A reference dataset of in-vivo human left-ventricular fiber architecture in systole and diastole

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Introduction: Computational cardiac modelling has been established as a valuable tool for simulating electrophysiology and electromechanics of the heart [1], with promising applications to "personalized medicine" [2]. Realistic computational models require a detailed description of left-ventricular cardiac fiber architecture. So far, information on the architecture of myofiber aggregates has been obtained from histology or from diffusion tensor imaging (DTI) of excised post-mortem hearts. However, ex-vivo physiological conditions including ventricular pressure and residual contractile forces deviate significantly from in-vivo conditions, hence potentially impacting measured fiber metrics. The objective of this work was to obtain and make available cardiac DTI data of the in-vivo human heart with full cardiac coverage in both peak systole and mid diastole including correction for myocardial strain.

Methods: Data from one healthy volunteer without history of cardiac disease (heart rate 85 ±2 bpm, weight 65 kg, age 26) were acquired using a dual-phase dual-slice stimulated echo acquisition mode (STEAM) method [3] on a 1.5T Philips Achieva system (Philips Healthcare, Best, The Netherlands) equipped with a 5-channel cardiac receiver array. Written informed consent according to institutional guidelines was obtained from the subject prior to imaging. The acquisition (ECG trigger delays: 260ms & 560ms) was separated into 22 navigator-gated (gating window 5mm) breath holds and data along ten diffusion encoding directions [4] with a b-value of 450s/mm^2 and nine signal averages were obtained. The entire left ventricle was covered in both systole and diastole with a total of 12 slices with the following imaging parameters: field-of-view (FOV): 224×100mm^2, in-plane resolution: 2.2×2.2mm^2, slice thickness: 6mm, TE/TR 18ms/2R-R intervals, partial Fourier factor 0.62.

To correct diffusion tensors for material strain, additional 3D tagging data were acquired and incorporated into the diffusion tensor calculation [3]. Cardiac motion data were obtained using complementary spatial modulation of magnetization tagging (CSPAMM) [5] with spatial and temporal resolution of 3.5x7.7x7.7mm^3 (FOV: 108x108x108mm^3) and 18ms, respectively. Tagging data acquisition was navigator gated (acceptance window 15mm) within three consecutive breath holds, each spanning over 18 heartbeats. Upon affine image registration [6] of the diffusion-weighted images, data were filtered using a low-rank model and edge constraints according to [7] (rank order L: 8, regularization parameter λ: 50). Diastolic and systolic diffusion tensors were mapped into a prolate spheroidal coordinate system [8] for 3D diffusion tensor field reconstruction. Data analysis was performed on the local helix elevation (helix angle α) and the deviation of the helix from circumferential structure (transverse angle β). Sheet angles γ were defined as the angle between the third eigenvector and the surface parallel to the endo- and epicardium.

Results: Data across the entire left ventricle were successfully acquired in both systole and diastole. Figure 1 shows the helix angle maps in long axis and short axis views (basal, mid, apical) upon dense tensor field interpolation [8]. The linear relation of helix angles as a function of transmural position can be seen in Figure 2A. The slope of a linear fit for all segments was found to be steeper in systole -1.10±0.08°/% transmural depth than in diastole -0.86±0.03°/% transmural depth with a mean helix angle range of (95.4±12.1)° in systole and (68.1±5.9)° in diastole (Figure 2B,C). Transverse angles β were distributed around zero degrees in both systole (-3.1±26.1)° and diastole (1.2±21.5)° (Figure 2D). Sheet angles in diastole show a high population for very high and low values (±90°), whereas the sheet angle distribution in systole has more counts of small angulations (Figure 2 E,F).

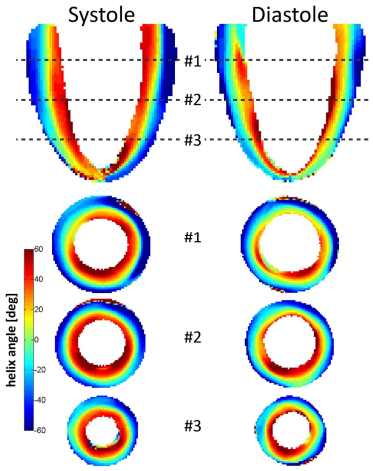

Fig. 1: Helix angle maps for systole and diastole in long and short axis view orientations (basal, mid, apical region).

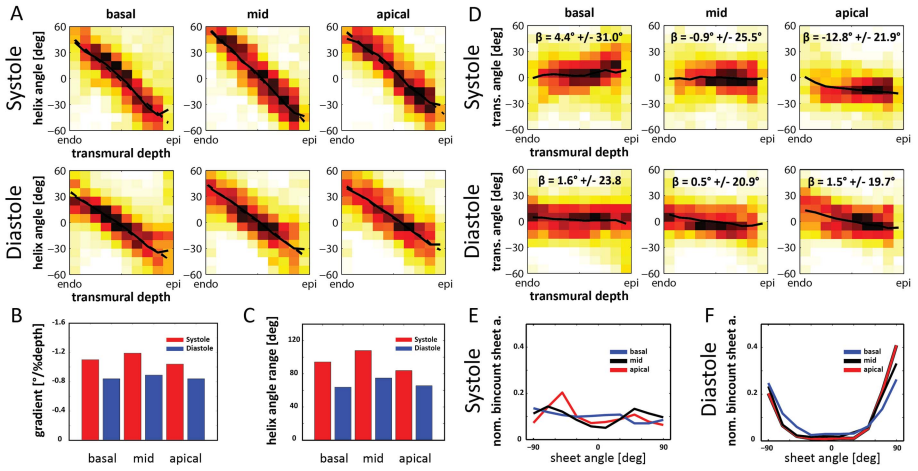

Fig. 2: Transmural course of helix angle for basal, mid, apical region in systole and diastole (A). Slope of a linear fit model for helix angle change from endo- to epicardium (B) and corresponding helix angle range (C). Transmural course of transverse angles β with mean ± one standard deviation (D). Sheet angle distribution for basal, mid, apical region in systole (E) and diastole (F).

Conclusion: The data presented here provides a comprehensive set of information on cardiac fiber architecture. In combination with available motion data it has the potential to improve the general understanding of cardiac mechanics and may serve as realistic input for computational heart modeling projects. The data are available at: www.biomed.ee.ethz.ch/cardiacdtiatlas

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