Quantitative Prediction of Cardiac Functional Improvement after Myocardial Revascularization using Cine MRI and Mechanical Modeling

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Introduction. Patients who undergo myocardial revascularization by either coronary artery bypass surgery (CABG) or percutaneous transluminal angioplasty (PTCA) may experience an increase in ejection fraction (EF) due to recovery of function in hibernating myocardium. A priori determination of which patients would experience an improvement in EF with revascularization, and quantitatively determining the amount of the increase, would be advantageous to patient management.

The objectives of this study were: 1) develop a simple mechanical model of ventricular function based on the contractile properties of the myocardial tissue as determined by cine MRI, 2) scan a series of patients before revascularization with cine MRI, and apply the model to quantitatively predict the increase in EF after revascularization, and 3) scan the patients with cine MRI after revascularization and compare the predicted EF to the actual EF.

Methods. Patients. Ten patients (7 males, 3 females), ages 54-73, participated in the study. All patients had chronic left ventricular (LV) dysfunction. Patients with acute myocardial infarction (MI) were excluded from the study to eliminate potential confusion from "stunned" myocardium or recently infarcted myocardium. The average time between the pre-revascularization MRI scan and the revascularization procedure was 2.5 days (range=1-7). The average time period between the revascularization procedure and the post-revascularization scan was 7.5 months (range=1.5-12).

MRI Imaging. Images were acquired on a 1.5 Tesla imager (Philips Medical Systems ACS-NT15, Best, NL). Survey images were obtained in three orthogonal planes. A gradient-echo, ECG gated, 16-frame cine image of the heart was obtained in the vertical long axis plane followed by a series of eight, 8-10 mm thick, 16-frame cine images in the short axis plane. A field-of-view of 300 mm, a scan matrix of 192 x 256, a TR=14, a TE=7, and a flip angle of 50° was used. On two subjects a breath-hold, segmented, gradient echo, echo-planar imaging (EPI) technique was used for acquiring the short axis images [1]. The image resolution and timing parameters used for the EPI scan were equivalent to those used in the conventional gradient echo scan.

Image Analysis. Each of the 6-8 cine slices was radially divided into 8 segments. Cine images were reviewed to identify regions which are hypokinetic (<1.5 mm of wall thickening). In these regions of abnormal function, the reviewer characterized the myocardium as hibernating or infarcted based on the following criteria: If end-diastolic wall thickness is preserved in these dysfunctional regions (end-diastolic wall thickness greater than or equal to 5.5 mm), the myocardium was considered hibernating myocardium. If end-diastolic wall thickness was less than 5.5 mm, the region was considered infarcted myocardium, which will not recover function. All regions not identified as having abnormal function were considered normal myocardium [2].

Mechanical Model. After revascularization, increased contractility of revascularized segments could then be entered into the model to calculate a post-revascularization ejection fraction. The major assumption of the model were: 1) all hibernating tissue returns to normal contractility after revascularization, 2) normal and infarcted tissue did not change function after revascularization, 3) the longitudinal strain was unity, 4) the left ventricle has a circular cross section in the short-axis, 5) normal LV contractility has no regional variation.

Results. All ten subjects completed the pre- and post-revascularization scans without incident. Improvement in cardiac function was seen in all subjects to varying degrees. Once the ten predicted post-revascularization EF was 50.4%, and the mean actual post-revascularization EF was 49.0%, table 1.

Correlation between the actual and predicted post-surgery EF’s yielded R-squared value of 0.94, figure 1. The average difference between the predicted and actual EF averaged over all the subjects was 1.4 EF percentage points (range -1.1 to 5.5). Using a t-test, there was no significant difference between the predicted and actual post-surgical EF’s at a p-value of 0.01.

Table 1. Mean values for pre-revascularization EF, predicted and actual post-revascularization EF, and the difference.

<table>
<thead>
<tr>
<th>Pre-Revasc EF (%)</th>
<th>Predicted post-Revasc EF (%)</th>
<th>Actual post-Revasc EF (%)</th>
<th>Difference (Actual - Predicted EF)</th>
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<tbody>
<tr>
<td>44.8 +/- 16.7</td>
<td>50.4 +/- 16.4</td>
<td>49.0 +/- 16.1</td>
<td>1.4 +/- 1.8</td>
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</table>

Figure 1. Correlation between actual and predicted post-revascularization EF’s. The R-value is 0.94.

Discussion. In this initial study, functional response to stress was not included. Addition of stress imaging should improve the model’s accuracy, particularly in a broader patient group.

The model used is quite simple. The model treats the myocardium as a single membrane, homogeneous in the thickness direction and stepwise homogeneous in the circumferential direction. Several improvements to the model are planned, including: 1) accounting for the location of hibernating regions (hibernating regions next to infarcted areas may return to only 50% normal function [3]), 2) accounting for the amount of residual end-diastolic wall thickness in areas of sub-endocardial infarct, 3) accounting for changes in function in normal tissue after revascularization.

Conclusion. We have preliminarily shown that a simple mechanical model of ventricular function based on cine MRI derived parameters can quantitatively predict improvement in ejection fraction after revascularization.