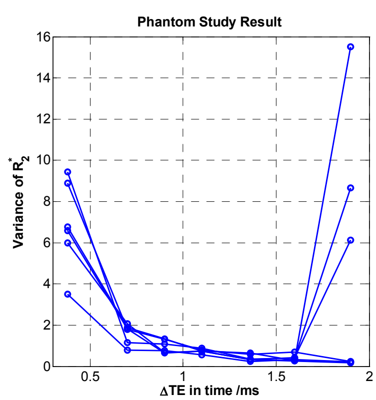

Fig.2 Variance of R_2* from phantom experiment.

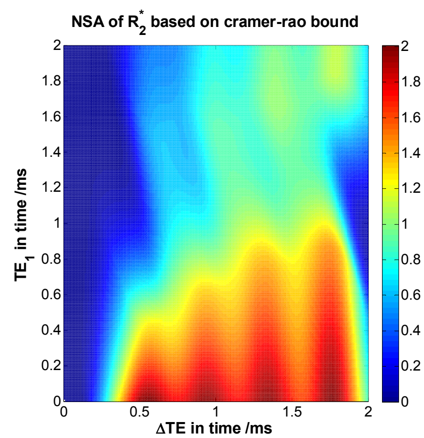

Fig.3 NSA of R_2* estimation based on Cramer-Rao theory.

Discussion and Conclusion

Based on the Monte Carlo simulations and phantom experiment studies, the ideal TE_1 and ΔTE combination can be found for the complex-fitting method when T_2* quantification is interested. The results are different from those when water and fat quantification are of interest [2]. The difference between simulation and Cramer-Rao theory may be caused by the nonlinear relationship between the source signal and R_2*. According to the definition of NSA in [2]: $NSA(\rho) = \delta_s^2 / \delta_\rho^2$ Where ρ is the parameter to be estimated and δ_s^2 is the variance of the measured images. Unlike the water or fat quantification, the noise of measured images non-linearly affects the estimation of R_2*. Our other simulations also show that when keeping the SNR constant while improving the magnitude of source image, the variance of R_2* is a constant. So NSA based on Cramer-Rao theory might not directly direct the choice of echo time combination for estimating R_2*.

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References: [1]. Reeder et al, MRM 2004;51:35-45. [2]. Pineda et al, MRM 2005; 53:625-635. [3]. Chebrolu et al JMRI 2010; 32:493-500. [4]. Hamilton et al, NMR Biomed 2011; 24:784-790. [5]. Bernard et al JMRI 2008 27:192-197. [6] Yu et al, JMRI 2007; 26:1153-1161.