Automated T2* Mapping with Susceptibility Removal for the Assessment of Cardiac Iron Content

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Introduction: Hematological conditions such as β-thalassemia major and sickle cell disease often require blood transfusions for disease management. Heavy iron accumulation in the heart can occur from multiple transfusions and can lead to life-threatening conditions such as arrhythmias and impaired left ventricular function [1-4]. One of the most commonly used methods for noninvasive cardiac iron measurements is T2* mapping of the mid-papillary short axis of the left ventricle, where low T2* values (<20 ms) are indicative of a higher risk of iron-induced cardiac complications [2-4]. Typically, T2* measurements are made in a region of interest (ROI) in the intraventricular septum (IS) to avoid T2*-lowering susceptibility effects from lung, liver, and epicardial fat [5]. In this work, we implemented and evaluated an automated method that incorporates an autoregressive moving average (ARMA) model [6] of the complex signal from a multi-gradient echo (mGRE) acquisition to map the field and T2* of the whole left ventricle (LV). Using the field map, areas of high susceptibility due to various causes including air/tissue interfaces, deoxygenated blood in the cardiac veins and epicardial fat are identified and extracted without additional user input for automated ROI analysis in the T2* based assessment of cardiac iron.

Methods: Twenty-four patients with suspected iron overload were scanned in accordance to an IRB-approved protocol. All patients were examined on a 1.5T scanner and mGRE short-axis images were obtained in a single breath-hold. Echo times (TE) ranged from 1.5ms to 21.3ms at 1.8ms increments (ETL 12). Other imaging parameters were: flip angle 25º, slice thickness 8mm, matrix 128 × 128 and FOV 300-400mm depending on the patient size. Magnitude and phase images were obtained as inputs for the ARMA algorithm, which then calculates the chemical shift and T2* by assuming a linear combination of complex exponentials with noise. This algorithm characterizes the signal as a rational polynomial in the z-domain via the z-transform and the poles of the polynomial corresponds to the field and T2*[6]. A ROI was selected encompassing the entire LV. This is the only user interaction needed for the T2* calculation. From these field gradient values in the ROI, the median gradient was obtained and all voxels with gradients above the median were excluded from the final ROI and T2* calculation, respectively. The algorithm identified extraneous voxels that are not connected to other voxels and omitted them from the T2* calculation. The ARMA-fitted T2* values of the remaining area are used to obtain mean values and standard deviations (std) for T2* in the LV.

Results: Table 1 outlines the mean T2* measurements between the entire LV, IS, and ARMA-defined regions over all 24 patients. There was no statistical difference in the mean T2* values between the IS and ARMA regions (p=0.31). The population mean T2* of the entire LV was lower than the T2* measurement from the two ROIs (IS and ARMA) (p<0.01). The mean (std) IS ROI volume was 21.1% (3.4%) of the volume of the left ventricle. In comparison to the IS volume, the volume for T2* measurements defined by the ARMA model was 39.8 (5.5%) (p<0.0001) of the whole LV. Although, on average, the volume for the ARMA-defined region was significantly higher, the coefficient of variation (CoV) of the T2* measurements between the IS and ARMA did not differ from the IS CoV. Compared to the LV CoV, there was an 18% decrease in the CoV calculated by the ARMA technique (p<0.0001). In evaluating the four regions of the LV, there were areas where susceptibility was consistently high in our patient cohort regardless of iron-overload. Table 2 displays which areas were used for ARMA-defined T2* measurements, which corroborates with other studies investigating T2* variations in the LV [7,8]. An example of the regions selected by the ARMA method is shown in figure 1. As shown in [7,8], the IS had the least susceptibility as seen in figure 1.

Discussion: By using the field map provided by the ARMA model of the mGRE acquisition, areas of high susceptibility not due to iron were automatically identified and removed to reduce the T2* variation in the left ventricle. With this technique, T2* values were reported with higher precision providing more volume for T2* measurements than with conventional manual segmentation. With this method, the user only outlines the LV, then the T2* is automatically calculated in areas where susceptibility from various sources is relatively minimal. Therefore, this method shows potential in reducing bias in manually-selected T2* measurements for iron overload assessment.