Determination of Transmural, Endocardial and Epicardial Radial Strain and Strain Rate from PCMR Velocity Data

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INTRODUCTION: Strain (ε) and strain rate (SR) are measures of myocardial contractility [1]. Strain is defined as the deformation of an object normalized to its original shape, and SR is the speed at which that deformation occurs [2]. Since strain and SR are not affected by contractile function in adjacent myocardial regions, they are more direct measures of regional myocardial function than tissue velocities [3]. SR imaging by ultrasound has demonstrated the ability to differentiate between ischemic and non-ischemic myocardium [4], and when used in combination with dobutamine stress testing, has been able to differentiate between stunned and ischemic myocardium [5]. Although the applications of SR imaging have been promising, myocardial *radial* SR continues to be difficult to measure *in-vivo*. Two derivatives (one spatial and one temporal) are required to extract this value from displacement data such as ultrasound speckle tracking or MR tagging. Since each derivative introduces additional noise into the signal, SR curves have often been difficult to interpret. PCMR is able to acquire three-dimensional velocity information throughout the entire myocardium at high spatial resolution, allowing subendocardial strain and SR to be computed directly from velocity measurements.

PURPOSE: 1) To develop a technique for measuring radial strain and SR from PCMR tissue velocity data and 2) To evaluate differences in radial strain and SR between the endocardial and epicardial layers of the myocardium.

METHODS: Experiments were performed on a 1.5T Philips Medical Systems Intera CV MRI scanner using a cardiac coil. A segmented, navigator-echo and ECG-gated sequence was used to acquire three-directional velocities within the myocardium [6]. Velocity was acquired at basal and mid short axis slices in the myocardium and presaturation slabs were used on each side of the slab to null in-flowing blood. VENC value was 30 cm/s, temporal resolution was 26 msec, and voxel size was 1.4 x 1.4 x 8mm. Velocity maps were acquired in 10 normal volunteers.

SR was calculated directly from the radial velocity data. For each phase in the cardiac cycle, change in velocity along line running radially through the myocardial wall was plotted vs. the change in radius. SR was determined as the slope of the regression line [7], Figure 1. It is important to note that this value gave the average transmural SR throughout the entire myocardial wall. To compute endocardial and epicardial SR values, the thickness of the myocardial wall along each radial line was subdivided, and the SR was computed independently for each region. Strain was determined by integration of the SR curves ($\varepsilon = \int SR\, dt$).

To validate strain measurements made with PCMR tissue velocity data, endocardial and epicardial borders were traced on a basal slice of short axis SSFP images acquired at the same location as the PCMR tissue velocity maps. Radial strain was computed from these contours based on myocardial thickness over time. Strain values were averaged into six basal segments in accordance with the AHA model. Peak strain values within each segment were compared to peak strain values computed from the MR phase contrast velocity data at the same locations. $p < 0.05$ was considered statistically significant.

In all datasets, transmural, endocardial, and epicardial SR values were determined for 48 locations in each phase of the cardiac cycle. In both basal and mid slices, values were averaged into six segments to adhere to the AHA 17-segment model of the myocardium. Peak endocardial and epicardial values were compared using a paired, 2-tailed t-test with $p<0.05$ considered statistically significant.

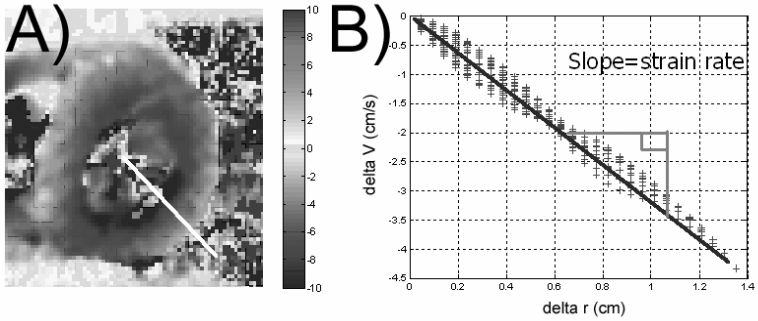

***Figure 1**: Method for computing radial strain and strain rate from PCMR velocity data. A) shows a short-axis MR image of the myocardium with one of the 48 lines along which radial velocities were computed. Along this particular line the myocardium is 8-pixels thick, meaning a velocity difference was computed between 15 half-pixel steps. B) shows a plot of change in radius (dr) vs. change in velocity (dV) along the line shown in A). There are 105 unique two-value combinations of dV/dr, for the 15-steps across the myocardium explaining the large number of points shown in B).*

RESULTS: Excellent agreement was observed between peak strain values computed from contours drawn on the cine SSFP images and strain derived by PCMR tissue velocity images. Peak strain values computed by cine SSFP and PCMR were not significantly different in any of the six basal segments examined. Across all six basal regions, average peak strain determined by the contours was 38.1+/- 5.4%, and by the PCMR velocity technique was 38.0+/-6.2 %.

Peak endocardial radial strain values were significantly larger than peak epicardial strain values. In the basal slice, the value of peak endocardial radial strain was 45.3+/-25.6% and the value of peak epicardial radial strain was 35.6+/-20.7%, $p<0.05$. The same trend was observed in the mid slice (peak endo=41.3+/-31.9%, peak epicardial radial strain=31.6+/-18.9%, $p<0.05$).

Peak endocardial SR values were also larger than peak epicardial SR values. This endocardial-epicardial SR gradient was observed consistently during systole in both slices, Figure 2. The same trend was observed during diastole with peak endocardial SR values being larger in magnitude than peak epicardial SR values, although the differences were not significant.

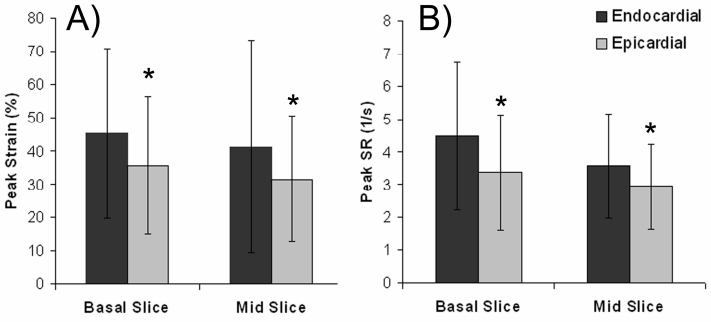

***Figure 2**: Peak endocardial and epicardial strain A) and SR B) values during systole. * denotes where peak endocardial values were significantly larger than peak epicardial values to the $p<0.05$ level of significance..*

CONCLUSIONS: We have presented a method for deriving radial strain and SR from PCMR velocity data. Excellent agreement was demonstrated between peak strain measurements derived with the presented method and strain measurements computed independently from contours drawn on cine SSFP images. The method presented allows differentiation between transmural, endocardial and epicardial values, and the presence of endocardial-epicardial radial strain and SR gradients was demonstrated.

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