Characterization of 3D Myocardial Wall Motion in the Mouse with MR Tagging

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Introduction

Genetically manipulated mouse models are playing an important role in the investigation of human cardiac diseases. The development of rapid, noninvasive methods for characterizing ventricular motion in these animals can provide new opportunities to elucidate the molecular mechanisms of myocardial function. MR tagging provides the first opportunity to examine regional myocardial deformation noninvasively, as well as to evaluate it more comprehensively and serially. The utility of MR tagging in quantifying 2D myocardial strains in small animals has been demonstrated recently. However, there has been limited effort on 3D strain quantification in mice.

The current study developed a novel 3D myocardial strain analysis method combining HARP and homogeneous strain analysis, which allows fast 3D strain calculation. The radial, circumferential, and longitudinal strains were quantified in mice. To investigate the accuracy of strain calculation from 2D MR tagging, radial and circumferential strains calculated from 2D tagged short-axis images were directly compared with those calculated from full 3D data set.

Methods

MR Imaging 2-month-old C57/BL6 mice (n=6) were scanned on a Varian (Varian Associates, Palo Alto,CA) 4.7T scanner with a 2.5 cm surface RF coil. Tagged images of five short-axis (SA) slices were acquired from apex to base with 1 mm slice thickness. Four radially distributed long-axis (LA) slices were acquired every 45°. ECG triggered gradient-echo sequece were applied with SPAMM1331 using the following imaging parameters: TE, 3 ms; field of view, 4 cm × 4 cm; matrix size, 256×128; tag resolution, 0.5 mm. TR was adjusted according to the heart rate such that 15 frames were acquired per cardiac cycle. Two sets of SA tagged images were acquired with tags in perpendicular directions, yielding a tagging grid pattern when the two data sets were combined. A third tagging set was acquired on radially distributed LA images with tag lines perpendicular to LV long-axis.

Image Analysis Tag lines in both SA and LA images were traced using a MATLAB-based image analysis software package (CVMRI). HARP analysis was applied as a fast and semi-automatic approach for tag tracking (1). All the imaging planes were registered relative to the center of midventricular SA plane. Longitudinal coordinates were calculated by linear interpolation using intersecting tag points from corresponding LA sections in a transferred cylindrical coordinate system. Figure 1 illustrates the reconstructed tagging markers in 3D myocardial coordinates at end-diastole and end-systole. 3D homogenous strain analysis was used to calculate radial and circumferential strains in septum, posterior, lateral, and anterior segments of LV. Specifically, myocardium was divided into tetrahedrons using four non-coplanar adjacent tag points as the vertices. The six components of the symmetric 3D strain tensor were calculated from the deformation of these tetrahedrons. The strain tensor was further transformed to a local coordinate system defined by radial, circumferential, and longitudinal directions to find the normal strains in these directions.

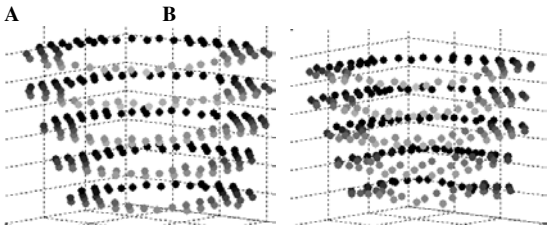

Figure 1. 3D tagging markers at end-diastole (A) and end-systole

Results

Figure 2 shows the average peak radial, circumferential, and longitudinal strains at end-systole. Longitudinal strain was relatively homogeneous over different ventricular segments with an average of 12.11±1.83%, indicating significant though-plane motion that cannot be quantified by previous 2D method (2). In contrast, radial and circumferential strains showed significant heterogeneity in difference segments. Similar to the observations in humans, the largest values were typically observed in the anterior-lateral wall (3).

To investigate the accuracy of strain calculation from 2D MR tagging, radial and circumferential strains in the four ventricular segments of five short-axis slices measured from 3D method were compared to those calculated from 2D tagged short axis images only. We found strong correlation between the two methods (R=0.96 for radial strain, R=0.91 for circumferential strain). The data indicate that despite the through plan motion, strain quantification from 2D MR tagging can provide accurate measurements of ventricular deformation in the radial and circumferential directions.

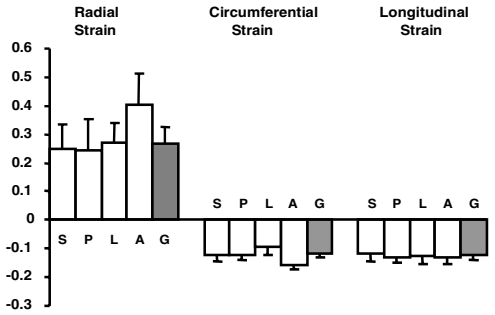

Figure 2. Radial, circumferential and longitudinal peak strains in septum (S), posterior (P), lateral (L), anterior (A) segments and midventricular short-axis slice (G).

Conclusion

In the current study, a novel 3D strain analysis method was developed, which allows fast quantification of the 3D ventricular strain. In vivo experiments demonstrate high heterogeneities in radial and circumferential strains and relative homogeneous distribution of longitudinal strain in mouse heart. Our 3D analysis results also indicate a very high correlation with 2D results in radial and circumferential strain calculation.

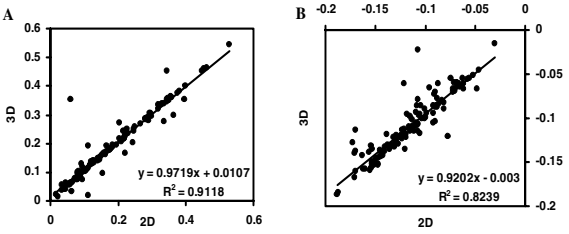

Figure 3. Correlation between myocardial strains assessed by 2D and 3D strain analysis, radial strain (A) and circumferential strain (B).

References

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