Measurement of Ventricular Wall Motion, Epicardial Electrical Mapping, and Myocardial Fiber Angles in the Same Heart

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Abstract. Methods for the precise measurement of three dimensional myocardial motion non-invasivley with MRI have recently been developed. These methods use a technique called "presaturation tagging" to mark the myocardium, and rapid MRI to track the motion of these markers. A unique capability of this method is the production of strain images representing the local deformation of the myocardium. These images clearly show the sequence of events during the activation of the heart, and can demonstrate abnormalities caused by asynchronous electrical activation or ischemia. Coupled with the near simultaneous mapping of electrical depolarization with an epicardial sock array, we can investigate the relationship between electical activity and mechanical function on a local level. Registered fiber angle maps can be obtained in the same heart with diffusion MRI to assist in the construction of the mechano-electrical model of the whole heart.

1 Introduction

The ability to measure the precise mechanical function, the electrical function, and the underlying fiber architecture in the same heart in vivo may uncover the interactions of these constituents in normal and abnormal cardiac function.

The measurement of the electrical activity of the heart is a mature field of research employing intra-cavity electrodes [8], baskets, optical techniques [13], monophasic action potentials [5] and body surface electrode mapping [2,3,9] among other techniques.

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Methods for measuring local three dimensional myocardial motion non-invasively with MRI have been developed using presaturation tagging patterns [1,10,17]. Recently, methods for measuring the diffusion tensor in vivo have lead to a method for measuring the fiber angle in soft tissue [6,14].

An experimental protocol has recently been developed in which electrical mapping, myocardial strain mapping and fiber angle mapping can be achieved in the same heart [4]. The data are registered so that local correlations can be made between these three features.

2 Cardiac Tagging Techniques

In cardiac tagging a set of saturation pulses placed in the tissue provides a signal intensity pattern in the tissue; the change in shape of the intensity pattern in the image reflects the change in shape of the underlying body containing the intensity pattern. Originally demonstrated by Zerhouni et. al. [17] with saturation pulses, and by Axel with SPAMM pulses [1], it was shown that parallel lines can be used to mark the tissue effectively.

The objective of the analysis of tagged images is to track the 3D motion of each material point in the heart, and then to compute the six components of the strain tensor at each point for a sequence of time points throughout the heart cycle. The strain tensor characterizes the local deformation of the myocardium. Bulk translations and rotations of the entire heart may actually dominate the displacement and velocity measurements, but these are of limited value as an index of local myocardial contraction. In order to obtain precise quantification of the regional strains, the position of the tags must be measured with a “tag detection” algorithm [7]. Once the relative position of the tags have been determined as a function of time, these data can be used to estimate the strain tensor at each point in the myocardium. One method for doing this is a displacement field model based on B-splines [12].

3 Measurement of Myocardial Function During Asynchronous Activation

In order to evaluate the relationship between electrical excitation and the onset of mechanical contraction, MR tagging experiments were performed during ectopic pacing in anesthetized normal dogs [4,11,15]. When systolic contraction was evoked by right atrial pacing, the LV was excited via the normal pathway of the Purkinje system and the pattern of mechanical activation was found to be very uniform as a function of position. However, when the heart was paced from a ventricular site, significant asynchronous and spatially heterogeneous contraction was observed.

The precise sequence of events during ectopic excitation was particularly evident on the strain images. Fig. 1 shows the evolution in time of the circumferential component of the 3D strain tensor (Ecc) evaluated at the mid-wall for two pacing