EN ROUTE TO PROBING HUMAN MYOCARDIAL MICROSTRUCTURE IN VIVO USING SUSCEPTIBILITY BASED MRI AT 7.0 T

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Target audience: This work is of interest for basic MR researchers, imaging scientists, clinical scientists, radiologists and cardiologists.

Purpose: The complex microstructure of the myocardium is pivotal for regional and global cardiac function and can provide important information about the underlying (bio)physical principles and (patho)physiological mechanisms [1]. Today, invasive histology and diffusion weighted imaging (DWI) are commonly used to probe myocardial microstructure. In vivo DWI of the human heart has been described, but remains challenging due to its propensity to cardiac and respiratory motion [2, 3]. Susceptibility weighted MRI has been shown to reveal myocardial microstructure in the perfused ex vivo rat heart and holds the promise to be less sensitive to motion than DWI [4]. Susceptibility based MRI provides excellent contrast which can be used to investigate tissue microstructure and track fibers in the brain [5, 6]. Recognizing this opportunity the work explores the applicability of susceptibility based MRI for probing myocardial microstructure. Since susceptibility effects increase with field strength, it is conceptually appealing to pursue susceptibility sensitized MRI at ultrahigh magnetic fields [7]. For this purpose this work examines the applicability of MRI phase contrast and the feasibility of myocardial SWI [8] of the in vivo human heart at 7.0 T. For comparison myocardial T_2^* mapping was performed at 7.0 T.

Methods: In a pilot study, volunteer experiments with healthy volunteers without any know history of cardiac disease, were conducted using a 7.0 T whole body system (Magnetom, Siemens Healthcare, Erlangen, Germany). The scanner was equipped with a gradient system (Siemens Healthcare, Erlangen, Germany, Gmax=40 mT/m, slew rate=200 mT/m/ms). A 16 channel transceiver array tailored for cardiac imaging was used for excitation and signal reception [9]. For SWI of the heart and for T_2^* mapping a cardiac triggered multi echo gradient echo technique ((TE = 2.04-10.20) ms, spatial resolution = (1.1x1.1x4.0) mm^3) was used [10]. A low flip angle (α=20°) was used to preserve myocardial signal. Midventricular short axis views and four chamber views were acquired. An MR stethoscope (MRI.TOOLS GmbH, Berlin, Germany) was applied for cardiac gating. Volume selective shimming was carried out prior to data acquisition to make sure that the image contrast is not dominated by macroscopic B_0 inhomogeneities but rather by microscopic susceptibility changes. The shim volume was adjusted to cover the whole heart. SWI processing was applied according to [8] with the exception that no minimum intensity projection was performed since single slices were acquired in our proof-of-principle study. A positive phase mask was calculated from the phase image (TE=6.12) and applied to the magnitude images with a mask exponent of 8. For later echo times the SWI processing caused a signal loss in the right ventricular lateral myocardium due to a phase artifact.

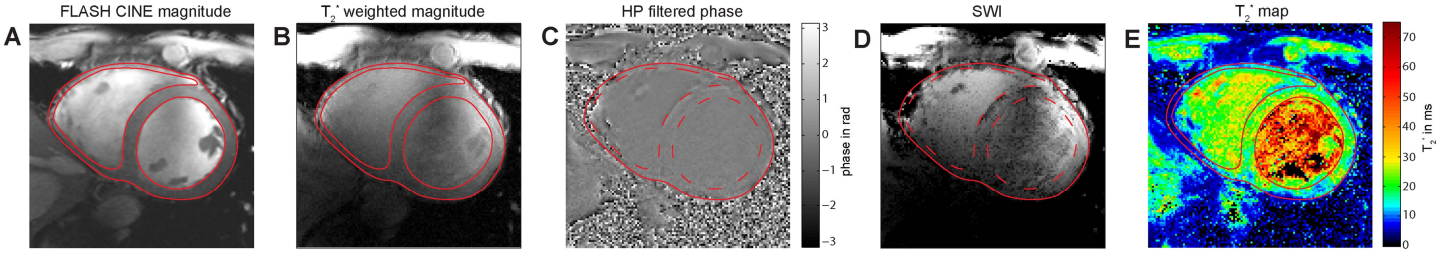

Figure 1: A) FLASH CINE magnitude, **B)** T_2^*-weighted magnitude and **C)** highpass filtered phase image (TE_{eff} 8.16ms) of a mid-ventricular short axis view of the human heart obtained at 7T. **D)** Corresponding SWI image and **E)** T_2^* map. Please note the difference in T_2^* for the blood in left and right ventricle as well as the T_2^* changes in the ventricular septum.

Results: Highpass filtered phase was found to be rather uniform across the heart for the echo times used as demonstrated in Figure 1C. The T_2^* map (Fig. 1E) shows a large difference in T_2^* between right and left ventricular blood which can be attributed to the increased fraction of paramagnetic deoxyhemoglobin in the right ventricle. A minor change in T_2^* obtained for the ventricular septum is visible from endo- to epicardial layers [10]. Despite the significant T_2^* difference between right and left ventricular blood the highpass filtered phase map shows only little phase differences for both ventricles (Fig 1C). The interface between the right ventricle and the septum is clearly visible in the phase images as well as some subtle trabecular structures in the right ventricle. These regions show enhanced contrast in the SWI image (Fig. 1D) versus the magnitude image (Fig. 1B). Also a slight signal attenuation for the blood in the left ventricle can be detected in the SWI image.

Discussion and Conclusion: En route to probing human myocardial microstructure in vivo using susceptibility based MRI our results demonstrate that further to 2D CINE gradient echo imaging and T_2^* mapping, phase contrast and SWI of the human heart are feasible at 7.0 T. The results show that highpass filtered phase is rather uniform across the heart in healthy volunteers at 7.0 T, but shows small changes in the ventricular septum. Hence phase based SWI processing provides only little contrast enhancement. This is surprising, since T_2^* values which are also related to susceptibility show substantial changes across the heart. Further research is required to examine the various influences on image phase in the heart such as tissue magnetic susceptibility, paramagnetic deoxyhemoglobin, tissue microstructure and blood flow. We anticipate to extend our explorations to quantitative susceptibility mapping [11] to overcome the non-local nature of image phase and to provide local information about microscopic susceptibility. Since the susceptibility effects depend on the tilt angle between myocardial fibers and the external magnetic field [12], susceptibility-based imaging at 7.0 T holds the promise to contribute to explorations into in vivo probing of myocardial fiber structure.

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