Myocardial T2* Measurement in Iron Overloaded Thalassemia: An Ex Vivo Study

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Introduction

Myocardial T2* values derived from MRI has been increasingly used for iron quantification in thalassemia (1-3). This technique has produced good quality images and gained reasonable reproducibility (2). However, little attention has been paid to the methods of deriving myocardial T2* from the exponential decay curve. Noise analysis, model selection and curve fitting algorithm optimization can all play an important role to further improve this technique in terms of accuracy and reproducibility. For thalassemia patients with heavily iron loaded hearts T2* is short (<10ms) giving rise to a rapid decay in signal intensity. In this scenario, the signals of later echo images are likely to be buried in the ambient noise and artifacts, and consequently can not be used for T2* curve fitting. Currently, there is no consensus on how to process these later images. In practice, some researchers fit the decay curve with a bi-exponential model, others with an exponential plus a constant offset and some just truncate the fit after the first few points to make the curve fitting better. Therefore, there is a need to clarify these issues for more accurate T2* measurement and hence improve both the diagnosis and management of the thalassemia patients.

Material and Methods

An *ex vivo* heart from a 30 year old male was scanned on a 1.5T whole-body Siemens Sonata system using a four-element cardiac phased array coil. A special chamber was constructed to maintain the heart and the temperature was kept at 37.0 °C. Multiple 5 mm short axis slices were positioned between the base and the apex of the left ventricle. The gradient-echo sequence developed for *in vivo* scan (2) was adjusted for the *ex vivo* scan. The parameters were kept same apart from the field of view which was tailored for the small *ex vivo* heart scan giving a voxel size of 1.2x1.2x5 mm^3. Images were acquired at sixteen echo times (3.1–39.1 ms, with 2.4 ms increments). For each slice, multiple scans were repeated with varying NEX of 1, 2, 4, 8, 16, and 32 to acquire images with different signal-to-noise ratio (SNR). The study was approved by the local ethics committee.

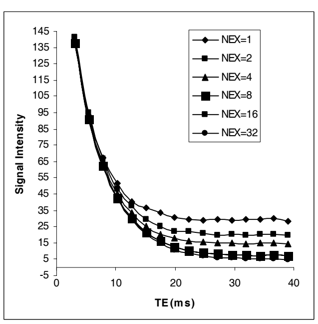
The corrected signal intensity *A* for a given region of interest (ROI) can be calculated by $A^2 = E(M^2) - 2\sigma^2$, where M is the measured signal intensity and σ^2 is the variance of the background noise. A rectangular ROI of 2048 pixels free from myocardial signal was dawn in each image and the average of its power values was measured as $2\sigma^2$.

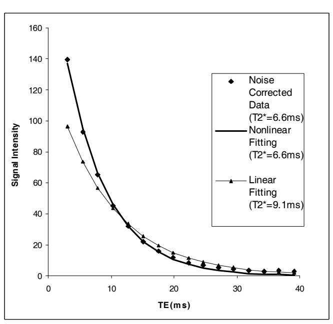
Three models were evaluated in the current study. The simplest is the mono exponential decay model with an equation of $SI = P_0 \bullet e^{-TE/T2^*}$, where P_0 represents a constant of magnetization, TE represents the echo time and *SI* represents the image signal intensity. In this approach, a truncating method was proposed to combine with the mono-exponential model to deal with low SNR data points (*truncating model*), where data points representing images of SNR<2 were discarded. A second model adds an offset to account for noise and artifacts (*offset model*) $SI = P_0 \bullet e^{-TE/T2^*} + C$ where C is a constant to be estimated. The third is the *bi-exponential model* $SI = P_a \bullet e^{-TE/T2^*_a} + P_b \bullet e^{-TE/T2^*_b}$.

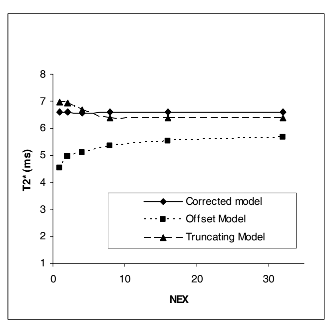
The simplest form of curve fitting is linear regression and the Levenberg-Marquardt method of nonlinear estimation was also employed for a comparison. For both the offset model and bi-exponential model, there is no linear method available and hence the Levenberg-Marquardt algorithm was adopted. All the analysis was carried out on a PC using MATLAB and Thalassemia-Tools software (a plug-in of CMRtools, Cardiovascular Imaging Solutions, London).

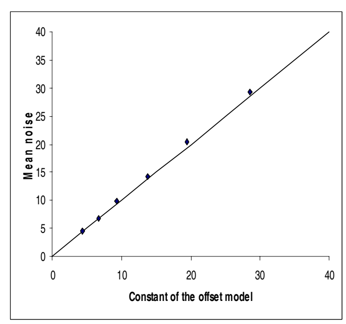
Results and Discussion

Fig. 1 demonstrates that the background noise mainly affects low SNR later echo images. While the nonlinear algorithm fitted the noise corrected data perfectly, the linear algorithm caused apparent errors (Fig.2). The T2* estimation after noise correction is accurate and reproducible. Fig. 3 shows that the T2* value from the offset model increases with NEX (max difference of 23%) but generally underestimates the true value. Also, T2* values obtained with truncating model are closer to the true value (Fig. 3). Fig. 4 shows that the estimated constant of the offset model is equivalent to the mean value of the noise. Finally, the first component obtained using the bi-exponential model was always the same as the T2* obtained using the offset model.









Conclusions

The results show that the noise is non-additive for magnitude MRI images but can be corrected for accurate and reproducible T2* measurement. They also suggest that the T2* decay curve of the iron overloaded myocardium is mono-exponential and that the nonlinear curve fitting algorithm should always be used for correct T2* measurement. Both the offset and bi-exponential models underestimate T2* values by an amount dependent on the noise which renders them less reproducible. Although the truncating model is more subjective, it proves to be more accurate and stable than the offset or the bi-exponential model. This study shows that a correct model and proper interpretation of the results can improve both the accuracy and reproducibility of T2* measurement for quantifying myocardial iron in thalassemia. Further research is needed to address noise and artifacts due to motion and blood for *in vivo* scans.

Acknowledgement

This work is part of the project “MR OF HEART IRON: T2*/T2 CALIBRATION & APPLICATION”, supported by NIH Grant: R01 DK66084-01.

References

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