Global and regional deformation analysis of the myocardium : MRI data application

Rim AYARI ABID[1], Asma BEN ABDALLAH[1], and Mohamed Hédi BEDOUI[1]

Biophysics laboratory-TIM, UR 08-27 Faculty of Medicine of Monastir, Tunisia

Abstract. One of the major concerns in cardiac imaging is finding an efficient method for the deformation analysis in the left ventricle of the heart (LV). This paper deals with the results of using a regional analysis of left ventricular of the heart applied on MRI data. Our analysis consists of segmenting 3D objects modeling the myocardium of the LV into 17 regions according to the AHA (American Heart Association) standard. Curvature variation was calculated using the Hotelling MT2 two samples difference metric for the global objects and their different 17 regions during 25 instants of the cardiac cycle. It has been validated with real MRI data. Experimental results demonstrate the great robustness and efficiency of our method to detect pathological regions of myocardium.

Keywords: Heart left ventricle (LV), 3D object, AHA standard, Surface curvature, MRI data, Modified Hotelling MT2 metric, Regional analysis.

1 Introduction

Coronary Artery Disease (CAD) involves the narrowing of the coronary arteries that supply the heart tissue with oxygen and nutrients due to plaque built up along the inner walls of the arteries of the heart. It is the most common cause of heart attacks. The diagnosis of CAD is based on the determination of the site, the extent and the severity of the pathology. In this context, there have been several contributions to determine precisely the location and the extent of stenosis in case of CAD. Among these methods we cite superquadric model [14, 10], baseline surface [11], regional volumes evolution [12], quadric fitting methods [1], three-dimensional active mesh models [13] and regional curvature analysis [20]. We note that using curvature values to analyse the LV deformation is one of the most used methods for 2D and 3D images. Several methods used curvatures, we cite Friboulet et al. [21], were they have calculated the curvature distribution on the left ventricle surface using an iterative relaxation scheme. Curvature distribution values is displayed by voxel. From this visualization they have evaluated the structural stability of the curvature characteristics with the left ventricle deformation. Clarysse et al. [22] have used regional approach based on curvature values in order to analyze specific areas of the endocardium. They have combined geometrical and spacial information in order to reach spatiotemporal analysis and automatic recognition of deformable surfaces. In a previous work

[3, 4], we used curvature values to detect pathology extent in data obtained from myocardial scintigraphy imaging techniques. The work presented in this paper consists of using curvature values and the modified Hotelling T2 metric (MT2) to accurately localize and quantify deformations in LV for data obtained from MRI techniques. Our approach was tested on six patients. Each patient had 25 3D object showing its evolution of the different instants between diastole and systole. The paper is organized as follows. First the proposed method and its different steps are detailed. Then, the database which used to validate our approach are presented. After that, the obtained results are discussed. Finally the main conclusions and suggests directions for future works are proposed.

2 Method

The aim of this work is to study the myocardium movement during the cardiac cycle. More precisely, we want to detect regions with pathological behavior. The first step is to study the global variation of the myocardium to know its status: whether it is pathological or not. The second step is to divide the 3D object that modeling the myocardium. We adopt the AHA standard because it allows an adequate sampling.

2.1 Partitioning of LV surfaces into 17 regional segments

AHA standard recommends a division into 17 regions as described in figure 1. The myocardium is divided into four sections in the long axis, namely the basal, middle cavity, apical and apex regions. The apical part is then geometrically divided into four regions. Each part of the basal and middle cavity is also geometrically divided into six regions.

2.2 Triangular mesh generation

Since the curvature computing requires the use of polygonal surface mesh, a triangulating surface process is applied for every resulted region after applying the AHA division. For the triangulation, we adopt the Delaunay triangulation method. According to the Delaunay definition, the triangle circumcircle formed by three points from the original set is empty if it contains no other vertices than its own. Replacing the circles circumscribed by spheres, it is possible to extend the definition to three dimensions.

2.3 Curvature computation and modified Hotelling MT2 metric

In this work, we use the MT2 two-sample group difference metric for the myocardium global and regional analysis. The MT2 metric provides an extent for differences between SPHARM descriptors values at stress and rest. It is very effective for the computation of two group differences. In [6] authors have used

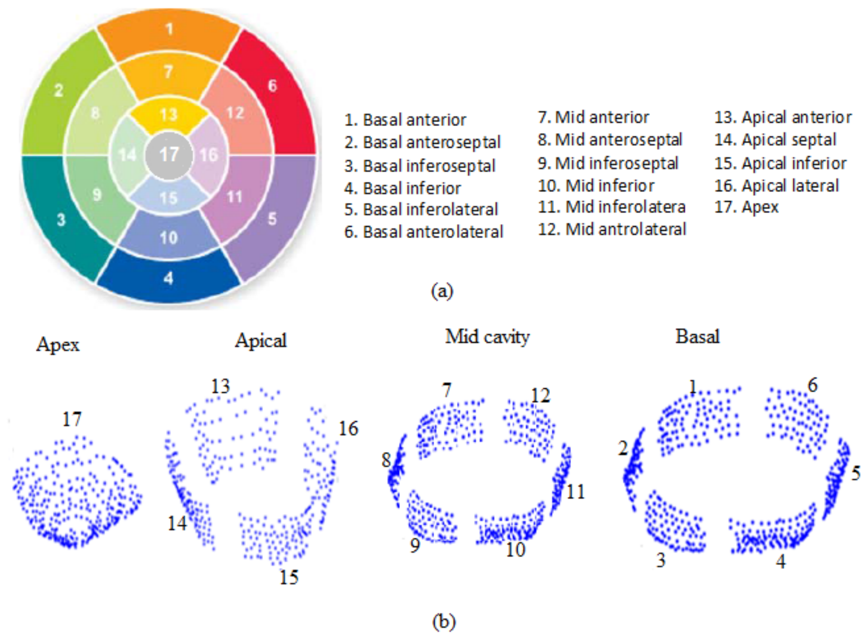


Fig. 1. (a) Standardized international nomenclature for the LV and correspondence on the mesh, (b) LV regions of interest.

the MT2 metric for statistical shape analysis using spherical wavelet shape representation. Given a group i with n_i samples, we designate by μ_i the mean and by Σ_i the covariance of a 3D feature. The MT2 for two groups 1 and 2 is given by equation 1.

$$T2 = (\mu_1 - \mu_2)^T (\Sigma_1 \frac{1}{n1} - \Sigma_2 \frac{1}{n2})^{-1} (\mu_1 - \mu_2) \tag{1}$$

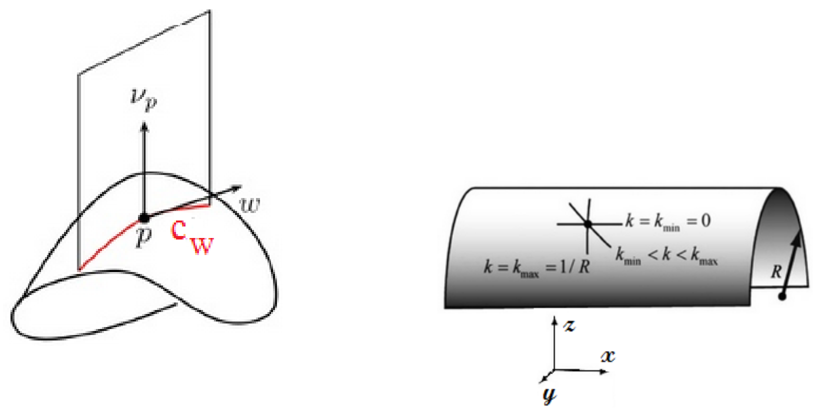
As descriptors, we use Gaussian and Mean curvature values. Curvature provides information to describe how a surface changes its shape locally. Given a point P on a surface M, we call Vp, the normal vector and W the tangent vector belonging to TpM which is the tangent space (figure 2). The curve can be defined as the intersection of M with the plan spanned by the normal vector and W [23]. This plane is given by:

$$(t, s) \mapsto p + tv_p + sw$$

The curvature of such a curve C_w is the normal curvature K_w of M in the direction W. Then C_w is given implicitly by:

$$f(p + tv_p + sw) = 0 \ \forall t, s$$

With f is the regular map .



(a) (b)

Fig. 2. (a) Normal curvature of a point on a surface, (b) Directions of the principal curvatures of cylinder (radius R).

$$K_w = < W, T_p v \cdot W > \tag{2}$$

Where $< .,. >$ denotes the standard inner product and $T_p v$ is the Weingarten map [23]. The principal curvatures K_{min} and K_{max} (see figure 2) are the extreme normal curvature K_w relative to the principal curvature directions W_{min} and W_{max}. The gaussian curvature K_G is defined as the product of principal curvature as described in equation 3.

$$K_G = K_{min} * K_{max} \tag{3}$$

The mean curvature K_M is the arithmetic mean of principal curvatures (equation 4).

$$K_M = \frac{K_{min} + K_{max}}{2} \tag{4}$$

3 Experimental results

3.1 Database structure

Our database is composed of 150 3D objects outcome of cardiac MRI imaging techniques of six patients. These objects are obtained after a delineation of a set of 2D image sequences. Such a set is used to construct a 3D triangular meshes. Each patient has 25 objects for different 25 instants of cardiac cycle. Figure 3 shows an example of these objects at instants T1, T7 and T25. We note that T1 is the beginning of diastole, T7 is the end of diastole and the beginning of systole and T25 is the instant of end systole.

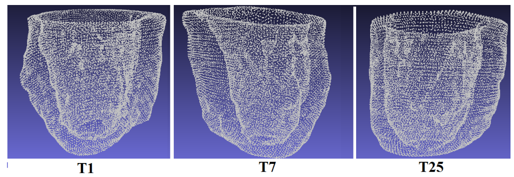


Fig. 3. Rendered surfaces of the myocardium at T1 : beginning of diastole, T7 : end of diastole and the beginning of systole and T25 : end systole.

3.2 Results and discussion

Firstly, we compute the curvature values of every point in the 25 objects of each patient. The Hotelling MT2 values is then calculated between each two successive instants : we calculate the curvature values variation between T1 and T2, then between T2 and T3 up to T24 and T25. Values are then presented in six curves as shown in figure 4.

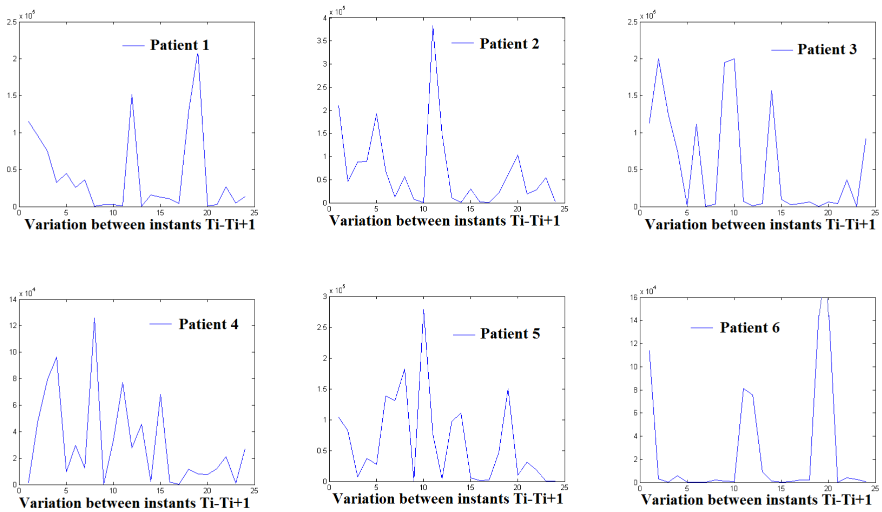


Fig. 4. Global variation of curvature values at 25 instants

This different curves are used to specify the pathological state of the different patients. We noticed that, for patient 1, 2 and 6, the variation of curvature values is lower than other patients. During several instants the myocardium of these patients has not moved well and it had a reduced kinetic. Thus, our approach may be an efficient way for characterizing the myocardium disease severity. We will see later that the regional analysis can provide more significant information about the disease extent of these patients.

Afterwards, we proceeded to the analysis of regional LV deformation. First, each 25 object modeling myocardium of every six patient are divided into 17 regions according to AHA standards. For each region, we proceed by calculating separately its curvatures values after applying the triangulation process. After that, we compute for every region the Hotelling measure between different curvature values. The obtained results are reported in Figure 5. We are interested in patients 1, 2 and 6. As shown, the regional curves of these patients show a lot of regions with low curvature values variation. This proves that these regions have not a good kinetic. Contractility of regions are low when its MT2 values are not high. More precisely, these regions indicates the poorly irrigated territories of the heart and allows to have a precise location of the ischemia. These results may refine the diagnosis, experts may revise their initial diagnosis based on simple visualization by providing objective arguments. Indeed, our measurements could qualify the site as well as the disease extent.

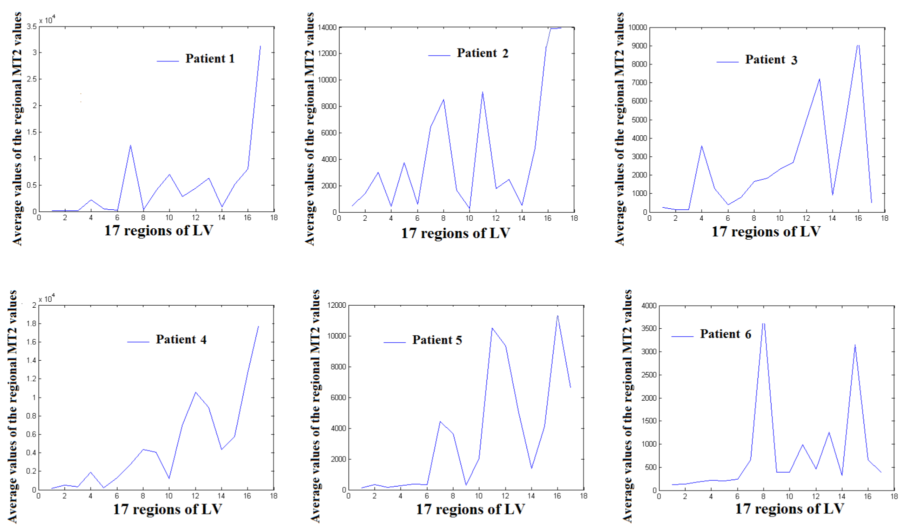


Fig. 5. Average of regional variation of curvature curvature values

4 Conclusion

The present work is aimed at offering a global and regional analysis of the LV in order to refine the diagnosis and specify the ischemic territory. Our approach was tested on 150 3D objects outcome of cardiac MRI imaging techniques of six patients. We used the Hotelling metric MT2 computation for curvature values variation at the vertices of the triangulation of 3D objects modeling the myocardium. In order to progress to a regional analysis, we carried out, a division into 17 regions according to the AHA standard. This method provides a good agreement between the global and regional analysis. These results need to be well oriented by enriching the database and getting supplementing information about the studied patients.

References

1. Y. Su, L. Zhong, CW. Lim, D. Ghista, T. Chua, RS. Tan: A geometrical approach for evaluating left ventricular remodelling in myocardial infarct patients. Computer methods and programs in biomedicine, v 108, Issue 2, 2012, pp 1–11.
2. A. BenAbdallah, F. Ghorbel, K. Chattia, H. Essabbaha, MH. Bedoui: A new uniform parameterization and invariant 3D SPHARM shape descriptors for shape analysis of the hearts left ventricle A pilot study. Pattern Recognition Letters, v 13, 2010, pp 1981–1990.
3. R. Ayari, A. BenAbdallah, F. Ghorbel, MH. Bedoui: Analysis of Regional Deformation of the Heart's Left Ventricle Using Curvature Values with Hotelling T2 Metric, Computer Graphics, Imaging and Visualization (CGiV), IEEE 13th International Conference, 2016, pp 115–118.
4. Rim AYARI, Asma BEN ABDALLAH, Faouzi GHORBEL and Mohamed Hdi BEDOUI. Analysis of Regional Deformation of the Heart Left Ventricle. Medical Imaging, IRBM - Elsevier "Innovation and Research in BioMedical engineering, v 38, 2017, 90–97.
5. H. Huang, L. Shen, R. Zhang, F. Makedon, B. Hettleman, J. Pearlman: Surface Alignment of 3D Spherical Harmonic Models: Application to Cardiac MRI Analysis, Lecture Notes in Computer Science, Vol. 3749, 2005, pp 67–74.
6. Nain, D. Styner, M. Niethammer, M. Levitt, J. J. Shenton, M. E. Gerig, G. Tannenbaum: tatistical shape analysis of brain structures using spherical wavelets, In Biomedical Imaging: From Nano to Macro, IEEE International Symposium ,2007, pp 209–212.
7. D. Goldberg-Zimring, I. Talos, F.Bhagwat, J. G. Haker, S. J. Black, P. M. Zou, K. H: Statistical validation of brain tumor shape approximation via spherical harmonics for image-guided neurosurgery. Academic radiology, 12(4), 2005, pp 459–466.
8. H. Huang, L. Shen, R. Zhang, F. Makedon, B. Hettleman, J. Pearlman: Surface Alignment of 3D Spherical Harmonic Models: Application to Cardiac MRI Analysis, Lecture Notes in Computer Science, Vol. 3749, 2005, pp 67–74.
9. M. Styner, I. Oguz, S. Xu, D. Pantazis and G. Gerig: Statistical group differences in anatomical shape analysis using Hotelling T2 metric. Medical Imaging, 2007, pp 65123–65123.
10. E. Bardinet, L. Cohen, N. Ayache: Tracking and motion analysis of the left ventricle with deformable superquadrics. Medical Image Analysis, v 1, 1996, pp 129–149.
11. M. Hubka, JA. McDonald, S. Wong, EL. Bolson, FH. Sheehan: Monitoring change in the three-dimensional shape of the human left ventricle. JAm Soc Echocardiogr, v 17, 2004, pp 404–410.
12. F. Bernis, Ch. Léger, V. Eder: Regional analysis of left ventricle of the heart. Computerized Medical Imaging and Graphics, v 30,pp 153–161, (2006).

13. S. Kermani, MH. Moradi, H. AbrishamiMoghaddam, H. Saneei, MJ. Marashi, D. ShahbaziGahrouei: Quantitative analysis of left ventricular performance from sequences of cardiac magnetic resonance imaging using active mesh model. Computerized Medical Imaging and Graphics, v 33, 2009, pp 222–234.
14. F. Solina, R. Bajcsy: Recovery of parametric models from range images , The case for superquadrics with global deformation. IEEE Computer Society Press, v 12, 1990, pp 549–553.
15. G. O. Young, "Synthetic structure of industrial plastics (Book style with paper title and editor)," in *Plastics*, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 15–64.
16. CH. Brechbühler, G. Gerig, O. Kübler: Parametrisation of closed surfaces for 3D shape description. Computer image and vision understanding, v 61, pp 154–170, (1995).
17. A. Kelemen, G. Szekely, G. Gerig: Elastic model-based segmentation of 3D neuroradiological data sets, IEEE Trans. Med. Imaging, vol. 18, No. 10, pp 828-839, (1999).
18. M. Styner, JA. Lieberman, D. Pantazis, G. Gerig: Boundary and medial shape analysis of the hippocampus in schizophrenia, Medical Image Analysis, vol. 8, No. 3, 2004, pp 197–203.
19. G. Gerig, M. Styner, D. Jones, D. Weinberger, J. Lieberman: Shape analysis of brain ventricles using SPHARM, MMBIA, pp 171–178, (2001).
20. G. Mancini, SF. DeBoe, MJ. McGillem, and ER. Bates: Quantitative regional curvature analysis: A prospective evaluation of ventricular shape and wall motion measurements, Amer. Heart J., vol. 116, No. 6, 1988, pp 1616–1621.
21. Denis Friboulet, Isabelle E Magnin, Christophe Mathieu, Andreas Pommert, and Karl H Hoehne. Assessment and visualization of the curvature of the left ventricle from 3d medical images. Computerized Medical Imaging and Graphics, 1993, 257–262.
22. Patrick Clarysse, Denis Friboulet, and Isabelle E Magnin. Tracking geometrical descriptors on 3d deformable surfaces : application to the left-ventricular surface of the heart. Medical Imaging, IEEE Transactions on, 1997, 392–404.
23. Kunzinger, Michael. Differential geometry 1.Summer Term, 2008.