Diffusion tensor imaging of the heart in vivo
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Myocardial fibers are organized to support efficient pumping function of the heart. Understanding the functional significance and organization principles of the myocardial fibers could shed light on pathophysiology of the heart disease. Diffusion tensor imaging (DTI) is a technique that measures the diffusion of water molecules based on the diffusion-induced signal attenuation. DTI has been shown to characterize structural property of the tissue at microscopic level. Application of DTI to a beating heart is challenging because the bulk motion of the heart is much faster than the Brownian motion of water molecules. The diffusion-induced signal attenuation could be overwhelmed by the cardiac bulk motion. To overcome this problem, a special pulse sequence called double gated stimulated-echo sequence is designed in which two unipolar diffusion-encoding gradients are applied at identical phases of two consecutive heart beats. The stimulated-echo signal, however, is only a half of the spin echo signal. Therefore, a respiratory-synchronized acquisition scheme over multiple averages is devised to compensate for the low signal-to-noise ratio. Another problem of the stimulated-echo sequence is that the spatial modulation created by the first unipolar diffusion-encoding gradient lasts for almost one cardiac cycle until it is counter balanced by the second unipolar gradient. The spatial modulation undergoes a deformation in simultaneity with the cardiac deformation. This leads to the deformation of the measured diffusion tensor. To avoid the deformation effect on diffusion measurement, DTI should be acquired at one of two sweet spots, one at mid systole and one at mid diastole, in which the deformation effects are canceled over a cardiac cycle. After addressing the above problems, we first applied the in-vivo cardiac DTI sequence to a group of healthy subjects. We found a consistent helical orientation of the myocardial fibers across the left ventricular wall, consistent with the findings on quantitative histology. We further demonstrated that the myocardial fibers are oriented in a specific relationship with the principal shortening orientation to maintain uniformity of fiber shortening across the wall. In patients with hypertrophic cardiomyopathy, the myocardial fibers in the hypertropied segments showed substantial disarray, not only reducing the fiber shortening but also disrupting the normal relationship between fiber and principal shortening orientations. In patients with myocardial infarction, we found an interval change in myocardial fiber orientation in both infarct and remote zones. The interval change in fiber orientation is correlated with the interval change in wall thickening of the opposite zones, indicating a cross-zonal interaction between myocardial fiber orientation and regional wall function.