Interpreting Myocardial Morphology and Function from DENSE MRI Data Based on Fluid Mechanics Concepts

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Introduction: The concept of the helical heart was first introduced by Torrent-Guasp [1]. It is hypothesized that ventricular cavities are defined by a single rope-like muscle band forming a double helix structure (Figure 1). However, this model of cardiac anatomy and fiber orientation has not been verified experimentally in vivo and its consequences for cardiac function have not been tested. Displacement Encoding Stimulated Echo (DENSE) is a phase contrast method for measuring the Lagrangian displacement fields of the myocardial wall in vivo [2]. It provides a high spatial density of displacement measurements in the myocardium via stimulated echoes, while the image is always acquired at the same time point in the cardiac cycle.
Streamlines are defined in fluid mechanics as traces tangent to the flow velocity vectors at any given point in time and show the flow stream direction. We propose to apply this stream function concept to determine wall point trajectories from DENSE MRI data, where the traces now start from the initial position of each point and are tangent to the respective displacement vectors any instant. The resultant curves show the displacement pattern of points within the cardiac wall and can potentially identify myocardial fiber orientations or preferential contraction pathways.

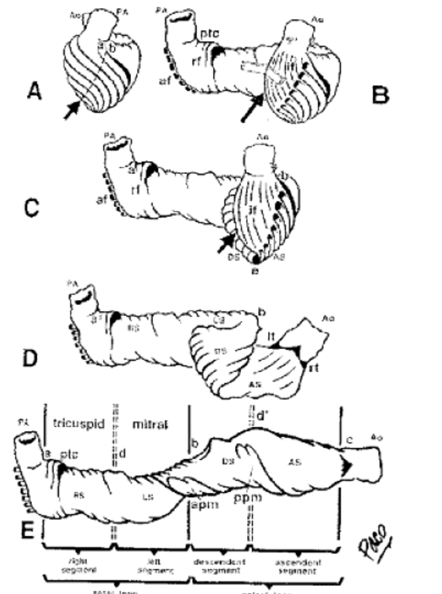

Figure 1. Schematic representation of the Torrent-Guasp concept of the myocardial band.

Purpose:
1. Identifying myocardial fiber orientations and wall dynamics in vivo based on the Torrent-Guasp hypothesis of the helical heart
2. Using DENSE and other MRI techniques as a means to accomplish the first goal
3. Determining wall point trajectories from in vivo DENSE data via the application of the stream function concept adapted to the myocardial displacement field

Methods: DENSE MRI data has been acquired for a human subject and two canine hearts at 1.0 mm spatial and 100 frames/second temporal resolutions. Trajectories of points on the heart walls are then derived from their displacement vectors in space, by applying the general stream function concept described above. This is done both longitudinally in 3D for the series of contiguous short axis slices, and in 2D for individual slices.

Results: The DENSE data presented in Figure 2 show a single phase 3D set from a human subject averaged at one time point during the cardiac cycle, i.e. end systole. In other words, the vectors illustrate the total displacement of each pixel between the QRS complex (start of systole) and the end-systolic phase. Point displacement trajectories described above are plotted on this 3D displacement field, where the onset of a helical pattern from the apex and following on to the planes above is evident. The 2D curves on Figure 3 are representative of the in-place stream traces on one sample apical short axis slice of the left ventricle. These trajectories identify the circumferential torsion occurring in the myocardium over the systolic period as well as the fiber orientation.

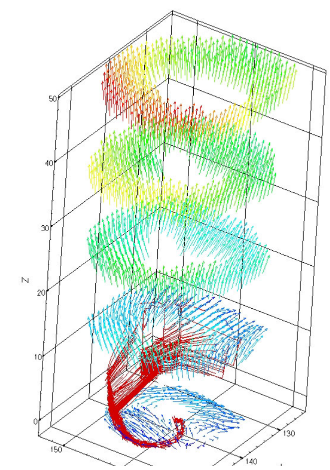

Figure 2. The onset of the helical structure from the stream functions (red curves_ plotted for the 3D displacement vector field acquiring suing the DENSE method from a human subject. Note that the vertical axis is expanded.

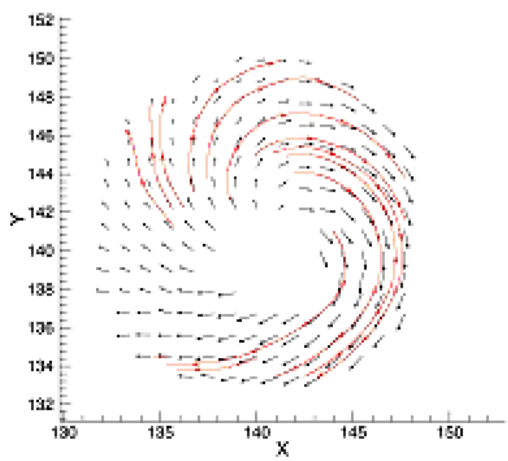

Figure 3. In-plane streamlines plotted for apical short-axis slice of DENSE data for a human left ventricle.

Conclusions: Our work in progress demonstrates the possibility of inferring myocardial fiber orientation and morphology from DENSE MRI data. The using this technique is superior to any other tracking. The initiation of a 3D helical spatial and temporal resolution of the data acquired imaging modality involving myocardial tagging and structure has been demonstrated, as well as varying contraction patterns across the ventricle wall. The results provide implications for cardiac function, such as preferential contraction pathways, and will have an impact on clinical diagnosis and treatment in the future.

References:
1. Torrent-Guasp F et al. “Spatial Orientation of the Ventricular Muscle Band: Physiologic Contribution and Surgical Implications.” J Thorac Cardiovasc Surg 122.2:389-392 (2001). 2. Aletras AH, Ding S, Balaban RS, and Wen H. “DENSE: Displacement Encoding with Stimulated Echoes in Cardiac Functional MRI.” J Magn Reson, 137:247-252 (1999).