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The automatic framework for quantitative 3D myocardial structure analysis

Obtaining a quantitative micro-structure analysis of the myocardium is essential to its understanding as a structured continuum. To address the interplay of structure and intrinsic antagonistic function of the myocardium while comparing normal and diseased hearts there is a strong need for an automatic, robust and precise framework to measure in a rapid procedure the 3D arrangement of bundles of cardiomyocytes. In this work we focus on pneumographic micro-CT measurements of porcine hearts. The main contribution is an automatic framework for quantitative 3D structure analysis of the whole myocardium with the same impressive resolution like the measured data. Prior to and during micro-CT- imaging the myocardial interstitial space was slightly pneumatically distended for better discrimination of the heart muscle´s lamellar basic structure. Compressed air was perfused through the coronary arteries, resulting in an isolated distension of the perimysial inter-lamellar space, while the dense endomysial compartment was not reached by gas. CT-imaging was performed in a Scanco Medical micro-CT device. Via novel mathematical imaging techniques and efficient computer algorithms, adequate for very high-resolution data sets, we can obtain precise quantitative values of helical and intruding angles at each voxel of the myocardium. The mathematical framework is based on three main steps: (1) a preprocessing component, where fine fibre structures are enriched by nonlinear anisotropic noise filters and simultaneous contrast enhancement, (2) an orientation estimation component, which uses novel structure tensor methods to compute the local orientation at each voxel and (3) an advanced automatic segmentation method which extracts a 3D surface of the myocardium and simultaneously computes normal vectors, serving as precise reference directions for computing helical and intruding angles given by (2). With this imaging tool we can quantify global alignment of heterogeneously interconnected networks of lamellar units. Due to the full coverage of the cardiac mesh and simultaneous segmentation we can also analyze and compare angular distributions between different myocardial compartments. We measure a particularly high prevalence of intruding and extruding structures which deviate from the tangential alignment and which are inclined towards endocardium and epicardium with angles exceeding 40 degrees. Computed helical and intruding angles in the whole myocardium are pivotal data to explain form-stabilizing structures as well as those which drive ventricular wall motion. In the future this might allow further analysis of the relative prevalence of constrictive as compared to dilative forces. According to histological findings and underlined by data from direct measurements of contractile forces in normal and diseased hearts, the relationship of those two opposing forces is disturbed, resulting in a derailment of the intrinsic antagonism of the myocardium, particularly in cases of ventricular hypertrophy which in most cases is complicated by fibrosis.

Biography

Christoph Brune is a tenure track Assistant Professor for computational mathematics (NWO, NDNS+) in the Department of Applied Mathematics at the University of Twente. In 2011-2012, he was a CAM Assistant Adjunct Professor in the Department of Mathematics at University of California Los Angeles (UCLA) working together with Prof. Andrea Bertozzi and Prof. Stanley Osher on projects in inverse problems, 4D imaging/image processing, optimal transport and machine learning. He taught classes and supervised Bachelor, Master and PhD students.

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