Model Based Automated 4D Analysis for Real-Time Free-Breathing Cardiac MRI

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Background. With recent developments in real-time data acquisition and signal processing, Cardiac Magnetic Resonance Imaging (CMR) is able to provide morphological and functional information even in the presence of variations in cardiac cycle length or for patients having difficulty with breathholds [1]. Fast and accurate quantitative assessments of cardiac function require precise localization of the structures of interest while taking into account any potential source of error from the image acquisition. Simultaneously, the increasing availability of medical imaging databases and advances in machine learning techniques enable automatic estimation of cardiac parameters from imaging data using discriminative learning methods. We propose to automatically provide quantitative estimates of left (LV) and right (RV) ventricles morphology and dynamics by fitting a parameterized 4D cardiac model to volumetric CMR data while simultaneously correcting for spatial slice mis-alignment. We show that our method can be applied to both steady state free precession (SSFP) breath-hold short axis stacks as well as to a recent real-time free-breathing protocol (RTFB) [1].

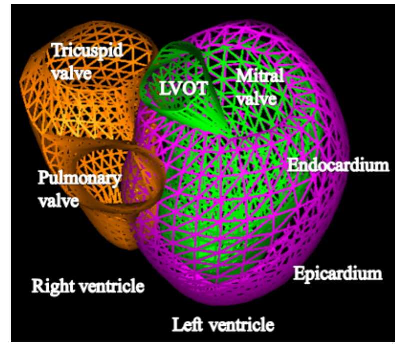

Fig. 1 Bi-ventricular model

Methods. For both SSFP and RTFB images acquired using an undersampled radial trajectory and reconstructed using through-time radial GRAPPA (see [1] for detailed protocol), a pseudo 3D volume is initially reconstructed according to the MR physical coordinates. Next, given a database of aligned stacks with expert delineations of the chambers we train a series of detectors that are able to estimate the model parameters relative to imaging data (see Fig 1). The standard model parameters are heart pose (translation, rotation and scale) and boundary location to which we add the global position of each slice. We estimate heart pose and boundary including dynamics as described in [2, 3, 4]. Intuitively, during the training phase, we learn prior knowledge of the cardiac anatomy from the database and embed it into a detailed parametric 4D models of the LV and RV where key physiological landmarks are specifically encoded (Fig. 1) [3]. For the position of each slice we estimate the translation using global image information under a heart shape constraint given by the 4D model to preserve the curvature of the heart. Therefore we simultaneously solve for inter-slice alignment and estimate an accurate, patient-specific 4D heart model. The outline of the algorithm is: 1. Automatic estimation of 3D model from cine MRI stack [4] (method relies on shape priors robust to misalignment); 2. Determine the myocardium region from 2D model intersection and perform inter-slice registration using a diffeomorphic symmetry-consistent image registration algorithm [5]. 3. Update slice translation only using the myocardium region and reconstruct the pseudo-volume. Recursively iterate the process.

Results and discussion. We have applied the automated 4D MR analysis to an initial set of 10 patients with data acquired using a radial trajectory reconstructed with through-time radial GRAPPA for real-time free-breathing acquisitions [1]. The model was trained off-line on a regular breath-hold set of 100 volumes (from 70 patients) with a cross-validated error of 2.9±4.8mm for the endocardium. An example of the slice re-aligning result is illustrated in Fig. 2 along with a typical result of fitting the 4D model. Automated analysis was possible on all cases and for 5 patients we compared the results with acquisitions under regular breath-hold protocol (see table). Average difference for left-ventricle ejection-fraction (EF) is 3.44±4.1%, ED volume is -0.4±2.2ml and ES volume is -5.3±5ml which are within the accepted clinical variability. We also compared the EF values relative to user delineated contours resulting in a difference of 2.4±5.8% (SSFP) and -1.7±3.3% (RTFB).

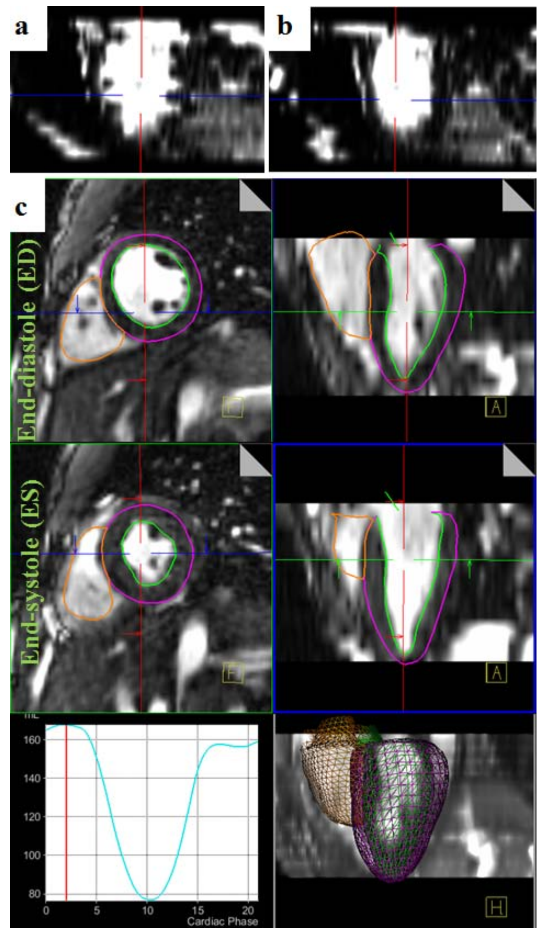

Fig. 2 Pseudo 3D volume based on physical coordinates (a) and aligned based on model (b); Fitted 4D model (c)

	Breath-hold	Free-breathing
	EF(%) (EDV[ml]/ESF[ml])	
P1	58.3 (168.1/70.0)	54.4 (168.1/76.6)
P2	48.3 (131.1/67.7)	52.0 (133.9/64.2)
P3	59.6 (129.7/52.4)	53.6 (128.2/59.4)
P4	58.5 (147.8/61.3)	53.3 (150.4/70.2)
P5	57.5 (144.7/61.4)	51.7 (142.8/68.9)

Conclusion. We have shown that using a model based approach it is feasible to automatically provide quantitative assessments of both the LV and RV in a real-time, free breathing, non-gated protocol without errors from slice alignment artifacts. This method has the potential to dramatically simplify the workflow for many cardiac MR patients and for the clinicians responsible for extracting the diagnostic information.

References. [1] Seiberlich et al. MRM, 65:492-505, 2011. [2] Georgescu et al. IEEE CVPR, 2:429, 2005. [3] Zheng et al. IEEE TMI, 27:1668, 2008. [4] Lu et al. FIMH, 250-258, 2011. [5] Guetter et al. ISBI, 590-59, 2011.