Isotropic whole-heart cine imaging with atlas-based segmentation

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Introduction

New approaches to segmentation and registration using probabilistic cardiac atlases enable consistent measurements to be made within populations and have the potential to find associations between genetic variation and continuous phenotypes (1). The use of whole-organ imaging for atlas-based techniques is appealing as it enables consistent mathematical and statistical modeling of cardiac anatomy and physiology without geometric assumptions or section mis-registration. Previous reports on breath-hold whole-organ imaging have used SENSE (2, 3) and kt-BLAST techniques (4, 5), but none of these have used isotropic resolution. In this work we use a 32-channel receive coil with a SENSE acceleration factor of 4 and partial Fourier encoding to obtain near-isotropic cardiac cine images in a single breath-hold. We then used atlas-based methods to segment the 3D dataset and build parametric maps comparing variations in regional wall thickness between patient groups and controls.

Method

The CMR studies were performed on a 1.5T Philips Achieva system (Best, Netherlands). Thirteen healthy volunteers, 5 patients with hypertrophic cardiomyopathy (HCM) and 5 patients with dilated cardiomyopathy (DCM) were imaged. A 32 element cardiac phased-array coil was used for signal reception. Scout images were obtained and used to plan an axial stack of cine balanced-steady state free precession (b-SSFP) images in the left ventricular short axis plane from base to apex using the following parameters - voxel size 2.0 x 2.2 x 8 mm, 12 sections, flip angle 60º, slice thickness 8mm with a 2mm gap, bandwidth 1250 Hz/pixel, TE 1.5 ms, TR 3.0 ms and 30 cardiac phases. In healthy volunteers a single breath-hold 3D b-SSFP sequence was acquired in the same short axis orientation using the following parameters - voxel size 2 x 2 x 2 mm, 48 sections, flip angle 50º, bandwidth 1250 Hz/pixel, TE 1.5 ms, TR 3.0 ms and 20 cardiac phases, typical breath hold 20 seconds. In the patient group images were acquired following an intravenous bolus of Gadobutrol 1.0 mmol/ml (Gadovist; Bayer Schering Pharma, Berlin, Germany) using a section thickness of 4mm to reduce a typical breath-hold to 10 seconds. For all 3D imaging a SENSE acceleration factor of 2 in both phase-encoding directions was used and a partial Fourier factor of 0.6.

The cardiac images of each subject were registered to an atlas using non-rigid registration to obtain a deformation field. Then the atlas was propagated to each cardiac image with each voxel in the image classified as left ventricular blood pool, myocardium or background. The endo-cardial and epi-cardial surfaces were reconstructed using the marching cubes algorithm and smoothed using a low-pass filter. The wall thickness was determined as the distance between each point on the epi-cardial surface and its closest counterpart on the endo-cardial surface. We mapped the wall thickness to the atlas surface for all the subjects, so that they could be compared point-by-point.

Manual left ventricular volumetry was performed using Philips (Best, Netherlands) software. Stroke volume was also obtained from velocity mapping at the aortic root. Contrast ratios (CR) were calculated using the following equation: $CR = SI_1 - SI_2/\sqrt{(SD_1^2 + SD_2^2)}$, where SI_1 and SI_2 are the mean signal intensities of relatively homogeneous areas of the myocardium and blood pool and SD_1 and SD_2 are their respective standard deviations.

Results

The cardiac surfaces were correctly identified by the segmentation algorithm in each case and a multiplanar reconstruction is shown in Figure 1. CRs of blood:myocardium in the patient group were 8.6±1.7 (2D) vs 12.4±2.7 (3D), P=0.01. In healthy volunteers the respective CRs were 14.3±3.8 (2D) and 11.3±3.4 (3D), P=0.0004. A Bland-Altman comparison of stroke volumes derived from velocity-encoding and automated segmentation showed a mean bias of -10.1% (limits of agreement -22% - 1.8%) and manual volumtery a mean bias of 2.9% (limits of agreement -11.4% - 17.1%). Co-registered surface models showing the variation in pooled wall thickness measurements in HCM and DCM patients is given in Figure 2.

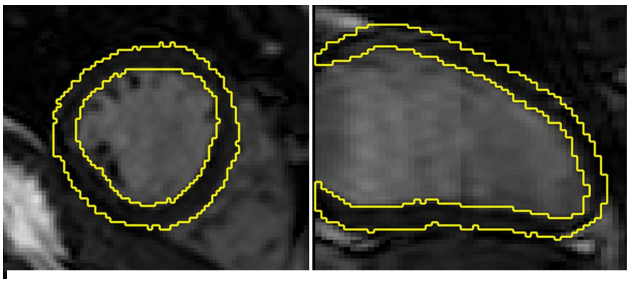

Figure 1: Multiplanar reconstruction of breath-hold cine imaging of the whole-left ventricle with atlas-based segmentation.

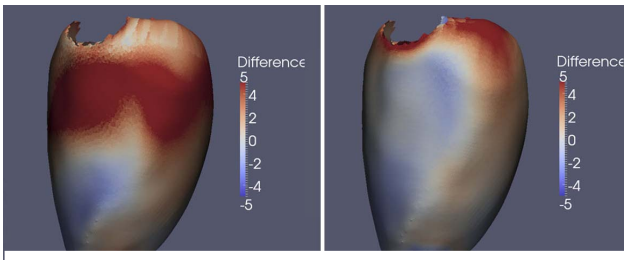

Figure 2: Co-registered surface models comparing wall thickness in a HCM patient (left) and a DCM patient (right) with data from the control group.

Discussion

Three-dimensional imaging provides comparable contrast with 2D imaging when gadolinium has been given, but has a slightly lower contrast without it. Atlas-based segmentation has a small bias towards smaller left ventricular stroke volumes which may be related to the inclusion of trabeculae in the blood volume. Istotropic whole heart breath-hold cine imaging is a feasible approach for cardiac phenotyping which provides a consistent dataset for 3D atlas-based segmentation and parametric modeling.

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