Mechanical Activation in the Bi-Ventricular Paced Heart with High-Resolution MRI Tagging

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Introduction

It has previously been shown that pacing the heart from a single ventricular site causes an asynchronous contraction of the left ventricle (LV) resulting in significant discordant wall motion [1,2]. Using the methods of high-resolution MR tagged imaging and mechanical activation mapping we demonstrate that bi-ventricular pacing (pacing from two ventricular sites) can be used to greatly enhance the synchrony of LV contraction.

Methods

Experimental Preparation Six mongrel dogs (weight 19-27 kg), were anesthetized and ventilated with O2 supplemented with 1-1.4% isoflurane. The chest was opened and bipolar non-ferromagnetic electrodes were placed on the right ventricular apex (RVa), left ventricular base (LVb), and right atrium (RA). Each electrode was filtered to prevent voltage induction from external sources. A Millar catheter was placed in the LV to monitor pressure. The heart was paced using a GRASS stimulator, with the stimulus level set high enough to ensure consistent capture, at each of the three sites separately and from the RVa and LVb sites simultaneously (bi-ventricular pacing). The normal activation of the heart was suppressed by using A-V synchronous pacing at a rate above the spontaneous rate.

MRI Acquisition The MRI tagged images were acquired during 10-20s breath-hold periods with a segmented k-space acquisition [3]. The signal to trigger the tagging pulse preceded the pacing spike by 40 ms. This resulted in tagging during late diastole and imaging from end diastole through systole. The scanning parameters were: 28-32 cm field of view, 256x(96-110) acquisition matrix, 3-5 readouts per movie frame, 7mm slices. The images were taken at 15-20 ms intervals. A parallel line tagging pattern with 5 pixels separation between tags was used. For each of the four pacing protocols 7-9 short axis slices were taken with the tags at 0 degrees and with the tags and readout gradient rotated 90 degrees [3]. Nine long axis slices with the slices oriented radially from the center of the LV cavity were imaged with the tags parallel to the short axis imaging planes.

Data Processing The tagged MR images were analyzed by delineating the contours and the tags using a semi-automated software package [4]. The 3D Lagrangian strain tensor was calculated by field-fitting the displacements [5] using a mesh size of 3 radial, 7-9 longitudinal and 24 circumferential points. For this analysis only the circumferential strain (E_{cc}) at the midwall was considered, resulting in an (7-9)x24 set of material points for each heart. E_{cc} at each mesh point was then fitted across time with a seventh order polynomial which provided a good trade-off between accuracy of fit and noise reduction in the data. From the fit the time of mechanical activation was determined as the onset of shortening [1].

Results

Figure 1 shows the mechanical activation map of the left ventricle for each of the four pacing sites in a typical experiment. For RA pacing the activation map shows synchronous contraction. For LVb and RVa pacing early contraction is seen near the pacing site and the activation moves slowly to the side opposite the electrode. Bi-Ventricular pacing greatly reduces the asynchrony of contraction and leads to an activation pattern which more closely resembles RA pacing. Table 1 summarizes the average times and standard deviations across all experiments to activate 75% of the material points in the LV for each pacing protocol.

<table>
<thead>
<tr>
<th></th>
<th>RA pace</th>
<th>Bi-Vent.</th>
<th>RVa pace</th>
<th>LVb pace</th>
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<tbody>
<tr>
<td>Time</td>
<td>69 ±18 (ms)</td>
<td>82 ±21 (ms)</td>
<td>100 ±18 (ms)</td>
<td>121 ±24 (ms)</td>
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</table>

Discussion

In bi-ventricular pacing there is a small region of prestretch between the two electrodes but this is considerably smaller than the prestretch seen on the single ventricular site pacing. Bi-ventricular pacing has been shown, in a limited number of patients with dilated cardiomyopathy, to improve the hemodynamic function of the LV [6]. Using mechanical activation mapping it can be seen that the mechanism for this improvement may be due to increased synchrony of contraction. Since these methods are non-invasive they can be effectively used for analyzing and improving pacing protocols.

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References