Medical Sensors Project Report

Quantification of trabeculae inside the heart from MRI using fractal analysis

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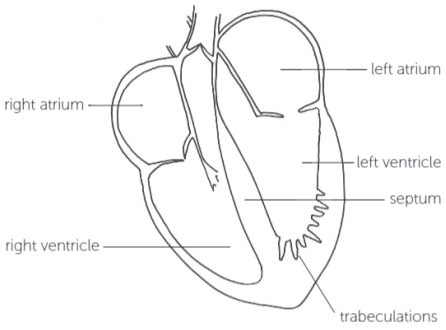
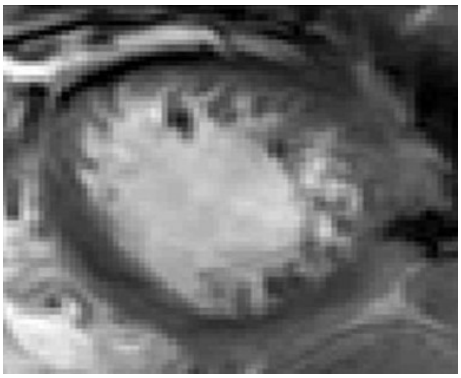
1 Introduction

The aim of our project is to implement two different methods for quantification of left ventricular (LV) trabeculae. In the left ventricular noncompaction cardiomyopathy (LVNC) the lower left chamber of the heart contains pieces of muscle that extend into the chamber. These pieces of muscles are called trabeculations [1]. In such case the heart muscle can be represented as a sponge-like network of muscle fibers. Many patients with LVNC have no symptoms, but still they may be at risk for complications associated with the diagnosis, such as arrhythmias, thromboembolism or even sudden cardiac death. it is important for anyone at the risk group to be followed by a cardiologist.



(a) *Heart with LVNC [2]*



(b) *MRI of a heart with LVNC[3]*

Figure 1: *Left Ventricular Noncompaction*

Nowadays there is no conventional tool to quantify left ventricular trabeculae and noncompaction and there exists many opportunities for research in this field.

2 Methods

In the following sections of the report we would like to describe approaches proposed in articles, our implementation, then we compare final results and determine better solution for diagnosis of LV noncompaction cardiomyopathy. For software development, we used Matlab ver. R2016a (MathWorks, Natick, MA). To test implemented algorithms 3 sets of CMR images were used.

2.1 Semiautomatic Detection of Myocardial Contours

The first research is called "Semiautomatic Detection of Myocardial Contours in Order to Investigate Normal Values of the Left Venticular Trabeculated Mass Using MRI". In this method epicardial, endocardial and trabeculae contours are detected automatically. The user clicks on the LV cavity to initialize the seed, which is a starting point for region-growing. From this seed, neighboring pixels were added into the region if their intensity is comprised $\pm 10\%$ of the mean intensity value of the area[4]. Using active contour and acquired noncompacted contour, the endocardium border is determined. To compute the epicardium border, the pixels were mapped into polar coordinates to transform ring-shaped region of interest into rectangular ones, and

then an outer boundary was computed by dilating the endocardium border. This boundary was used as seeds for region-growing, and the resulting contour was transformed back into Cartesian coordinates to obtain epicardium border. Then papillary muscles were segmented using semiautomatic threshold once the user clicked on them, the result was propagated into other slices automatically. If papillary muscles could not be distinguished from trabeculae, they were counted as trabeculae. At the final stage, compacted mass, noncompacted mass, end-diastolic volume and NC:C ratio were computed.

In our method we ask user at first manually draw epicardial border. After that user must click on LV cavity to choose starting seed for region growing. The threshold can be adjusted in order to detect trabeculae area accurately. After region growing active contour automatically applies to detect endocardial border. For higher accuracy user can select such parameter as "Contraction bias". Positive values bias the contour to shrink inwards, while negative values bias the contour to expand. After that user can select papillary muscles, which are also detected automatically using region growing, threshold can be manually adjusted if necessary. If some borders were not detected correctly, user can clear them and start again. Once all borders are chosen, user has to press button "Calculate areas" to compute compacted mass, noncompacted mass and NC:C ratio. Body Surface Area (BSA) is calculated according to the formula of Dubois and Dubois.

$$BSA = 0.007184 \times Weight^{0.425} \times Height^{0.725}$$

2.2 Fractal analysis

Another method for trabeculae quantification is fractal analysis [5]. This method is used to quantify complex geometric patterns in biological structures. In the application to the left ventricle trabeculation, fractal analysis can be used to study irregularity and complexity of the endocardium border and distinguish healthy patients from patients with excessive trabeculae of the left ventricle by comparing fractal dimension of the endocardium border.

The method used to calculate fractal dimension is box-counting method. The idea behind is to break the image of complex structure into smaller box-shaped pieces and by scaling the size of a box analyze how many boxes have pixels belonging to the structure inside. The amount of these boxes decreases exponentially with increasing spacing of box grid, and the exponential is equivalent to the fractal dimension.

So, the first step that we have to perform in order to get fractal dimension is the image segmentation to extract the endocardial border. In case of our implementation we did pre-processing step of manual cropping the image to simplify the process of segmentation. To find edges in the article authors used Sobel operator. We decided to find threshold using Otsu method and convert image to black and white and then find borders using Matlab function bwmorph. After the border is found we can process it with box-counting method.

The article authors were using function from FracLac plug-in in ImageJ, while we created our own function. For every slice first we put our cropped and segmented image in image with square shape (the length is closest larger power of 2 of the largest dimension) simply adding black pixels when it's necessary. Then we count non-empty boxes every time increasing the box side size 2 times. After this we calculate fractal dimension by computing tangential in logarithmic graph (number of boxes versus box size). As output our program shows the plot of fractal dimensions of slices from basal to apical part of heart.

3 Results

In the Table 1 you may find results of original semiautomatic method according to the age and gender[4].

TABLE 1					
Measurement	20-39 years	40-59 years	60-79 years	Males	Females
NC [g]	11.72 ± 3.98	11.62 ± 3.88	11.20 ± 4.17	12.50 ± 4.19	10.53 ± 3.5
NC/BSA [g/m2]	6.43 ± 1.95	6.35 ± 2.13	6.07 ± 2.04	6.38 ± 2.05	6.19 ± 2.02
C [g]	117.40 ± 30.33	113.98 ± 23.99	111.94 ± 28.59	130.47 ± 26.93	98.41 ± 17.46
C/BSA [g/m2]	64.03 ± 10.49	61.63 ± 10.99	60.85 ± 12.42	66.49 ± 12.10	57.85 ± 8.59
NC:C ratio	10.20 ± 3.18	10.44 ± 3.54	10.15 ± 3.16	9.71 ± 3.05	10.81 ± 3.42

Normal values for noncompacted and compacted masses are $6.29 \pm 2.03[g/m^2]$ and $62.17 \pm 11.32[g/m^2]$ respectively. The normal NC:C ratio is $10.26 \pm 3.27\%$

Using our method implementation, we have processed images for 3 patients. The results are represented in the Table 2.

TABLE 2			
Measurement	Male 50 years	Female 51 years	Female 28 years
NC [g]	24.28	8.46	9.40
NC/BSA [g/m2]	13.58	4.23	7.02
C [g]	128.97	73.37	72.07
C/BSA [g/m2]	72.15	36.65	53.85
NC:C ratio	18.83	11.53	13.05

For the first patient we received slightly high value of noncompacted mass and therefore high NC:C ratio, that can be interpreted as the presence of pathology. For the woman of 51 years old the result of NC mass lies in the normal range. The compacted mass is lower than we expected, however, it can be a result of wrongly chosen epicardial boundaries on some images. But still the NC:C ratio is in a normal range. For the last patient, the women of 28 years, we may observe good results of NC/BSA, C/BSA and NC:C ratio.

Below the result of fractal analysis (fractal dimension across the left ventricle from base to apex) for all three patients are shown.

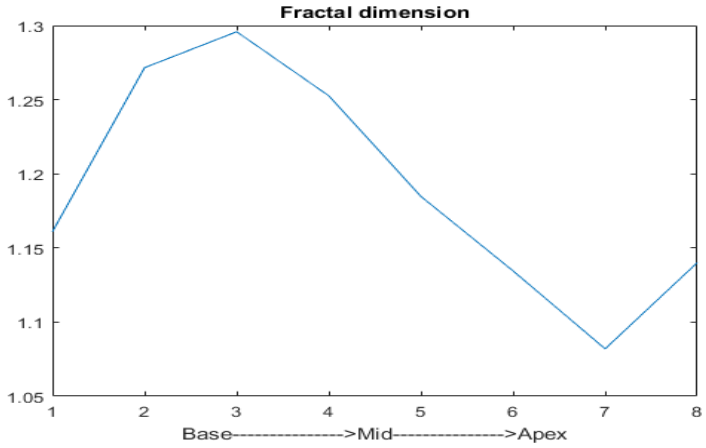


Figure 2: *FD across the ventricle for Case05*

The pattern of the curve in this case and values of fractal dimensions look like in healthy patient case, so we can conclude, that this patient doesn't have LVNC.

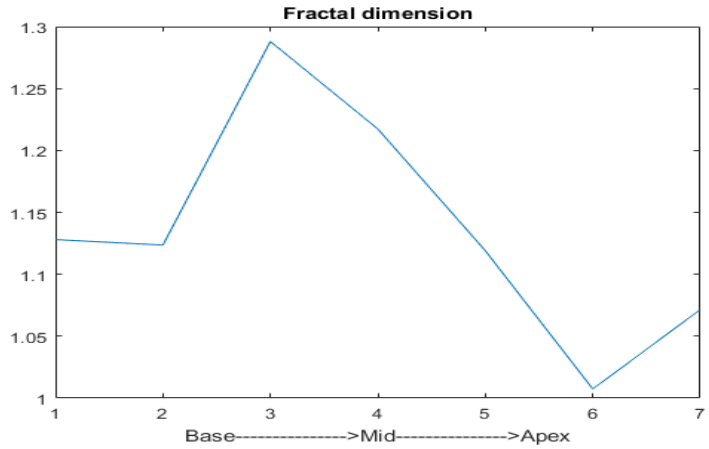


Figure 3: *FD across the ventricle for Case12*

The pattern of the curve and values of fractal dimensions for this patient also look like in healthy patient case. In this case we also can conclude, that this patient doesn't have left ventricle noncompaction.

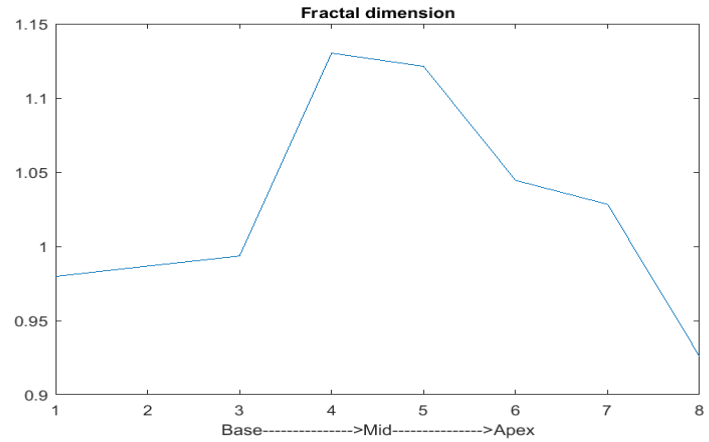


Figure 4: *FD across the ventricle for Case16*

Though the form of the curve is almost like for healthy patient, fractal dimensions are low. This may be caused by corrupted segmentation.

4 Conclusions

We have implemented two methods to determine the level of LV noncompaction. One of the greatest advantages of the Semiautomatic Detection is that results are clear for the doctor, all values have certain units and according to the values of noncompacted mass, compacted mass

and NC:C ratio it is easy to determine the diagnosis of a patient. All borders can be well detected and they appear in color for better discernibility. Segmentation has demonstrated good results, even if the contour was not determined correctly, there is a possibility to adjust threshold that influence the accuracy of the boundary detection. However,this method requires more time for processing since doctor has to draw manually or select areas with different values of threshold.

Fractal analysis provides faster computation, however the results of this method are not intuitive and unitless. Therefore doctors may face problems with interpreting the results. Another drawback is that fractal dimensions mostly differ in apical area where the quality of images of these slices is poor. Also automatic segmentation doesn't always provide good result (in case of poorly contrasted images) and further development of the method should be done.

Despite the easiness of promising fractal analysis usage we find Semiautomatic Detection more informative and comprehensible for doctors.

References

[1] Cincinnati Children's Medical Center. *Left Ventricular Non-Compaction Cardiomyopathy (LVNC)*. https://www.cincinnatichildrens.org/service/c/cardiomyopathy/types/left-ventricular-non-compaction-cardiomyopathy

[2] Cardiomyopathy UK. *Left ventricular non-compaction. An introduction to LVNC*. 2016. http://www.cardiomyopathy.org/left-ventricular-noncompaction/intro

[3] Lian-Yu Lin, Mao-Yuan M. Su, Van-Truong Pham, Thi-Thao Tran, Yung-Hung Wang, Wen-Yih I. Tseng, Men-Tzung Lo Jiunn-Lee Lin. *Endocardial Remodeling in Heart Failure Patients with Impaired and Preserved Left Ventricular Systolic Function-A Magnetic Resonance Image Study*. 2016. https://www.nature.com/articles/srep20868

[4] Bricq S., Frandon J., Bernard M., Guye M., Finas M., Marcadet L., Miquerol L., Kober F., Habib G., Fagret D., Jacquier A., Lalande A. *Semiautomatic detection of myocardial contours in order to investigate normal values of the left ventricular trabeculated mass using MRI.*. J. MAGN. RESON. IMAGING 2016;43:1398–1406.

[5] Gabriella Captur, Vivek Muthurangu, Christopher Cook, Andrew S Flett, Robert Wilson, Andrea Barison, Daniel M. Sado, Sarah Anderson, William J McKenna, Timothy J Mohun, Perry M Elliott and James C Moon *Quantification of left ventricular trabeculae using fractal analysis*, Journal of Cardiovascular Magnetic Resonance 2013, 15:36

User guide

Choose a method to process images.

1. If you have chosen “Semiautomatic detection”.

   1.1. Open an image in dicom format.

   Make sure that the image has an explicit format *.dcm, for example, “Image01.dcm”. Otherwise program will not be able to open the image.

   1.2. Click on “Epicardial border” and manually draw the contour.

   If it is incorrect, click on “Clear border” and draw again.

   1.3. Click on “Select LV”, trabeculae area will appear in green and endocardial border will appear in red.

   If borders were chosen incorrectly, try to set another threshold to receive better result for trabeculae area and set another parameter of shrinking to detect endocardial border. Negative values of coefficient lead contour to expand, while positive values perform shrinking.

   1.4. If there are papillary muscles on image, use button “Select Papillary Muscles” and click on PM on image.

   If the result is not correct, press “Clear Papillary Muscles” and adjust threshold.

   1.5. Click “Calculate areas”.

   You will see that the counter at the right bottom of a program changes its value. Program automatically calculate NC, C areas and NC:C ratio.

   1.6. Click “Open image” and repeat steps 1.2-1.5.

   Once you process all images click on “Show results”. You will see values for NC, NC/BSA, C, C/BSA and NC:C Ratio.

   1.7. If you want to process images for next case, click “Reset All Results”, the counter will be set to zero again and repeat steps 1.1-1.6.

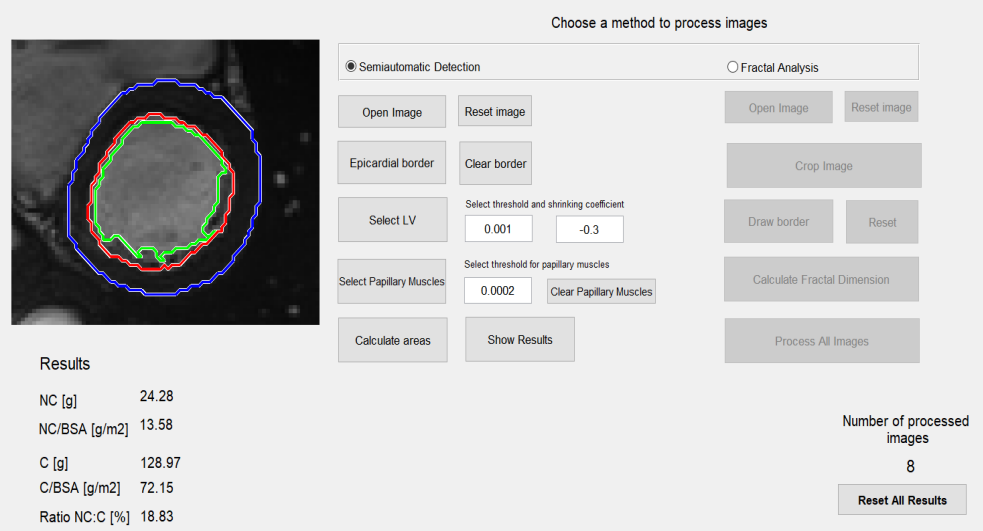


Figure 5: *Semiautomatic detection*

2. If you have chosen “Fractal Analysis”.

   2.1. Open an image in dicom format.
   Make sure that the image has an explicit format *.dcm, for example, “Image01.dcm”. Otherwise program will not be able to open the image.

   2.2. Click “Crop Image”.
   Choose a region of interest so it completely covers Left Ventricular (see the example below). Double-click on the center of the region to approve the borders.

Figure 6: *Example of cropped image in Fractal Analysis*

   2.3. Draw Endocardial border.
   If you did not perform it correctly, click on “Reset” and choose “Draw border” again.

   2.4. Click on “Calculate Fractal Dimension”.

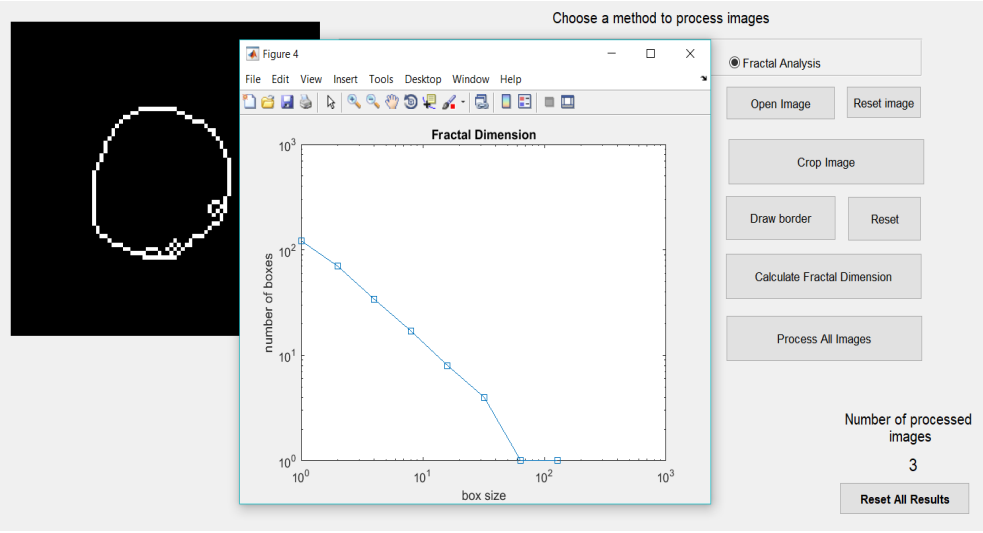


Figure 7: *Plot of fractal dimension*

You will see the resulting plot for the one image.

2.5. Click on “Open image” and choose next image. Repeat steps 2.2-2.4.

2.6. Once all images are processed click on “Process All Images”, the resulting graphic of FD across the left ventricle from base to apex will pop-up.

2.7. Click on “Reset All Results” to process images for the next case.