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Assessment of left ventricle dynamic from cardiac magnetic resonance imaging by means a correspondence approach

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Abstract. In this research, an approach to assess the heart dynamics is reported. The cardiac magnetic resonance images are considered for assessing the left ventricle motion and deformation. The shape of the cavity is obtained by means a segmentation procedure based on a clustering algorithm at an initial instant. This three-dimensional structure is used to establish a region of interest around the border of the structure. An optical flow method allows determining the displacement vector of this region and then defining the shapes of the cavity during the all cardiac cycle. The points of the left ventricle are followed using the displacement vectors in the cardiac cycle, obtaining thus, a dense motion field of the cavity. This approximate deformation field is refined with a correspondence method that working in the three-dimensional space. The mapping of the points that define the left ventricle in the cardiac cycle obtained with the correspondence procedure are then used for computing a set of clinical parameters that allows assessing the motion and deformation of this principal structure of the human heart. The torsion, radial and longitudinal contraction are quantified. The obtained results are promising for evaluating the heart dynamics.

1. Introduction

An important indicator of cardiovascular damage is the estimation of the motion and deformations of the myocardial wall due to the fact that it allows a deeper understanding of the function of this muscle. Both the reduction in myocardial stress and the intrinsic motions of the left ventricular cavity evidence the ischemia in the muscle [1, 2]. Magnetic resonance imaging (MRI) has been used to accurately estimate cardiac muscle motion and deformations in a non-invasive manner [3, 4], which evidences the scientific community interested in developing computational techniques that guide the understanding and identification of cardiac dynamics from medical images.

In clinical routine, for the calculation of left ventricle volumes, it is assumed that the ventricle has an ellipsoidal shape, where the major axis (L) of such geometric shape corresponds to the length between the valve aortic and apex, as shown in Figure 1. The minor axes D_1 and D_2 are considered equal and they are estimated from the major axis and the ellipsoid volume.

The left ventricle is the most important cavity in the human heart. Basically, the left ventricle dynamic behavior depends on two characteristics:

- The associated deformations to the cardiac muscle are derived from the muscular fibers contraction-relaxation process;
- The applied force and speed when contracting the cardiac muscle is different in each human, additionally, these parameters are variable with time and location of the muscle fibers.

In consequence, the left ventricle has a complex dynamical behavior that cannot be represented using a simple mathematical expression. The left ventricle motion during the systolic phase is considered as the combination of five types of movements: 1) translation, 2) rotation, 3) twisting, 4) accordion-like movement, and 5) movement of the endocardium towards the interior of the ventricular cavity. These components are not uniform throughout the left ventricular cavity. For example, the accordion-like movement with respect to the anatomical axis (aortic valve–apex) is significantly asymmetric. During systole, the plane of the mitral valve descends 1 to 2 centimeters towards the apex in adults with normal cardiac function, but the apex barely moves towards the base of the heart [5]. Out of possible motions of the heart, the movement of the endocardium towards the interior of the ventricular cavity is the dominating one in both ventricles, followed by the accordion-like movement [6]. The other three movements are less important when the cardiac muscle is normal [7]. Thus, the ellipsoid geometrical model is a poor representative of the left ventricular shape and leads to inaccuracies in the assessment of the left ventricle motion.

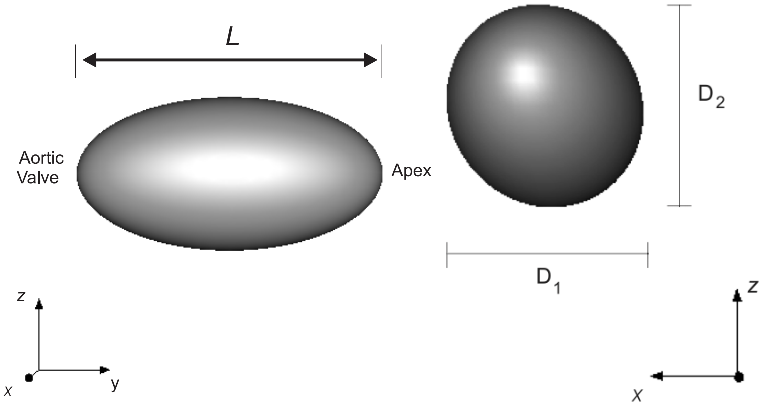


Figure 1. Ellipsoid that models the 3-D ventricular shape.

The electrophysiological and mechanical behavior of the cardiac muscle can be understood through the development of four dimensional (4-D) models that represent the heart function and dysfunction. In order for these models to contribute to the assessment of cardiac function, it is ideal that they be constructed from realistic organ information, in that sense, their construction from dynamic three-dimensional (3-D) image data is necessary [8].

The objectives of this work are focused on constructing a left ventricle model in 4-D (3-D time) and improving the knowledge about the left ventricle motion and deformation from MRI cardiac images.

2. Materials and methods

2.1. Materials

The proposed model requires information about the shape of the ventricular cavity. Such information is proposed to extract from cardiac magnetic resonance images (MRI).The images are acquired at the Centre Cardio–Pneumologique in Rennes, France. A 1.5-T MRI system, Signa LX General Electric Medical Systems is used for performing all explorations. In the explorations, ten contiguous cine short axis slices are acquired using ECG gating. The Table 1 shows the acquisition parameters. Two MRI datasets are considered in this work.

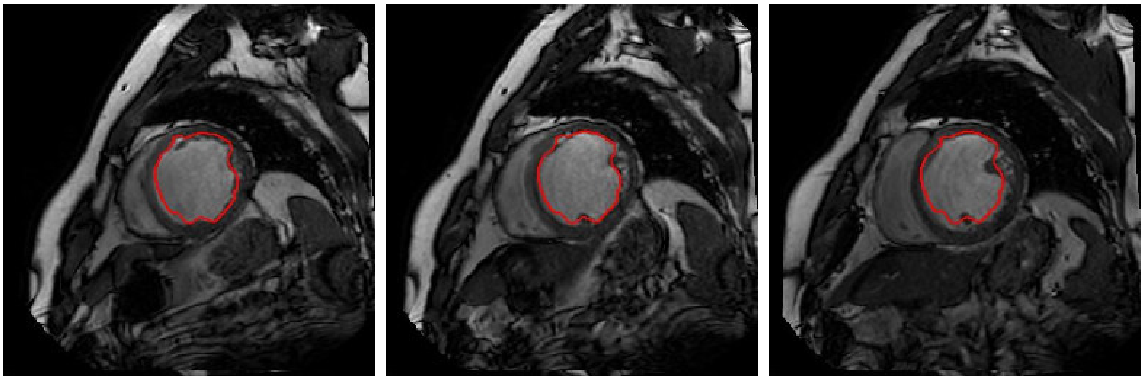
Table 1. MRI adquisition parameters.

Parameter	Value
TR	5 ms
TE	2 ms
Flip angle	40°
Slice thickness	7 mm
Matriz size	256×256
Field of view	420×420 mm
Images per cardiac cycle	40

2.2. Methods

From the MRI datasets, the approximate shape of the left ventricle is extracted using a clustering algorithm. Such an algorithm works in three–dimensional space and it is based on region growing segmentation technique. This segmentation technique requires an image element seed located inside the anatomical structure, and then extends to neighboring elements with similar image features [9].

The segmentation algorithm is computationally developed using the class of the medical image processing library in C ++ contained in the insight segmentation and registration toolkit (ITK) [10]. The class allows to segment image elements with similar statistics using a connectivity criteria. As a seed image element, the center of the three-dimensional image is considered. Such a class extracts a connected set of image elements whose intensities are consistent with the statistics of the image element considered from a seed point. The mean and variance across a neighborhood are calculated from a seed point. Subsequently, the voxels connected to this seed point are grouped whose values are within the confidence interval for the seed point. The confidence interval is the average plus or minus the control variable multiplied by the standard deviation. Figure 2 shows some slices of a dataset segmented. As can be seen from the Figure 2(a), Figure 2(b), and Figure 2(c), the segmentation obtained is not accurate, especially in the region that contains the papillary muscles.



(a) (b) (c)

Figure 2. Segmentation results. (a) Near the apex. (b) On the equator. (c) At the base.

The marching cube algorithm [11] is used to reconstruct the left ventricle three-dimensionally. Marching cubes have long been used as a standard method of indirect representation of volume from the iso-surfaces extracted from 3-D volumetric data [12]. The reconstruction is implemented with the help of the classes contained in the free distribution visualization software, visualization toolkit (VTK) [13]. Figure 3(a) and Figure 3(b) show two different views of the reconstructed 3-D left ventricle shape.

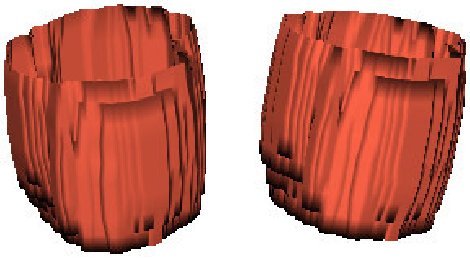

(a) (b)

Figure 3. Three-dimensional shape of the left ventricle. (a) Anterior view. (b) Posterior view.

A region of interest around the edge of the cardiac structure is then defined. This region is defined 20 pixels above the ventricular edge determined by the clustering algorithm. The region of interest established can be seen on each slice in Figure 4. The region of interest thus defined contains myocardial muscle information, as can be seen for three different slices in the Figure 4(a), Figure 4(b) and Figure 4(c).

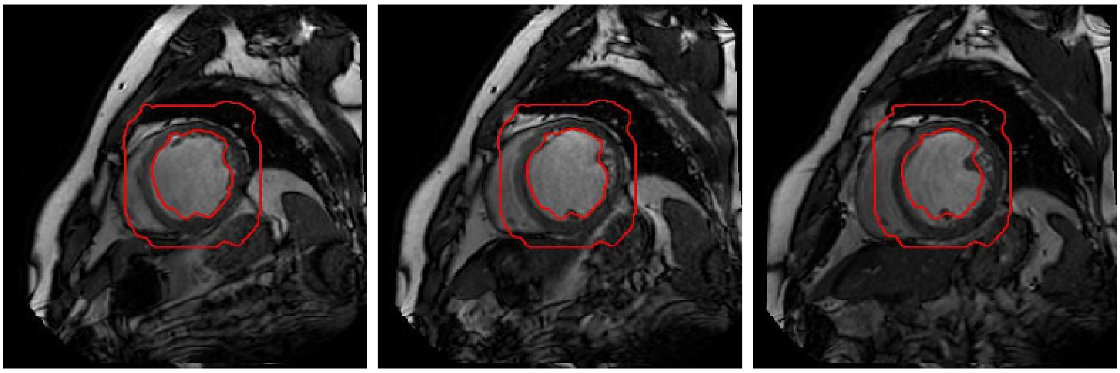

(a) (b) (c)

Figure 4. Regions of interest. (a) Near the apex. (b) On the equator. (c) At the base.

The motion of the myocardial wall of the left ventricle is analyzed on the region of interest previously defined considering an algorithm of optical flow [14]. The idea is to extract the apparent motion of the ventricular surface, by determining the apparent motion of the image elements in each consecutive MRI slice. The image data provided to optical flow algorithm by the region of interest in the MRI image allow determined the direction and orientation of the displacement vectors of this image region in the three-dimensional space.

The information about the cavity motion determined using optical flow, is optimized, first considering a 2-D nonrigid correspondence algorithm that establishes a correspondence between the consecutive displacement vectors obtained by optical flow. After, a 3-D curvature–based correspondence algorithm allows to optimize the previous correspondence. The method proposed by [15] is considered in this work in order to perform this optimization stage.

3. Results

The result of the optical flow allows to know where each point of the ventricular surface is oriented during the cardiac cycle as shown in the Figure 5. However, this apparent motion does not fully describe the ventricular dynamics, therefore the proposed optimization scheme must be applied and thus ensure that the final extracted motion corresponds to the true motion of the anatomical structure

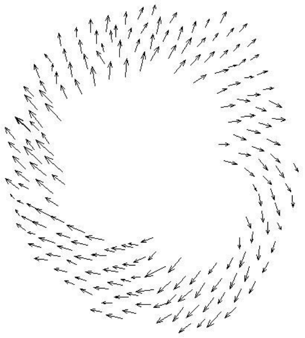
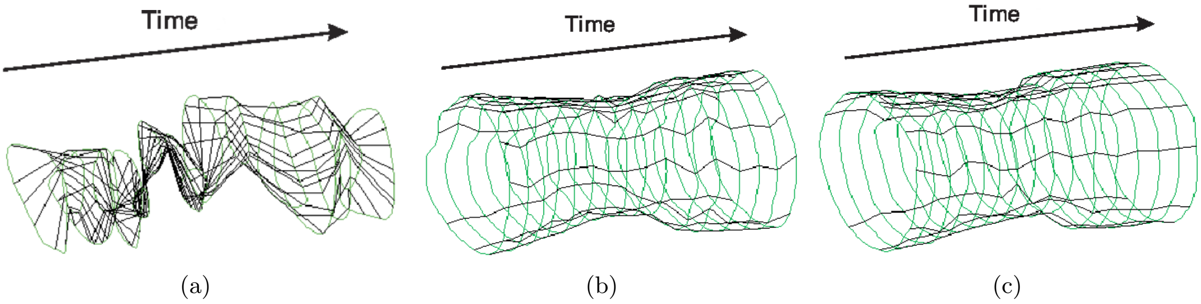


Figure 5. Displacement vector field obtained using optical flow.

Start points of each displacement vector are considered points between consecutive frames whose correspondence will be optimized by means of the non–rigid correspondence algorithm considered. Figure 6 shows the graphs of how the correspondences obtained from the left ventricle surface at apex, equator and the base of the cavity evolve over the cardiac cycle. In the Figure 6(a) it can be observed when moving towards systole (half of this graph), the translations and rotations associated with the apex of the endocardial wall, which represent an important pattern in the dynamic behavior of healthy subjects [16]. This behavior tends to soften as you approach final diastole. In the remaining graphs, it can be seen that the deformations associated with the contours that define the equator and the base of the left ventricle are smaller than those found at the apex level. Looking closely at such figures, the change of direction of the flow lines between points in correspondence can be verified, for those moments near the final systole. This is more evident at the equator level (Figure 6(b)) than at the base level (Figure 6(c)). The dynamics associated with the areas of the myocardium near the base of the left ventricle, when compared to the dynamics of the regions near the apex, are slower because this area is fixed by anatomical structures such as the atria, veins and arteries.



(a) (b) (c)

Figure 6. Evolution of correspondences for the LV. (a) At the apex. (b) On the equator. (c) At the base.

From the final displacement vector field of the endocardial wall of the left ventricle, a set of clinical parameters can be quantified for assessing the dynamic cardiac function. The indexes of radial contraction, longitudinal contraction and torsion are calculated in the planes at apex, equator and base. The radial distances measured along an axial plane allow to quantify the average contraction, whereas the changes along the longitudinal axis of the LV is estimated using the longitudinal contraction. On the other hand, the torsion index estimates the rotation of the heart from left to right at the instant when the contraction occurs.

Figure 7, Figure 8, Figure 9 show the radial contraction, longitudinal contraction and torsion indexes calculated from the correspondences obtained. Such parameters are calculated over 16 instants of cardiac cycle time. The final systole (maximum ventricular contraction) occurs at time 8 while the final diastole (maximum ventricular relaxation) occurs at time 16.

From the graph of average radial contraction of the left ventricle (Figure 7), it can be concluded that the maximum magnitude of contraction occurs at the apex level, the radial contraction at the apex level is greater with respect to the base. The slope of the line between two consecutive time instants shows that the radial contraction is greater as the cardiac cycle progresses towards the final systole and decreases when the final diastole is advanced in the three planes (apex, equator and base).

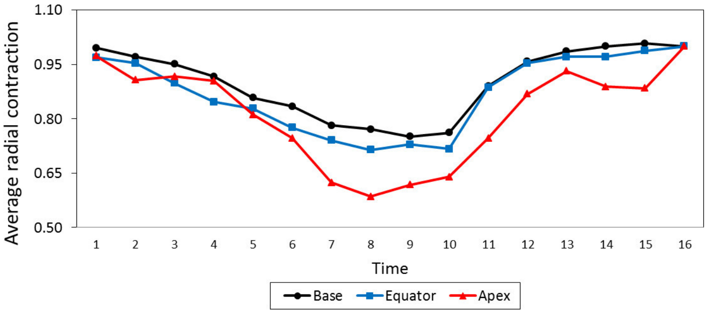


Figure 7. Radial contraction index.

With respect to longitudinal contraction (Figure 8), the greatest longitudinal shortening occurs at the base level, the apex moves very little in the direction of the base.

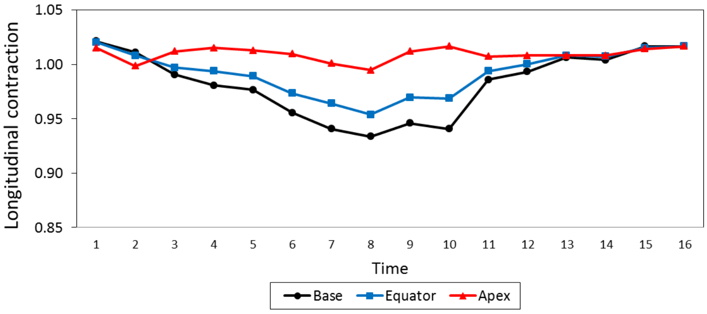


Figure 8. Longitudinal contraction index.

From the Figure 9, it can be seen that the amplitude of the torsion is greater at the apex and at the base with respect to the equator. The values of torsion at the apex and at the base have opposite signs, which indicates that the left ventricle is twisted in opposite directions at the base and the apex. In addition, small torsion values are observed when it is very close to the beginning of the systole (time 4) with gradual increments when moving towards the final systole (time 8).

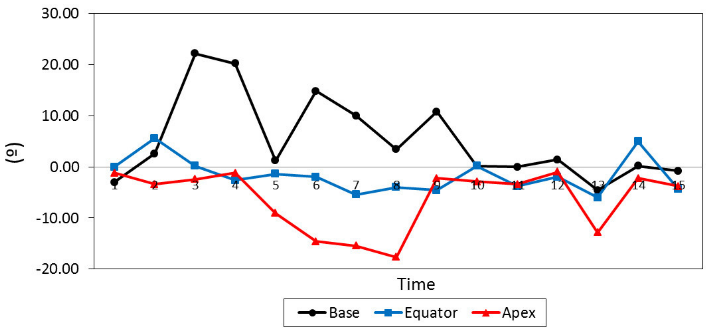


Figure 9. Torsion index.

4. Conclusions

In this work, a method for assessing of left ventricle dynamic from cardiac magnetic resonance imaging based on optical flow and a correspondence approach for calculating of Euclidean transformation that defines the motion between points of the cavity surfaces at the consecutive time instants, are reported.

The process of contraction/relaxation of the cardiac muscle fiber is accurately described by means of the field of the displacement vector obtained from the results achieved are consistent with the left ventricle motion considerations previously reported.

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