Ontological Labels for Automated Location of Left Ventricular Remodeling

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I. INTRODUCTION

In a previous study, Ardekani et. al. [1] used the Large Deformation Diffeomorphic Metric Mapping (LDDMM) [2] image registration algorithm to analyze the left ventricle of 25 human subjects at both end systole (ES) and end diastole (ED) phases of the cardiac cycle. Of these 25 subjects, 12 had nonischemic cardiomyopathy (NICM) and 13 had ischemic cardiomyopathy (ICM). An average template image at each of ES and ED was generated and then mapped using LDDMM to each patient image. A statistical analysis of the voxel-based Jacobian map, which encodes local tissue volume difference, found one region of statistically significant volume expansion in the NICM group compared to the ICM group. Visual inspection by an expert clinician located this region in the mid anterior subregion of the left ventricle.

II. METHODS

A. Ontology Extraction and Atlas Generation

Using vSPARQL—an extension of SPARQL allowing for recursive and sub-queries [3]—the subclass hierarchy surrounding the term Region_of_myocardium was extracted from the Foundational Model of Anatomy (FMA) [4].

An ex vivo magnetic resonance image (MRI) of a human heart’s myocardium was obtained from the Center for Cardiovascular Bioinformatics and Modeling (CCBM). The image was segmented according to the American Heart Association (AHA) 17 parcellation recommendation [5].

The binary segments were recombined into a NIfTI image with intent code 1002 (label map). The intensities of this atlas correspond to ten times the number of the corresponding AHA region. The header field aux_file points to a distinguished text file that maps each intensity to the appropriate term in the extracted ontology. For instance, the first line of the label map is ‘10 http://sig.biostr.washington.edu/fma3.0#Myocardial_zone_1’.

B. Mapping.

First, 255-valued binary images of both the atlas and the ES template were generated. This atlas was first coarsely aligned with the ES template via affine registration using the FSL Linear Image Registration Tool (FLIRT) [6] using 256 bins, 12 degrees of freedom, and trilinear interpolation. Then a four-stage cascading multi-contrast LDDMM mapping [7] was used to diffeomorphically register the linearly deformed binary atlas to the binary ES template. The affine transformation generated by FLIRT was applied to the ontologically labeled atlas and then the LDDMM-generated diffeomorphism was applied to this linearly deformed atlas as illustrated in figure 1. This registration also aligned the ontologically labeled atlas with the region of statistically significant volume expansion and the ES template with intensities corresponding to the p values of the analysis of the Jacobian map, both of which were in the same coordinate space as the binary ES template.

Because diffeomorphisms (differentiable homeomorphisms) preserve submanifolds, the 17 segments of the atlas are deformed onto the corresponding segments of the ES template.

C. Querying.

Once the atlas was mapped onto the average ES template, the ontological labels in the atlas were used to ask three (of many possible) questions:

Figure 1. 2D section of 3D cardiac image data used in diffeomorphic mapping (\(\phi\)) of an ontologically labeled atlas (left, \(I_0\)) onto the ES average template (right, \(I_1\)) with the region of significant tissue volume expansion colored.

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1) What regions of myocardium are annotated in the atlas?
2) What was the average $T$ value of the Jacobian map per region of myocardium?
3) In which region was significant tissue volume expansion observed?

These queries were implemented in Java using Jena along with the niftijlib library.

III. RESULTS

Q1. What regions of myocardium are annotated in this atlas?
A. Myocardial_zone_1, ..., Myocardial_zone_17

Q2. What is the average $T$ value for each region of myocardium?
A. See table I.

<table>
<thead>
<tr>
<th>Region</th>
<th>Average $T$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial_zone_13</td>
<td>3.401515481</td>
</tr>
<tr>
<td>Myocardial_zone_14</td>
<td>2.8456438</td>
</tr>
<tr>
<td>Myocardial_zone_7</td>
<td>1.7604088</td>
</tr>
<tr>
<td>Myocardial_zone_8</td>
<td>1.4498609</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table I  
AVERAGE $T$ VALUE BY REGION

Q3. Where is the region of statistically significant tissue volume expansion located?
A. Myocardial_zone_13 = apical anterior. See table II and figure 2.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Voxels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocardial_zone_13</td>
<td>696</td>
</tr>
<tr>
<td>Myocardial_zone_10</td>
<td>3</td>
</tr>
<tr>
<td>Myocardial_zone_9</td>
<td>2</td>
</tr>
<tr>
<td>Myocardial_zone_7</td>
<td>1</td>
</tr>
<tr>
<td>Myocardial_zone_4</td>
<td>1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Table II  
NUMBER OF VOXELS OF THE STATISTICALLY SIGNIFICANT ROI IN EACH REGION OF MYOCARDIUM. ALL OTHER REGIONS HAD NO VOXELS.

IV. DISCUSSION

While visual inspection located the region of statistical significant tissue volume expansion in the mid anterior, our ontologically labeled atlas-based methods found this region in the apical anterior. Although these two regions border each other, there is no fact of the matter about which method yields the correct location. Ontology based methods, however, have the advantage of being precise, automated, and reusable in future studies.