Kinematic analysis of left ventricular deformation in myocardial infarction using magnetic resonance cardiac tagging

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Abstract

The Magnetic Resonance (MR) tagging technique provides detailed information about 2D motion in the plane of observation. Interpretation of this information as a reflection of the 3D motion of the entire cardiac wall is a major problem. In finite element models of the mechanics of the infarcted heart, an infarcted region causes motional asymmetry, extending far beyond the infarct boundary. Here we present a method to quantify such asymmetry in amplitude and orientation. For this purpose images of a short-axis cross-section of the ejecting left ventricle were acquired from 9 healthy volunteers and 5 patients with myocardial infarction. MR-tags were applied in a 5 mm grid at end-diastole. The tags were tracked by video-image analysis. Tag motion was fitted to a kinematic model of cardiac motion. For the volunteers and the patients the center of the cavity displaced by about the same amount (p=0.11) during the ejection phase: 3.8±1.4 and 3.0±0.9 mm (mean±sd), respectively. Cross-sectional rotation and the decrease in cross-sectional area of the cavity were both greater in the volunteers than in the patients: 6.4±1.5 vs. 3.0±0.8 degrees (p<0.001), and 945±71 vs. 700±176 mm² (p=0.02), respectively. In the patients, asymmetry of wall motion, as expressed by a sine wave dependency of contraction around the circumference, was significantly enlarged (p=0.02). The proposed method of kinematic analysis can be used to assess cardiac deformation in humans. We expect that by analyzing images of more cross-sections simultaneously, the 3D location and the degree of infarction can be assessed efficiently.

Introduction

Deformation of the left ventricle is sensitive to cardiac disorders such as myocardial ischemia, cardiac infarction and hypertrophic cardiomyopathy [1–4]. Quantitative assessment of the deformation pattern may therefore be useful in the diagnosis of these diseases. The use of Magnetic Resonance (MR) tagging [5–8] was a break-through in the kinematic analysis of the heart. Using the technique of Spatial Modulation of the Magnetization (SPAMM) a grid of tags is attached to the cardiac tissue. Assessment of the motion of the grid enables noninvasive quantification of cardiac deformation.

Maier et al. [2] semi-automatically identified crossing-points of tags and determined rotational and radial displacement. Contours of the left ventricular cross-sections had to be delineated manually in all images. Young et al. [9] analyzed grid line intersection data for displacement, rotation, torsion, and local strains. More recently semi-automatic methods based on active contour models or ‘snakes’ were used to follow deformation of the tagging grid [10, 11]. These snakes were attracted to salient image features and could be interactively directed by external forces. Supervision and intervention were needed because of image artifacts or indistinct boundaries [12].
Interpretation of the MR information as useful clinical knowledge is still a problem. Deformation may be known, but translation of this information to regional function of the myocardial cells is not obvious because of uncertainties in the direction of the myofibers. Another problem is that only a limited amount of image data can be acquired due to the clinically limited acquisition time. The aim of this study was to develop a method to analyze MR tagged images automatically with a focus on deriving the maximum amount of deformation information from a minimum amount of image information.

To describe cardiac deformation we apply a kinematic model. From the viewpoint of data-analysis, the use of such motion foreknowledge enhances the signal to noise ratio in the analysis. The kinematic model is based on finite element calculations of deformation in an infarcted heart [13]. From that study, the effect of malfunction in the infarcted region appeared to extend far beyond the boundaries of that region. A promising variable for the detection of an infarction was asymmetry of contraction in a short-axis cross-section. When using for instance a more conventional measure such as systolic wall thickening [14], the MR-section must always cross the infarcted region, which cannot always be guaranteed. With our approach we hope to get a better estimate of location and severity of contractile disorders for a given, limited amount of MR image information.

In the present study we started simple, with just one short-axis slice of MR tagging information. The number of parameters in the kinematic model was minimal, just enough to describe the presence and degree of regional dysfunction. Besides rigid body motion and ejection, the left ventricular wall was allowed to contract asymmetrically in the first order, i.e., a sine wave dependency of contraction around the circumference. The sine wave was described by 2 parameters, determining the location and amplitude of asymmetry. User-interaction was limited to the approximate delineation of the region of interest in one image.

Methods

Image acquisition

Magnetic Resonance Images were obtained in 9 healthy volunteers and 5 patients using a 0.5 Tesla MR imaging system (Philips Gyroscan T5-II, Philips

Figure 1. MR-tagged short-axis images of the healthy left ventricle during contraction. The images were acquired at 20, 96 and 172 ms (from top to bottom) after the R-wave in the ECG. Deformation of the tagging grid is clearly visible. The tags gradually fade away. In the cavity of the left ventricle they disappear shortly after excitation of the grid due to the ejection of blood.