Image Processing and Visualization for MRI of Cardiac Function

Frederick H. Epstein, PhD, University of Virginia

Introduction. Quantitative imaging of myocardial motion is of growing importance, as novel applications such as imaging mechanical dyssynchrony in heart failure or detecting the functional affects of experimental therapies such as stem cells continue to develop. With an array of pulse sequences including velocity-encoded phase contrast (PC) (1), myocardial tagging (2;3), displacement encoding with stimulated echoes (DENSE) (4-6), and harmonic phase (HARP) methods (7), MRI is well-suited for tissue motion imaging. Using myocardial tagging or cine DENSE in particular, the myocardial magnetization is tagged at an initial point in time (typically immediately following R-wave detection), and, as the cardiac cycle progresses, serial images measure the motion of the tagged magnetization. In myocardial tagging, lines or grids of saturated tissue magnetization deform as the heart contracts, and in cine DENSE, phase shifts accumulate as the heart contracts. Using image processing and visualization methods applied to the raw tagged or DENSE images, physical quantities such as myocardial tissue displacement, strain, twist, and torsion can be computed and observed.

Image processing. A sequence of image processing steps is used to extract quantitative data from tagged or DENSE images. Commonly, a segmentation algorithm is initially employed to identify the endocardial and epicardial borders of the heart and to define the myocardial tissue within which tissue motion is to be computed. Ideally, this step would be completely automatic, but in practice it is typically semi-automatic, requiring some user interaction. For myocardial tagging, after segmentation of the myocardium, algorithms may be applied to detect the deformed tags, and the myocardial displacement field is subsequently estimated (8). Alternatively, HARP analysis, a method based on the phase of the filtered raw data, may be used for displacement and strain estimation (7). For cine DENSE, after segmentation is complete (9), algorithms for phase unwrapping and estimation of the displacement field are executed (10). For either method, once the displacement field is computed, the strain tensor field can be calculated and other derivative parameters describing heart function, such as twist and torsion, may be calculated (11). The strain tensor, which quantifies the change in shape of small elements of myocardium, is of particular interest, as regional shortening and lengthening are excellent indices of regional cardiac function. The strain tensor can quantify regional shortening and lengthening in directions that correspond to the natural anatomical coordinate system of the heart (radial, circumferential, and longitudinal), or in the directions of greatest and least deformation, known as the principal strains. Also, depending on the data acquisition method used, the resulting motion data are typically two- or three-dimensional.

Visualization. After image processing, quantitative motion data are available for each voxel throughout a 2D or 3D dataset, and as a function of time. The visualization and interpretation of these complex data are not trivial. For displacement, common displays include plotting displacement trajectories or showing videos of particle paths for the myocardial tissue (10). To visualize strain, maps or videos of individual strain components (typically circumferential shortening, radial thickening, and longitudinal shortening) can be displayed. Using more complex methods, maps or videos of deforming ellipsoids (Fig. 1) or superquadric glyphs can be used to better visualize the complete strain tensor in a single display (12). Also, plotting torsion as a function of cardiac phase is an effective method for visualizing the spatially-dependent twisting motion of the left ventricular.

Summary. Myocardial tagging, DENSE and other MRI methods can be used to acquire images that depict cardiac motion. To extract physical quantities from the images, image processing methods are applied. Typical quantities describing cardiac motion include 2D or 3D displacement, strain, twist, and torsion. Advanced visualization methods may be applied to help observers appreciate the detailed data that describe the complex motion of the heart.

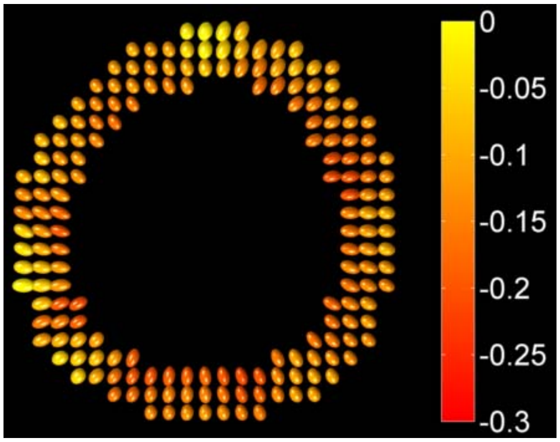

Fig. 1. Ellipsoid display of myocardial strain for an end-systolic mid-level short-axis DENSE image of the left ventricle. Each ellipse was initialized as a sphere. The deformed ellipses depict the strain of the myocardium as the heart contracted during systole. Each ellipse is color coded for circumferential shortening.

References

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