Imaging Three-Dimensional Myocardial Mechanics in Mice using Volumetric Spiral Cine DENSE

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Introduction. MRI of myocardial mechanics in mice enables the investigation of the roles of individual genes and experimental therapies in cardiac function. While two-dimensional methods such as tagging, harmonic phase analysis (HARP), and displacement encoding with stimulated echoes (DENSE) have previously been demonstrated in the mouse heart (1-3), myocardial mechanics are more comprehensively assessed using three-dimensional (3D) methods. In this study, we sought to develop and evaluate 3D cine DENSE acquisition and analysis methods for measuring 3D mechanics in normal mice.

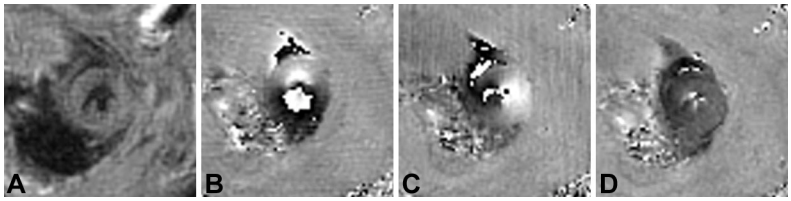

Figure 1. Example online reconstructed images of a mid-ventricular partition of one mouse. A: magnitude-reconstructed image. B-D: phase-reconstructed images with displacement encoded in the vertical, horizontal and through-plane directions, respectively.

Methods. An ECG-gated segmented 3D spiral cine DENSE pulse sequence was implemented on a 7T MRI scanner (Bruker Clinscan, Germany). A stack-of-spirals *k*-space trajectory was employed for 3D spatial encoding due to its rapid data acquisition, and short echo time. Three-point phase cycling was used for artifact suppression (4), four-point displacement encoding was used to efficiently measure 3D motion (5), and low-resolution field maps were acquired for online spiral deblurring (6). Magnitude and phase images were reconstructed online, and semiautomatic segmentation methods (7) followed by automatic strain, twist, and torsion calculations (8) were implemented offline. In accordance with protocols approved by the local animal care and use committee, 7 healthy C57Bl/6 mice were studied. During imaging, mice were anesthetized with 1.25% isoflurane, positioned in a birdcage RF coil with diameter of 30 mm and active length of 28 mm, and maintained at 36°C. ECG and respiration were monitored using an MRI-compatible system for small animals (SAII, Stony Brook, NY), and were used to trigger data acquisition. After localizer imaging, 3D cine DENSE imaging was applied. The parameters included voxel size = 0.25 × 0.25 × 0.4 mm^3, number of partitions = 21, flip angle = 15°, TR = 7 ms, TE = 0.69 ms, number of spiral interleaves = 36, number of cardiac phases = 14, and displacement encoding frequency = 1.0 cycles/mm. To further ensure minimal blurring, the readout samples per interleave were set to 1824, and the ADC dwell time was set to 2000 ns, limiting the spiral readout duration to 3.6 ms. The field of view was 28 × 28 × 8.4 mm^3, covering the entire mouse left ventricle (LV), as the longitudinal dimension of the mouse LV is approximately 6 mm. Scan time was approximately 23 minutes, depending on heart and respiratory rates.

Results. Volumetric cine DENSE data of all 7 mice were analyzed. Semiautomatic segmentation took approximately 1 hour per mouse. Three-dimensional mechanics were quantified throughout the LV, including the 3D normal strains (Err, Ecc, and Ell), shear strains (Erc, Erl, and Ecl), twist, and torsion. Example online reconstructed images of a mid-ventricular partition of one mouse are shown in Figure 1. Example maps of the 3 normal strains at the basal, mid-ventricular and apical partitions of one mouse are shown in Figure 2. Average mid-ventricular strain-time curves for the three normal strains and the three shear strains across all 7 mice are shown in Figures 3 and 4, respectively. All strain values are in close agreement with previous studies. Myocardial twist and torsion, similar to previous measurements in humans, are shown in Figure 5.

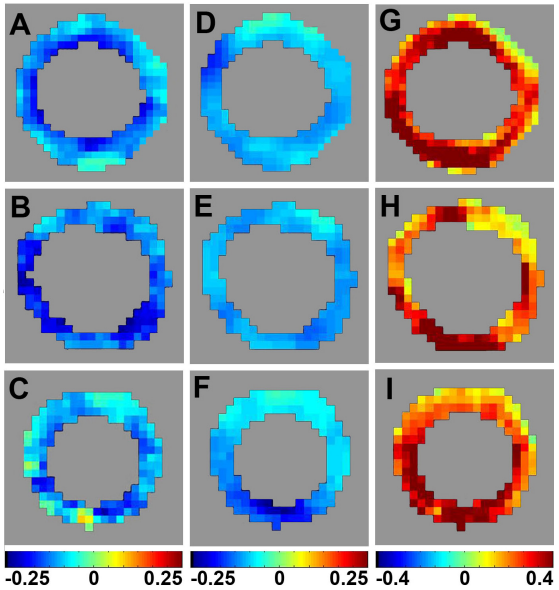

Figure 2. Example Ecc (A,B,C), Ell (D,E,F) and Err (G,H,I) strain maps of one mouse for basal (A,D,G), mid-ventricular (B,E,H) and apical (C,F,I) partitions, respectively.

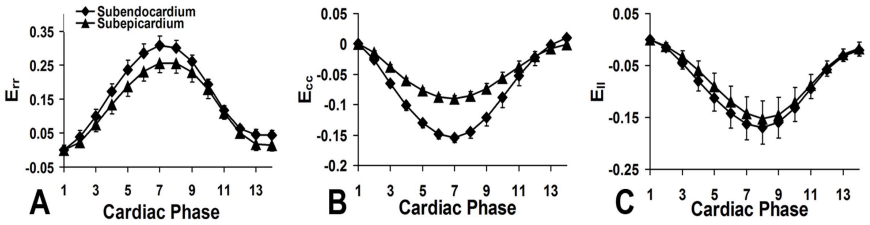

Figure 3. Normal mid-ventricular subendocardial and subepicardial strains (A: Err, B: Ecc, C: Ell) measured by 3D cine DENSE in 7 mice.

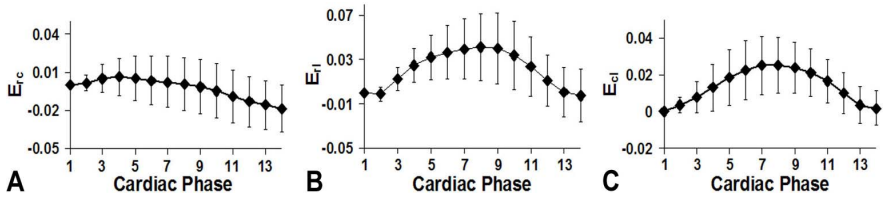

Figure 4. Normal mid-ventricular shear strains (A: Erc, B: Erl, C: Ecl) measured by 3D cine DENSE in 7 mice.

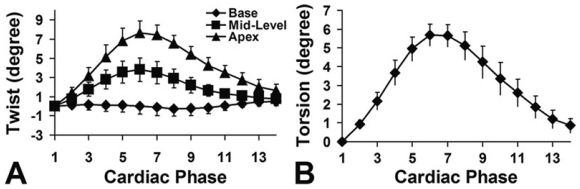

Figure 5. Normal LV twist and torsion measured by 3D cine DENSE in 7 mice.

Conclusions. Using these data acquisition and analysis methods, a comprehensive assessment of 3D myocardial mechanics in mice can be performed with a scan time of less than 25 minutes and a segmentation time of about an hour. In future studies, off-resonance blurring of spiral images could be reduced using better shimming or deblurring methods. These techniques have great potential for evaluating the effects of experimental therapies and for phenotyping genetically-engineered mice.

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