Regional Curvature Analysis in the Left Ventricle of the Heart using Hotelling T2 Metric

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Abstract—**This paper proposes a method for local deformation analysis of the heart's left ventricle (LV) which is of an utmost interest in characterizing the myocardium disease extent and severity. Our method is based on regional curvature variation calculation using the Hotelling T2 two samples difference metric. Our approach is validated on real data obtained from myocardial scintigraphy imaging technique. The curvature variation is calculated at stress and rest. Experimental results demonstrate the effectiveness and the validity of our approach.**

Index Terms—**Heart's left ventricle, myocardium scintigraphy, AHA standard, Surface curvature, Hotelling T2 metric, 3D object.**

I. INTRODUCTION

The shape analysis of the heart's left ventricle is used to better characterize the disease extent. In this context, several studies for the analysis of LV wall motion have been made. Ben Abdallah et al. [2] used the spherical harmonics functions to generate invariant descriptors with respect to the three geometric transformations: translation, rotation and scale to closed surfaces represented by triangular meshes. Global invariant descriptors were used to compute distances between endo- and epicardium at stress and rest respectively in order to diagnose coronary artery diseases (CAD) and to determine the severity of the pathology. Bernis et al. [3] have proposed a method to analyze the local wall motion of the heart's LV. This method is based on the estimation of local cardiac parameters such as evolution of regional volumes as function of time, ejection fraction, end-diastolic and end-systolic instants.

Besides, Hubka et al. [4] have developed a method for measuring change in regional LV shape by using a baseline surface with respect to some distance functions.

It is well known that curvature is one of the most useful criteria for local description of a given surface. According to the reviewed literature, we note that the local curvature provides an effective regional measure and it could be strongly applied to analyze surface deformation. Bourouis

[1] has used curvature for subcortical identification and labeling of 3D medical MRI images. He provides a segmentation procedure using geometric curvature properties. Authors in [5] have used quadric fitting methods to obtain the underlying geometry of the LV as well as a curvedness shape descriptors. Yong Yeo et al. [9] have proposed a curvature based method for the left ventricular shape analysis.

In this work, we aim to quantify the local deformations in the LV by measuring the regional curvatures variation between rest and stress using the Hotelling T2 metric.
The rest of this paper is organized as follow. The suggested method is presented in section 2. Experimental results are presented in section 3. Finally, section 4 summarizes the main discussions and conclusions.

II. PROPOSED METHOD

Our approach is based mainly on three essential steps. As input, we use a 3D surface represented by triangulated mesh. The first step is intended to divide the 3D surface object into 17 regions using the AHA standard. For every resulting region, the second step aims to compute the gaussian and mean curvatures related to every point. Finally, in the last step we analyze the curvature variation values in the LV performed at stress and rest using the Hotelling T2 metric.

A. 3D Object Segmentation and Mesh Generation

As input for the 3D segmentation process, we use four triangulated meshes representing the endocardium and epicardium at rest and the endo- and epicardium at stress. To divide every anatomical structure, we adopt the AHA standard (American Heart Association) [6] instead of an arbitrary division that is not useful for clinical use. This first step consists in first, segmenting the triangulated mesh and second generating 17 triangulated meshes.

3D object segmentation: The AHA standard is used in cardiology to segment the LV into 17 regions. First, the

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LV is divided along the Z-axis into four sections namely basal, middle cavity, apex and apical. The apical part is then divided into four regions (Fig. 1, regions: 13, 14, 15, 16). Every part of basal (Fig. 1, regions: 1, 2, 3, 4, 5, 6)and middle cavity (Fig. 1 regions: 7, 8, 9 10, 11, 12) is also divided into six regions.

After the 3D segmentation process, every region is described by a point cloud.

The resulting regions are provided in the table I.

TABLE I.

17 REGIONS OF THE HEART'S LEFT VENTRICLE

Range	Region's name		
1	Basal anterior	10	Mid inferior
2	Basal anteroseptal	11	Mid inferolateral
3	Basal inferoseptal	12	Mid anterolateral
4	Basal inferior	13	Apical anterior
5	Basal inferolateral	14	Apical septal
6	Basal anterolateral	15	Apical inferior
7	Mid anterior	16	Apical lateral
8	Mid anteroseptal	17	Apex
9	Mid inferoseptal		

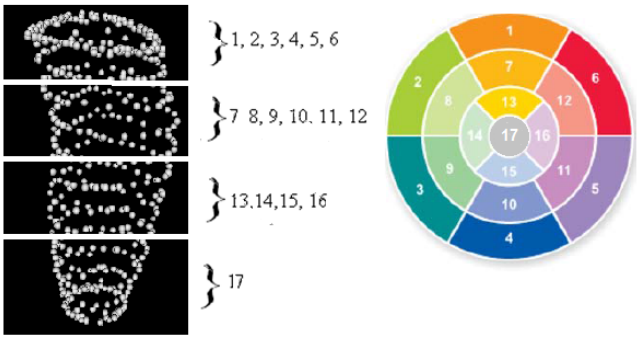

Figure 1. Standardized international nomenclature for the LV and correspondence on the mesh (left) [6].

Mesh generation: Since the curvature compute requires the use of polygonal surface mesh, a triangulating surface process is applied for every resulted region. We use the Delaunay triangulation method [10] (Fig. 2).

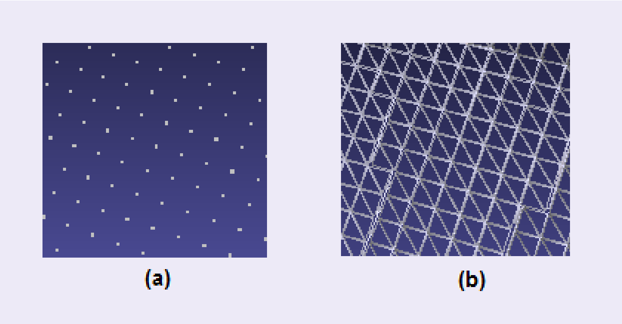

Figure 2. (a) The point clouds, (b) The triangular mesh obtained after applying Delaunay triangulation.

The next step details the surface curvature computing.

B. *Computation Surface Curvature*

The goal of curvature is to describe how a surface changes its shape locally. In this work, we use gaussian (2) and mean (3) curvature. Given a point P on a surface M, we called V_p, the normal vector and W the tangent vector belonging to T_pM which is the tangent space (fig. 3). The curve can be defined as the intersection of M with the plan spanned by the normal vector and W. The curvature of such a curve C_w is the normal curvature K_w of M in the direction W. This curvature is defined by (1).

$$K_w =< w, T_p . w > . \tag{1}$$

Where <.,.> denotes the standard inner product .

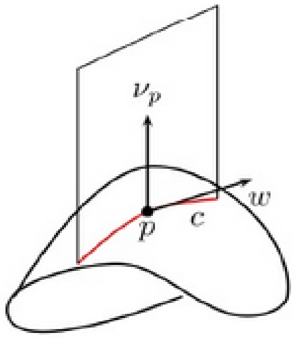

Figure 3. Normal curvature [7]

The principal curvatures K_{min} and K_{max} (see fig. 4) are the extreme normal curvature K_w relative to the principal curvature directions W_{min} and W_{max}.

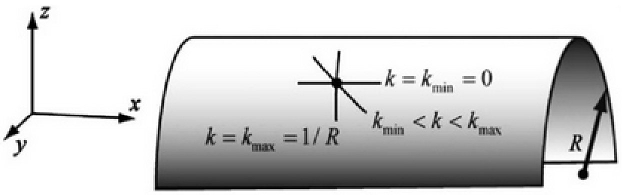

Figure 4. Principal curvatures directions [8].

The gaussian curvature K_G is defined as the product of principal curvature as described in (2).

$$K_G = K_{\min} * K_{\max} . \tag{2}$$

The mean curvature K_M is the arithmetic mean of principal curvatures.

$$K_M = \frac{K_{\min} + K_{\max}}{2} . \tag{3}$$

After computing the mean and gaussian curvature values in each point in the surface mesh, the next step is to analyse the variation of these values at stress and rest using the Hotelling T2 metric.

C. Hotelling T2 Metric

The novelty of our work is the use of the Hotelling T2 two-sample group difference metric for the LV regional analysis.

Yong Yeo et al. [9] have computed the principal curvatures average in every point of the 17 surfaces in the LV. The curvature average weak is his inability to differ between two groups if one contains low and high values and the second contains values close to the first group average.

The Hotelling T2 metric provides an extent for differences between gaussian and mean curvature values at every surface location. It is very effective for the computation of two group differences.

Given a group i with n_i samples, we designate by μ_i the mean and by by $\sum_i$ the covariance of a 3D feature. The Hotelling T2 for two groups 1and 2 is given by (4).

$$T2 = (\mu_1 - \mu_2)^T \left(\sum\nolimits_1 \frac{1}{n_1} - \sum\nolimits_2 \frac{1}{n_2}\right)^{-1} (\mu_1 - \mu_2). \qquad (4)$$

The group 1 (respectively group 2) contains mean and gaussian curvature values of either endo -or epicardium at rest (respectively at stress).

We note that this metric value increases when the two groups are different and it approaches zero when the groups are similar.

In the next section we present results for the variation curves analysis in the LV on two patients.

III. EXPERIMENTAL RESULTS

We validate our approach on real data obtained from myocardium scintigraphy imaging techniques.

A. Real Data

We used myocardium SPECT (Single Photon Emission Computed Tomography) images. The myocardium scintigraphy was performed to diagnose coronary artery diseases (CAD). This diagnosis was based on the determination of the site, the extent and the severity of the pathology on both stress and rest sequences.

The myocardium perfusion is estimated by comparing images at two instants which are rest and stress. We start by a 2D segmentation of the original scintigraphic data. We separate the anatomical structures of interest, namely the endocardium and the epicardium (Fig. 5). We obtain a sequence of 2D images to which we perform a 3D reconstruction to have a 3D object modeling either the endo- or the epicardium as shown in Fig 6.

Comparisons are made between two patients. One patient is healthy (P1) and the second is critically affected CAD (P2). we used 8 anatomical structures: the epicardium at rest of P1 and P2, the epicardium at stress of P1 and P2, the endocardium at rest of P1 and P2 and the endocardium at stress also of P1 and P2.

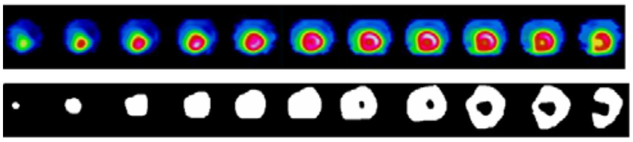

Figure 5. Delineation of the epicardium and the endocardium in 2D scintigraphic data sequence.

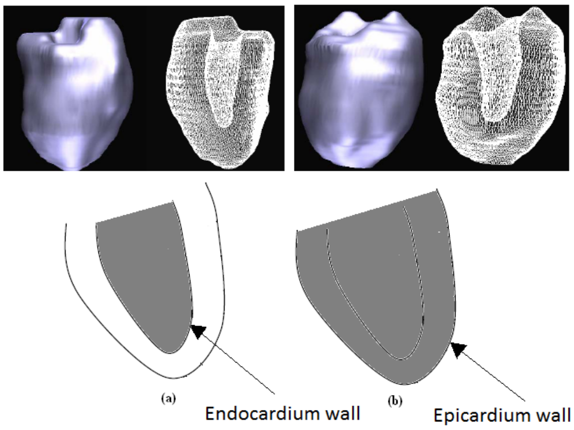

Figure 6. Creation of rendered surface: 3D object modeling either endocardium (a) or epicardium (b).

After getting the triangular mesh modeling the endo- and epicardium of patient P1 and patient P2, we apply the different steps of our approach. We divide every 3D objects into 17 regions according to AHA Standard. Then we generate the triangular mesh for every resulting regions using Delaunay triangulation.

A. LV Curvature Variation Computing

We calculate the mean and the gaussian curvatures at every point in every surface of the 17 regions related to either endo- or epicardium at rest and at stress for P1 and P2 as described in II.B.

For P1 (respectively P2), the endocardium is characterized with 17 groups of curvature values at stress and rest. Each group includes the mean and the gaussian curvatures of every point of the surface.

We have computed the curvature variation values using Hotelling T2 metric at stress and rest for every region and every patient. The obtained values for the epicardium (respectively endocardium) allowed us to develop ranges of variation as shown in Fig. 7 (respectively Fig. 8).

It is shown in fig. 7 that the T2 at most epicardium regions of the patient P1 had an elevated value compared to that of P2. This proves that epicardium of P1 had a good kinetic. All mid cavity regions of the P2 epicardium have a T2 value near zero which results in a low contractility. This may be a sign of an early ischemic.

Fig. 8 shows the Hotelling T2 metric values of curvatures groups between rest and stress in the 17 regions relating to endocardium of patient P1 and P2. Results depicted shows that for the endocardium most regions of the P2 had a very reduced kinetic. For P1 kinetic is much better than the P2.

It is shown that T2 values for the healthy heart differ greatly from those of the critically affected one. Thus, our approach may be an efficient way for regional analysis in the LV.

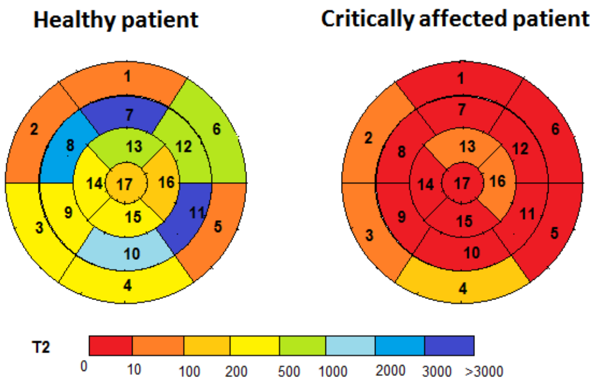

Fig. 1: Hotelling T2 metric of the epicardium regions between stress and rest.

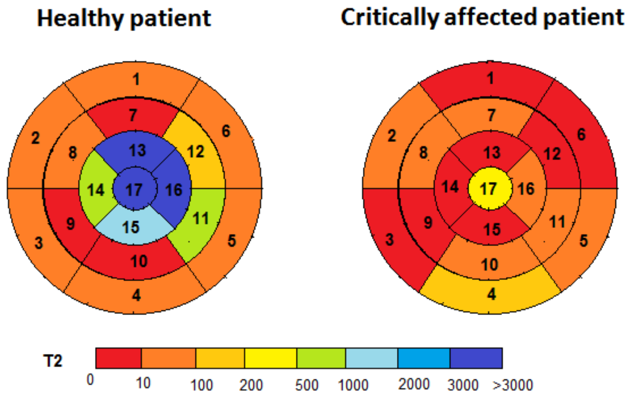

Fig. 2: Hotelling T2 metric of the endocardium regions between stress and rest.

IV. CONCLUSION AND DISCUSSION

In this paper, we have presented a method for local deformation analysis in the LV. Our approach is based on the surface curvatures variation between stress and rest using the Hotelling T2 metric.

Our approach is validated on two patients. Their myocardium SPECT were reviewed by two qualified nuclear medicine physicians. One of the patients was declared as healthy and the other was severe CAD. By the Hotelling T2 metric between mean and gaussian curvature values at stress and rest of P1 and P2, we find that patient P1 is healthy and P2 suffers from ischemia. These results are conform to clinical diagnosis. Results obtained in the regional curvatures analysis provides a good localization of myocardium regions which have lost most of the kinetics and contractility. This localization results from the near zero values of some regions curvatures variation. At first, these information help in the decide of the need for a possible intervention. In a second step, they could be used to verify the impact of the intervention. Indeed, our measurements could qualify the site as well as the disease extent.

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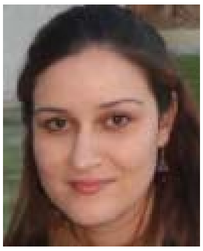

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