Imaging and visualization of cardiac muscle microstructure in rats using high-resolution MRI

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TARGET AUDIENCE: MRI scientists, radiologists and cardiologists.

PURPOSE:

Pathological changes in the cardiac muscle are major causes of death and disability in heart diseases. Ischemia of cardiac muscle leads to necrosis and myocardial infarction. Abnormal iron deposition is an important reason for heart failure in patients with transfusion-dependent anemia such as myelodysplasia, sickle cell anemia and beta thalassemia major [2]. Diffusion tensor imaging (DTI) is highly sensitive to 3D diffusion of free water in the tissue including muscle fibers. Susceptibility-weighted imaging (SWI) increases the conspicuity of iron-rich structures. The objective of this study is to identify the microstructural characteristics of cardiac muscle in rat hearts using multiparametric MRI.

METHODS:

Animal model preparation: The hearts of Sprague Dawley rats (n=4) were excised and then quickly perfused by 1×PBS to clean the residual blood from the heart and vessels. The hearts were then fixed by 4% phosphate buffered paraformaldehyde (PFA) solution for 14 hours and then were embedded in 2% agar phantoms for the following imaging procedures. ***MRI data acquisition:*** The samples were placed in a Bruker Biospec 7 T MRI system (Bruker Corporation, Billerica, MA). An RF volume coil with an inner diameter of 25 mm was used to transmit/receive the signals. The SWI measurements used a 3-dimensional FLASH sequence that is very sensitive to the presence of paramagnetic substances such as iron-compounds. 3D FLASH sequence was performed by using a voxel resolution of 0.078 × 0.078 ×0.156 mm^3, 3D matrix=256 × 256 × 128, TE/TR=5ms/60ms, FOV=45mm × 45 mm, NEX=20, scanning time=11 hours. Then, the cardiac fiber orientations were imaged with a spin-echo DTI sequence in 30 gradient directions (b=0, 1000 s/mm^2) at the 0.234 mm isotropic resolution, NEX=4. ***MRI image analysis:*** The SWI images were generated with a filter full-width of 96 and a phase mask multiplication of 4 during the image data collection. The SPIN software (www.mrimaging.com) was used for the image processing. DTI images were processed by the DSI Studio software (http://dsi-studio.labsolver.org/) to generate the muscle fibers of the hearts. ROIs were manually drawn on the walls of the left ventricle and papillary muscle at the equator level.

RESULTS:

(1) SWI can clearly identify the anatomical structure of the rat hearts including atria, ventricle, papillary muscle, mitral and the arterial and venous system (Figure 1). (2) High-resolution DTI imaging clearly identified the extract cardiac fiber orientations and related anatomies of the hearts (Figure 2). (3) The mean diameters of papillary muscle of rat hearts were 2.2 ±0.5 and 2.7 ± 0.4 mm, respectively. The mean thickness of anterior, posterior, interventricular septum and lateral left ventricular wall at equator level was 3.5±0.4, 3.3±0.2, 2.9±0.1 and 3.0±0.3 mm, respectively.

CONCLUSION:

(1) SWI provided useful information to explore the anatomical characteristics of cardiac muscle including left ventricle, atria and papillary muscle as well as mitral valve and venous and arterial system in the rats. (2) DTI muscle tractography provides anatomical details regarding cardiac muscle orientations and distributions. (3) All of these measures have important clinical implications to explore pathological changes in cardiac muscle, such as ischemia, necrosis and abnormal iron depositions. The experimental model could be potentially used to monitor the effectiveness of treatment.

REFERENCES: (1) Cheng et al,. Stroke.2013; 44: 2782-2786. (2) Queiroz-Andrade et al,. RadioGraphics,29, 75-1589.

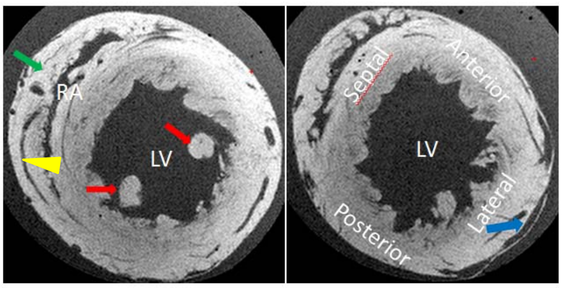

Figure 1. SWI images of a rat heart (axial view). SWI imaging can clearly identify the left ventricle (LV), right atria (RA), papillary muscle (red arrows), right coronary artery (yellow arrow) and cardiac vein system (blue arrow). The ROIs were drawn to measure papillary muscle and thickness of LV wall at anterior, posterior, septal and lateral walls.

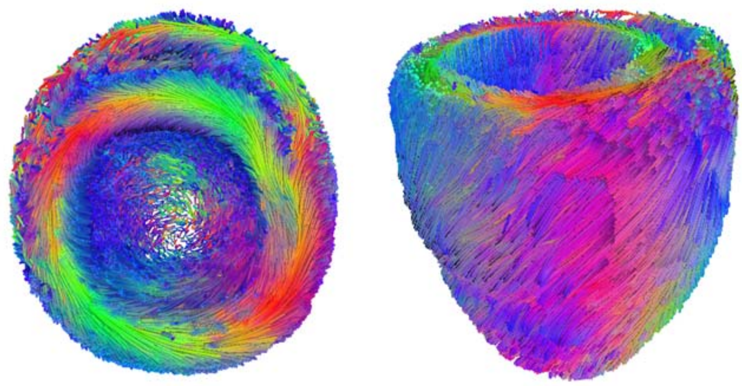

Figure 2. Color coded DTI tractography of a rat heart. 3D cardiac muscle fibers of left ventricle were clealy identified on the DTI images on the axial (left) and saggital view (right).