COMPUTATIONAL MODEL OF THE LEFT VENTRICLE MOTION USING Tagged MAGNETIC RESONANCE IMAGING (tMRI)

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Background: During the systolic motion of heart, apex and base of the left ventricle(LV) perform rotational (twist) motion in addition to their deformation motion; The midventricle, however, is considered as twist free area, where rotation is minimum. As viewed from base, apex rotates clockwise while base rotates counter-clockwise. This twist motion of LV is due to the differences between the structural organization of myocardial fibers in epicardium and endocardium. Study of cardiac motion in apex, base, and midventricle of normal heart is of interest to gain insight into the function of LV that cannot be easily obtained from ordinary short- or long-axis analysis [1]. This paper therefore aims to characterize the twist motion of the LV in the presence of axial deformation quantitatively.

Aims: The goal of this study is to develop a computational model to quantitatively characterize both the deformation and twist motions of the LV of the heart using tagged MRI (tMRI) data from the short axis view of rat and human hearts.

Methods: It has been shown that a Gaussian transformation is effective in describing the deformation of LV in its mid ventricle [2]. However, a simpler function (D) that changes inversely with r, and with better result for the deformation motion, is presented in this paper. Moreover, the deformation model is extended to include the apex and base motion by adding the rotation effect of the LV using the rotational transformation(R).

$$\mathbf{D} = \begin{pmatrix} 1+\frac{\alpha}{r} & 0 \\ 0 & 1+\frac{\alpha}{r} \end{pmatrix} \quad \text{and} \quad \mathbf{R} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \quad \text{with} \quad \theta = \pm\frac{\beta}{r}$$

where r is the distance from the center of LV to the point of interest, α and β are deformation and rotation parameters, respectively, and $\theta(r) = \theta(r)_{apex} - \theta(r)_{base}$ is twist angle between apex and base of the LV at any given point r. Note that the rotational angle of apex (θ_{apex}) and of base (θ_{base}) are defined by a positive and negative angles, respectively. To test our model, we used short axis images of apex and base of the LV from rat and human hearts during the cardiac cycle.

Results: In Fig. 1, the calculated results of deformation and twist motion of the LV based on our mathematical model are superimposed on the short axis images of the apex, the midventricle, and the base of a rat heart, where the result from the model is represented by a two-dimensional mesh, as in [2]. The three images on the left in Fig. 1 are the one near the end-diastole and hence there is little rotation. The three images on the right, on the other hand, have the peak rotation of the apex (upper image) and the base (lower image) that occurred at 40% of the full cardiac cycle. These results demonstrate that our mathematical model accurately describes the deformation and rotational motions of the LV. Figure 2 shows the changes in θ calculated from the model at the mid point between the endocardium and epicardium wall during the cardiac cycle. The deformation parameter changes with the phase number during the cardiac cycle is represented in Fig. 3. The computed rotation profile is in agreement with those reported recently by another study from the rat heart [3]. Compared to the published approaches, an advantage of our model is that it can provide the location change of any given point on the LV wall using one set of tagged MRI data obtained during a full cardiac cycle.

Conclusion: Our computational model is capable to accurately describing the dynamics of deformation and rotation motion of the LV of heart. The calculation of the twist angle based on this model is sensitive to small rotations of the apex and base at different locations of the LV wall. With this model, the twist angle θ as a function of r can be calculated from one set of tagged MRI data obtained during a full cardiac cycle. This model provides another dimension in the study of the twist motion of heart using tagged MRI data. Our current efforts are focused on applying this model on diseased rat and human hearts, which is clinically more relevant.

References:

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2. **Alrefae T**, Smirnova I.V, Cook, and L.T, Bilgen M: A model-based time reversal of left ventricular motion improves cardiac motion analysis using tagged MRI data. Biomedical Engineering Online 2008, 7:15.
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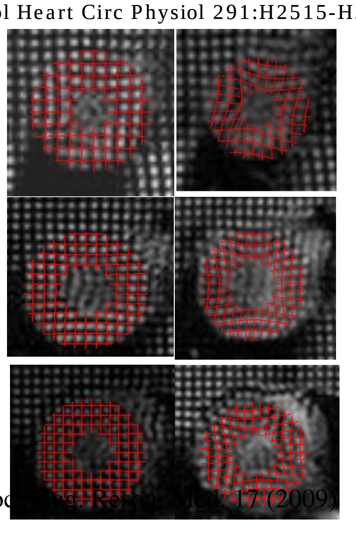
Apex

Midventricle

Base



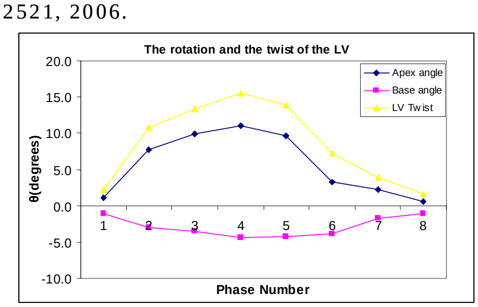


Fig.2. Average changes of rotational angle θ during a cardiac cycle versus phase number. Phase 1 is near the end diastole and phase 4 is at 40% of

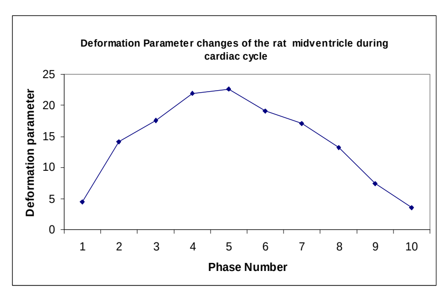


Fig.2. Changes of the deformation parameter during a cardiac cycle of control rat versus phase number. Phase 1 is near the end diastole and phase 4 is at 40% of cardiac cycle.