Detecting the onset of myocardial contraction and regional motion changes for XMR guided RF ablation

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Recent advances in non-rigid motion tracking techniques that use tagged MR (SPAMM) enable us to measure more subtle changes in cardiac motion patterns due to diseases such as arrhythmia, ischaemia and infarct, as well as to follow up medical treatment and to assist surgical intervention. One such example of disease with associated changes in motion patterns is a tachyarrhythmia: a pathological fast heart rhythm originating either in the atria (super-ventricular) or ventricles (ventricular), often the result of abnormal paths of conduction. Radio-frequency (RF) ablation is the indicated treatment for patients with life threatening arrhythmia as well as for those on whom drug treatment is ineffective. Applying a RF current via an ablation electrode induces hyperthermia and destruction of the abnormally conducting areas. These procedures are typically carried out under x-ray (2D) guidance, leading to errors in the location of the abnormal areas as well as to excessive radiation exposure for the patient.
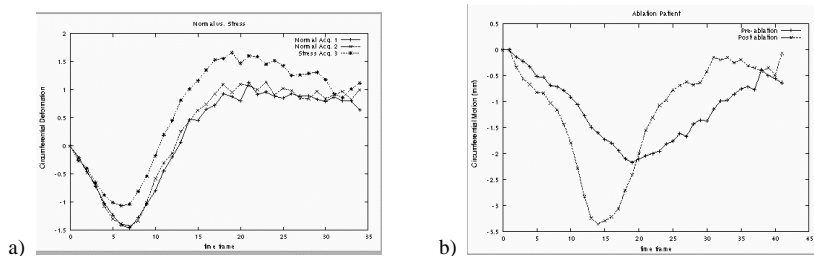
One of our goals is to provide pre- and intra-operative 3D MR guidance [1] by detecting the onset of regional motion and relating it to the electrical activation pattern. For this purpose we define a probabilistic measure of regional motion activation. This regional activation measure uses the differential operators velocity, strain, and rate of change of strain, all derived from a continuous and time varying 3D motion field. The motion field is extracted by using non-rigid 3D registration of tagged MR image sequences [2]. Although we are addressing the problem of inverse electro-mechanical coupling, that is, trying to infer the time of electrical activation by extracting information from the cardiac motion (Figures 1a and 1b show results on a cardiac atlas), we have also used a forward 3D electro-mechanical model of the heart [3] to validate our results (Fig. 1c). By using a probabilistic atlas of cardiac geometry and motion generated from 3D MR images sequences of 14 volunteers [4], we validate our activation measure in a realistic but smooth and virtually noise-free data set.

The other goal of this work is to detect changes in the regional motion patterns between two different image acquisitions. The purpose being the follow up of medical treatment in general, and in particular of patients that have undergone RF ablation [5], aiding thus the identification and localisation of abnormal regions and helping determine whether the ablation had the desired effect of regularising cardiac contraction. In order to be able to compare different image acquisitions, a common (cylindrical) coordinate system based on the left ventricle is defined for each subject, therefore avoiding potential misregistration errors due to subject motion between scans. The myocardium is then subdivided into small segments, and the descriptive motion-derived measurements for each myocardial segment computed during the cardiac cycle. A statistical measure is then used to classify each segment as having either no, small or significant changes.

We evaluated the methods with different types of images. Synthetic tagged MR image sequences were generated using a cardiac motion simulator [6]. The parameters were then modified to produce regions with different motion patterns, thus providing a case where the ground truth was available. Evaluation was also performed using repeat MRI acquisitions from five healthy volunteers, one of which was subjected to stress during one scan. MRI data was also acquired from a patient with super-ventricular tachyarrhythmia, before and after radio frequency ablation. The image acquisition and catheter intervention were performed with a combined x-ray and MRI system (XMR). Detection results were correct on synthetic data (Fig. 1d) and no region was incorrectly classified as having significant changes in the repetition studies. Significant changes in motion pattern were measured in the stress (Fig. 2a) and ablation studies (Fig. 2b). Furthermore, results seem to corroborate that the ablation regularised cardiac contraction.
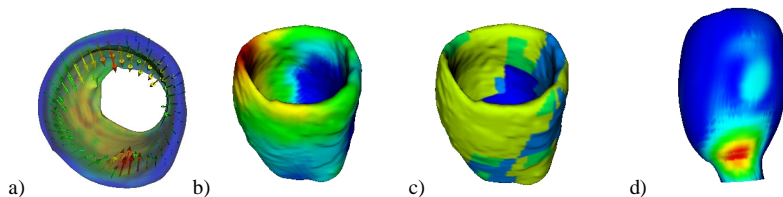
Figure 1. In (a) we can see a basal view of the cardiac atlas geometry, with some motion vectors. The *isochrones* maps show times of activation (from blue to red) for every region of the myocardium: computed from the reconstructed motion fields of the cardiac atlas in (b), and from the electro-mechanical model applied to the same myocardial geometry in (c). The LV surface in (d) shows results obtained on the reconstructed motion of synthetic MR data. The region where the abnormal motion was produced was accurately identified and can be seen in red and yellow.

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Figure 2. Time plots of circumferential motion of a myocardial segment. Results for the healthy volunteer (a) show no significant changes in the motion pattern between two repeat image acquisitions, but a noticeable change when stress was induced on the subject during a third acquisition. In the case of the patient (b) a significant change can be seen after RF ablation, when this region of the myocardium exhibits a faster and more pronounced contraction.