Temporal Relationship of Left Ventricular Angular Displacement, Torsion and Strain Assessed by High Frame Rate Tagged Cardiac Magnetic Resonance Imaging

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Introduction
Epicardial myocyte fiber orientation is longitudinal near the base and becomes more circumferential near the apex (1) resulting in a helical pattern. Torsion occurs as a result of the shortening of these helical fibers. We sought to characterize normal torsion and strain development in human subjects. We report the use of high frame rate cardiorespiratory gated 2D-tagged MRI to evaluate the normal timing and magnitude of angular displacement and torsion compared to the principal strains in different cardiac regions.

Methods
Twelve normal subjects (mean age 32±6, 9 male, 3 female) were screened by history, examination, and echocardiography. We used a fast segmented k-space MRI pulse sequence with tissue tagging (2) with the following parameters: cardiac frames=40, field of view=28cm, slice thickness=6mm, acquisition matrix=256x128, tag spacing=6mm, views per segment=2, receiver bandwidth = 32KHz, TR = 6.7msec, TE = 1.8msec, temporal resolution=13.4msec. Five equally spaced short axis images were acquired using a clinical 1.5T scanner (Signa, General Electric Medical Systems). The ECG and respiratory bellows signals were combined using custom electronics and the result was used to suppress respiratory artifact during image acquisition in free-breathing subjects (3). Angular displacement was defined as the change in angular position relative to the slice centroid of all tag intersections through the cardiac cycle. Torsion was defined as the difference in angular displacement between slices. The heart was divided into 4 regions (septal, inferior, lateral and anterior) based on the position of the anterior and posterior right ventricular insertion points and 5 levels from base to apex determined by the image slice location. The maximal principal strain, E1, was determined using a homogeneous strain analysis.

Results
Peak angular displacement occurred earlier at the base compared to the apex (97±13 vs. 313±33msec, p<0.001); however, torsion peaked in a more uniform fashion from base to apex (300±37 vs. 312±37msec., p=NS). The basal angular displacement reversed direction during mid-systole, thereby increasing base to apex torsion. The strain development curve was plotted against torsion for the upper septum and the mid-lateral wall (see Figure 1). These two areas were chosen to highlight any differences in activation time due to delays in the conduction system. We found that the shapes of the torsion curves were different than the strain curves. In early systole, two dimensional strain development exceeded torsion. In mid-systole, however, the normalized slope of the torsion was more rapid, so that by end systole, torsion peaked earlier than strain by ~75msec in both the septum and the lateral wall (see Table 1). We also found that torsion and strain peaked later in the lateral wall compared to the septum.

Figure 1. Mean torsion and maximum principal strain (E1) for the septal and lateral regions of the left ventricle.

Timing of Septal vs. Lateral Strain and Torsion

<table>
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<th>Time (msec)</th>
<th>Septal Torsion</th>
<th>Lateral Wall Torsion</th>
<th>Septal Strain</th>
<th>Lateral Wall Strain</th>
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</table>

Table 1. Mean ± SD of time to peak (ttm) of angular displacement (Ang Disp), torsion, and maximum principal strain (E1) in the septal and lateral regions of the LV. * p<0.02 vs septal.; † p<0.02 versus torsion

Discussion
In early systole, torsion is minimal due to a bulk rotation of the LV, so the torsion curve is sigmoidal because angular displacement is similar at all levels. During isovolumic contraction the fibers cannot shorten so their relationship is constant and minimal torsion is generated. The fibers are connected to the atrioventricular ring and may torque the entire heart a few degrees. As systole progresses, the helical longitudinal fibers shorten, resulting in differential angular displacement from base to apex, or torsion. Peak time to maximal strain and torsion are smaller in the septum than in the lateral wall because the septum finishes contracting earlier with a smaller peak strain and torsion. Since torsion peaks earlier than strain in both regions, and torsion is more dependent on longitudinal fibers, longitudinal strain may peak earlier than radial or circumferential strain. Further analysis of the data may better define this relationship.

Cardiorespiratory gated magnetic resonance imaging with tissue tagging can accurately assess regional variations in the timing of angular displacement, torsion and strain. These indices may be useful in characterizing disease states such as heart failure, transplant rejection and coronary artery disease.

References