Ventricular fiber optimization utilizing the branching structure

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In this lecture, we propose an algorithm that optimizes the ventricular fiber structure of the human heart. A number of histological studies and diffusion tensor magnetic resonance imaging analyses have revealed that the myocardial fiber forms a right-handed helix at the endocardium. However, the fiber formation changes its orientation as a function of transmural depth, becoming a left-handed helix at the epicardium. To determine how nature can construct such a structure, which obtains surprising pumping performance, we introduce macroscopic modeling of the branching structure of cardiac myocytes in our finite element ventricular model, and utilize this in an optimization process. We put a set of multidirectional fibers around a central fiber orientation at each point of the ventricle walls, and simulate heartbeats by generating contraction forces along each of these directions. We examine two optimization processes using the workloads or impulses measured in these directions to update the central fiber orientation. Both processes improve the pumping performance towards an optimal value within several tens of heartbeats, starting from an almost-flat fiber orientation. However, compared with the workload optimization, the impulse optimization produces better agreement with experimental studies on transmural changes of fiber helix angle, streamline patterns of characteristic helical structures, and temporal changes in strain. Furthermore, the impulse optimization is robust under geometrical changes of the heart, and tends to homogenize various mechanical factors such as the stretch and stretch-rate along the fiber orientation, the contraction force, and energy consumption.

