Feasibility of Cardiac Magnetic Susceptibility Measurement in Patients with Iron Overload

Z. J. Wang[1,2], Z. Chu[1,2], R. Muthupillai[2,3], R. Krishnamurthy[1,2], D. H. Mahoney[1,2], B. U. Mueller[1,2], K. L. McClain[1,2], R. Fischer[4], T. Chung[1,2]

[1]Texas Children's Hospital, Houston, Texas, United States, [2]Baylor College of Medicine, Houston, Texas, United States, [3]Philips Medical Systems, Cleveland, Ohio, United States, [4]Children's Hospital & Reaserch Center Oakland, Oakland, California, United States

Introduction

Blood transfusion therapy is life saving for patients with thalassemia [1], and reduces the pain from crisis and chance of stroke in sickle cell disease [2]. However, long-term transfusions, if not treated with chelation therapy, will lead to iron overload. Iron overload in the heart, mostly in the left ventricle (LV), is the leading cause of death for thalassemia patients receiving chronic transfusions [1]. Although liver iron concentration accurately reflects the total body iron store, it is not well correlated with the cardiac iron level. To manage cardiac overload and prevent heart failure, it is essential to monitor the cardiac iron directly, independent of the liver. Life-saving chelation therapy could be used earlier on patients with low liver iron level if the cardiac iron level is found to be high [3]. A method for measuring the cardiac iron concentration in patients has not been available in clinical practice. The purpose of this work is to demonstrate the feasibility of measuring the magnetic susceptibility of the heart for patients with iron overload.

Materials and Methods

MRI studies were conducted on a 1.5 T Gyroscan Intera whole body clinical scanner. The cardiac susceptometry data acquisition protocol used a 3D-TFE dual echo technique with cardiac triggering and navigator gating and tracking [4]. The images were acquired in the transverse orientation during diastole to minimize the effects of cardiac motion. The typical parameters for data acquisitions were: slab thickness = 20 - 30 mm, FOV = 300 mm, TR/TE1/TE2 = 9.8/4.7/7.1 ms, sampling pixel size 3.6x0.75x0.75 mm^3, reconstructed pixel size 1.8x0.6x0.6 mm^3, NSA = 1, water-fat shift = 0.3 pixel. Full motion compensation was used. Each data set was acquired in 7 to 10 minutes. The MRI signal was received using a synergy cardiac coil. In most cases the images with TE of 4.7 ms were sufficient for data analysis. The second TE data set was helpful to distinguish muscle and fat, if they looked similar on the first data set. From the phase map of the first echo, epi-myocardial magnetic susceptibility was estimated using intercostals muscle as reference, and endo-myocardial susceptibility was estimated using the oxy-blood inside the LV as reference using the relationship [5]:

$$\Delta\phi = 2\pi \cdot TE \cdot f_0 \cdot \frac{\Delta\chi}{3}(1 - 3\cos^2\theta_n + S_{hf}) \quad (1)$$

where $\Delta\phi$ is the phase difference between the myocardium and the reference, $\Delta\chi$ is the difference in magnetic susceptibility between the myocardium and the reference, TE is the echo time, f_0 is the transmitter frequency, θ_n is the angle between B_0 and the normal direction of the interface and S_{hf} is the hyperfine shift term, assumed equal to –0.13 [5]. Data analysis was performed using internally developed software written in IDL (Research Systems Inc., Boulder, CO). For comparison, cardiac T2* measurement [6,7] in a single slice was also carried out using a navigator gated, ECG triggered technique in the same session. The T2* pulse sequence used a train of 17 gradient echoes (TE from 1.5 to 15 ms) after each RF excitation pulse. T2* was quantified from manually draw left ventricular (LV) wall. The study was approved by the Institutional Review Board. Informed written consent was obtained in all cases.

Results

Five patients with thalassemia or sickle cell disease were studied (Table 1). Figure 1 demonstrates the cardiac susceptibility measurement in Patient 2. The left panel shows the phase and amplitude images. The LV is hypo-intense on the amplitude image due to a decrease in T2*, and hyper-intense on the phase image due to an increase in susceptibility. The right panel shows the phase profile along the normal direction of the interface. The correlation between 1/T2* and epi-myocardial susceptibility is shown in Figure 2.

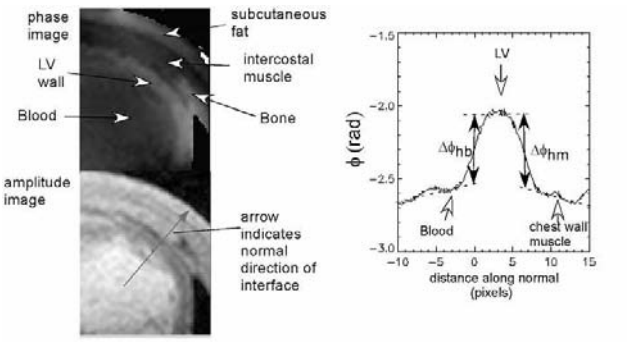

Fig. 1. Cardiac susceptibility measurement in a patient.

Table 1. Correlation of 1/T2* and LV susceptibility in patients.

I.D.	Age/ gender	Disease	1/T2* (s^{-1})	Magnetic susceptibility	
				Endo-myocardium (a)	Epi-myocardium (b)
P1	11y/f	Thal	22.2	0.00x10^{-6}	0.07x10^{-6}
P2	8y/m	Thal	87.0	0.89x10^{-6}	0.95x10^{-6}
P3	10y/m	Thal	357.1	7.60x10^{-6}	5.92x10^{-6}
P4	7y/f	SCD	23.1	0.00x10^{-6}	0.38x10^{-6}
P5	9y/m	SCD	22.3	-0.33x10^{-6}	0.25x10^{-6}

(a) Relative to oxy-blood. (b) Relative to intercostal muscle.

Discussion and Conclusions

It was proposed previously that a lipid layer on the surface of the left ventricle may be used as reference for epi-myocardial magnetic susceptibility quantification [4]. However, in some young patients, the lipid layer may be too thin. We found that intercostal muscle was a reliable reference for our patient population. We anticipate this approach would be applicable to most patients. Furthermore, the flow effect on the phase of the blood inside LV is minimal during diastole due to a short TE and flow compensation. The blood can be used as reference for endo-myocardial susceptibility measurement.

Magnetic susceptibility can be directly converted to a tissue iron concentration. Correlation of susceptibility with T2* in a reasonably large patient population will eventually allow us to convert a cardiac T2* value to a heart iron concentration. This will have important impact on patient management.

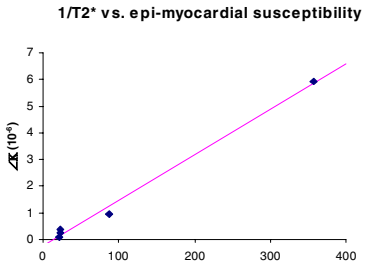

Fig 2. Correlation between 1/T2* and epi-myocardial susceptibility (r = 0.997).

References

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