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Analysis of Regional Deformation of the Heart Left Ventricle

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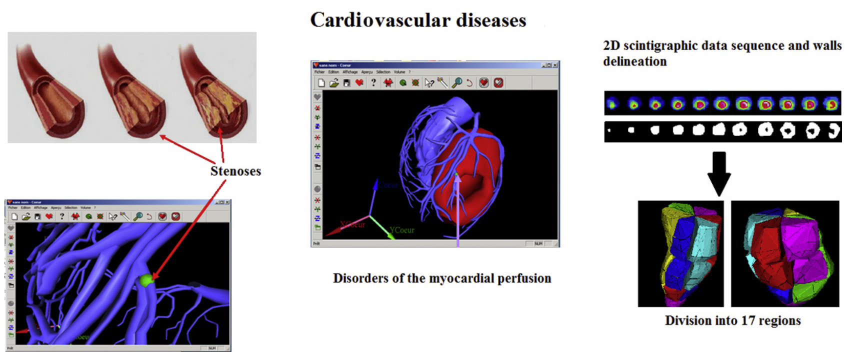
Graphical abstract



Abstract

Context: Cardiovascular disease remains the leading cause of death affecting the adult population. It involves disorders of myocardial perfusion which can lead to the disturbance in myocardial function and/or myocardial infarction. Finding an efficient method for the deformation analysis in the left ventricle of the heart (LV) is one of the major concerns in cardiac imaging.
Objective: In literature, most models provide global representation of the LV surface, that cannot specify the affected area. The present work is aimed at quantifying the local deformations in the LV by developing accurate computational approaches in order to refine the diagnosis and specify the ischemic territory.
Method: The proposed approach advocates the application of three different methods: (1) the numerical quantification of regional deformation based on SPHARM shape descriptors, (2) volume evolution, and (3) the Hotelling metric computation by use of the relative curvature at the vertices of the triangulation. In order to progress to a regional analysis, we carried out a division into 17 regions according to the AHA standard of LV object. It is worth noting that our two first methods are based on the application of the cloud closing process by generating new points on the cutting planes.
Results: The different approaches were tested on 44 patients. The obtained results show its effectiveness and validity by giving the degree and the location of the pathological deformation in the LV. We compared the obtained results with diagnostic offered by qualified nuclear medicine physicians. Also, we compared the obtained results of each methods in order to define the more robust approach.

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1. Introduction

Cardiovascular diseases remain the leading cause of death among adult population. They involve disorders of myocardial perfusion which can lead to the disturbance in myocardial function and/or myocardial infarction. To analyze cardiac function and viability of the myocardial tissue, cardiologists use different medical imaging techniques including: perfusion imaging, coronary angiography, multi-row X-ray scanner, MRI and ultrasound. The 3D reconstruction could improve diagnosis by providing more information. In this context, several approaches were proposed. For example, the superquadric model [1], polynomial surfaces Bezier or B-Spline [2], curvatures [3,4], 3D deformable models [5], Fourier descriptors [6], theory moments [7], spherical harmonic surfaces [8–11]. The present work is aimed at quantifying the local deformations in the LV by developing accurate computational approaches. The first approach was based on spherical harmonics descriptors [12], the second used volume evolution [13] and the third approach was based on curvature calculation by computing the gaussian and the mean curvatures. We compared the obtained results with the diagnosis offered by qualified nuclear medicine physicians. We also compared the obtained results of each method in order to define the most robust approach. The paper is organized as follows. First our proposed methods and their different steps are detailed. Then, experiments carried out to validate our approach are presented and the results obtained are discussed. Finally the main conclusions and suggestions for future works presented.

2. Methods

In order to achieve the quantification of the regional deformation we divided the 3D surface into 17 regions. We adopted the American Heart Association (AHA) standard as it allows an adequate sampling of the LV without exceeding the relevant limits for clinical and research purpose. For the first method, it was applied to closed surface of an object with a spherical topology to be written as an expansion of the spherical harmonic basis functions for the three coordinates. That is why we needed to apply a closing process. Before partitioning the 3D object, we propose to add points at the cutting planes on condition that all added points do not exceed the board of each region. These points are added according to a regular step depending on the point cloud density. The next step consisted in generating invariant SPHARM descriptors for those closed regions and computing invariant SPHARM distance (SHD) between the epicardium and the endocardium regions at stress. The overview of workflow related to the first method is shown in Fig. 1.

For the second method, its workflow is shown in Fig. 2.

To calculate the volume of every region we needed closed surfaces. The closing process was then necessary. The second step was to generate the triangular mesh for different closed

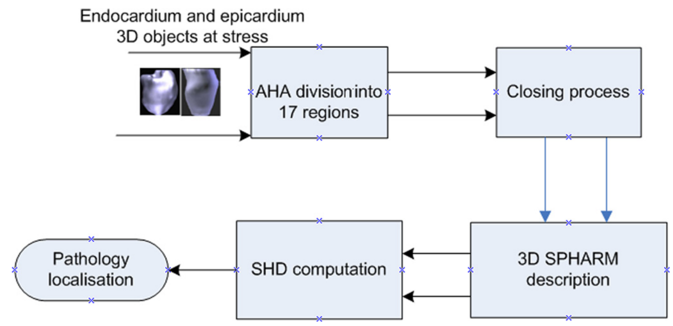

Fig. 1. Overall workflow of first method.

regions and calculate the volume variation between the endocardium and the epicardium at stress so as to quantify the local deformation. As for the third method (Fig. 3) we did not need to apply the closing process. The second step aimed to compute the gaussian and mean curvatures related to every point of unclosed region. We needed to generate its triangular mesh. Then after computing its curvatures values we analyze the curvature variation in the LV performed at stress using the Hotelling T2 metric. As it can be seen, these methods have common steps. In the following sections, we will detail each step of these approaches.

2.1. 3D processing

2.1.1. Partitioning in 17 AHA regions and closed process

The AHA standard recommends a division into 17 regions. First, the LV is divided into four sections by 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 (see Fig. 4).

2.1.2. Mesh triangulation

We adopted the Delaunay triangulation method because it is simple and easy to implement. 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. Fig. 5 shows the endocardium and epicardium region's after applying the AHA division, the closing process and the Delaunay triangulation.

2.2. Features

2.2.1. Spherical Harmonic Distance (SHD)

A closed surface of an object with a spherical topology can be written as an expansion of spherical harmonic basis functions for the three coordinates. Let x, y and z denote Cartesian object space coordinates and θ, ϕ spherical parameters space coordinate defined respectively on $[0, \pi]$ and $[0, 2\pi]$. The set