QUANTIFICATION OF LEFT VENTRICULAR HYPERTROPHY PARAMETERS BY ENDOCARDIUM SEGMENTATION OF 2D ECHOCARDIOGRAPHY IMAGES

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Abstract— Left Ventricular Hypertrophy has a risk of increasing the brevity of the population if left untreated. Quantitative aid in the diagnosis and prognosis of Left Ventricular Hypertrophy to field experts is very essential to classify the disease and proceed treatment. Endocardium segmentation of left and right ventricles is done through Local Chan Vese Model using Radial Charge Fitting Curve. This is followed by the quantification of parameters Left Ventricular End Diastolic Diameter, Intraventricular septum dimension and Posterior Wall Thickness to evaluate Left ventricle mass and Relative Wall Thickness. This evaluation is useful in classifying the cardiac disease Left Ventricular Hypertrophy as Concentric Hypertrophy, Concentric Remodeling, Eccentric Hypertrophy and no Hypertrophy. The segmentation results are obtained with minimal iterations and parameters quantification has 98.76% accuracy with that of expert’s report.

Keywords- Endocardium, Radial Charge Fitting Curve, Left Ventricular Hypertrophy, Left Ventricular End Diastolic Diameter, Intraventricular septum dimension, Posterior Wall Thickness, Left ventricle mass, Relative Wall Thickness

I. INTRODUCTION

Left Ventricular Hypertrophy (LVH) is an increase in mass of the left ventricular endocardium caused by increased workload in heart. It is a chronic disease which may lead to atrial fibrillation, diastolic heart failure, systolic heart failure and sudden death in hypertensive patients [1]. Left ventricular hypertrophy has to be diagnosed effectively with echocardiograms for reducing morbidity. The assessment of cardiac function is done from echocardiography images for analyzing the parameters like wall thickness, shape, mass of the ventricles and atrium [2]. The disease is identified by increase in left ventricle mass, or increase in wall thickness. Left Ventricular Hypertrophy can be classified based on ventricular dilation and wall thickening. The geometrical patterns of left ventricle leads to the classification of Left Ventricular Hypertrophy as Concentric Left Ventricular (LV) Remodeling, Concentric LVH and Eccentric LVH [3-6]. The exact diagnosis of the disease helps in regressing the hypertension and thus reducing the severity of the disease.

LVH can be best diagnosed with proper segmentation of endocardium, which will help in the evaluation of parameters namely, left ventricle mass, posterior wall thickness and inter ventricular septum thickness. Hence segmentation of endocardium plays a major role in the quantification of above said parameters. Many segmentation techniques are available in the literature, among which active contour models and level set methods occupy a prevailing position [7-12]. Later Local Chan Vese Model proved to be more effective with the inclusion of global statistics in the level set function [13]. But all these techniques requires initialization prior to segmentation with a contour. The segmentation results are sensitive to the location of the initial contour. This has computational complexity and avoids automation in segmentation. Hence to avoid this initialization problem, a new technique called Radial Fitting Curve based on Gauss law is proposed which generates the initial curve near the boundary [14]. After obtaining this contour, the segmentation of endocardium can be better tuned using Local Chan Vese Model.

Left Ventricular Hypertrophy can be classified based on ventricular dilation and wall thickening. The geometrical patterns of left ventricle leads to the classification of Left Ventricular Hypertrophy as Concentric Left Ventricular (LV) Remodeling, Concentric LVH and Eccentric LVH [15-18]. The disease has to be classified efficiently with parameters Left Ventricular End Diastolic Diameter (LVEDD), Posterior Wall Thickness (PWT), Intraventricular Septum Dimension (IVSD) and Relative Wall Thickness (RWT).

The manuscript is sculptured as LVH Parameters in section 2, Endocardium Segmentation & Parameters quantification in section 3, assessment of results in section 4, Parameter Quantification & Comparison with Expert’s Report is given in section 5 and conclusion in section 6. The aim of the work is to aid the medical experts in quantifying the parameters of LVH by endocardium segmentation.

II. LVH PARAMETERS

Left Ventricular Hypertrophy is characterized by enlarged endocardial mass or wall thickening. Geometric pattern of left ventricle can be defined based on relative wall thickness and left ventricle mass. Relative wall thickness is the ratio of diastolic Posterior Wall Thickness (PWT) to Left Ventricular End Diastolic Diameter (LVEDD). Left ventricle mass is the increase in the left ventricle cavity beyond its normal level. Left Ventricular mass is calculated according to the formula given by Devereux and Reichek [19] based on Penn Convention. The Penn convention includes endocardial boundaries of septum and posterior wall into the

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measurements of the LV internal diameter. LV mass is given by equation (2.1),

\[
LV\ Mass = 1.04 \times (LVEDD + IVSD + PWD)^3 - (LVEDD)^3 - 13.6g
\]

Relative Wall Thickness (RWT) is given by equation (2),

\[
RWT = \frac{2 \times PWD}{LVEDD}
\]

where

LVEDD – Left Ventricular End Diastolic Diameter
IVSD – Intraventricular Septum Dimension
PWD – Posterior Wall Dimension

The reference values of LV mass, LVEDD, IVSD, PWD and RWT are shown in Table 1 [20]

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEDD (cm)</td>
<td>Normal Reference Range: 3.9 – 5.3</td>
<td>Abnormal: &gt;5.3</td>
</tr>
<tr>
<td>IVSD (cm)</td>
<td>0.6 – 0.9</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>PWD (cm)</td>
<td>0.6 – 0.9</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>LV Mass (gm)</td>
<td>67 – 162</td>
<td>&gt;162</td>
</tr>
<tr>
<td>RWT</td>
<td>0.22 – 0.42</td>
<td>&gt;0.42</td>
</tr>
</tbody>
</table>

The left ventricle geometric patterns classify Left Ventricular Hypertrophy as no LVH, Concentric LV Remodeling, Concentric LVH and Eccentric LVH. Concentric LV remodeling is defined by normal mass and increased RWT. Concentric LVH is characterized by both increased mass and increased RWT. Eccentric LVH is described by increased mass and normal RWT. The reference range varies for male and female and is shown in Table 1.

![Figure 1: Classification of LVH](image)

Beyond the normal range, the values vary adversely and these abnormal cases are to be classified as Concentric LVH, Concentric LVR and Eccentric LVH. This classification is shown in figure 1.

The attributes in Table 1 are measured from Apical 4 chamber view of echocardiography images and, LV mass and Relative wall thickness (RWT) is calculated based on equations (2.1) and (2.2) respectively. The values obtained are used to classify LVH.

III. ENDOCARDIUM SEGMENTATION & PARAMETERS QUANTIFICATION

The measurement of the left ventricle geometric patterns plays a key role in classifying the disease exactly. These parameters have to be measured based on proper segmentation of endocardium. Here comes the significance of distinct segmentation of endocardium to have appropriate disease quantification. The accuracy of segmentation is most desired as the parameter quantification needed for Left Ventricular Hypertrophy and its classification is very critical. Hence segmentation using Local Chan Vese model with Radial Charge fitting curve will provide best results as per the requirement. The segmentation process followed by parameter measurement is proceeded as shown in Figure 2.

![Figure 2: Steps for Endocardium Segmentation & Parameter Quantification](image)

**Step 1: Speckle Noise removal**

Speckle noise is an innate noise present in ultrasound images. This speckle noise is a multiplicative noise which depends on pixel intensity. A straight kernel filter based on entropy is used to eliminate the speckle noise. The filter uses entropy parameter to measure the random occurrence of noise pixels in each row and column and to increase the image visibility. Straight kernels with 3 pixels each are chosen for the filtering process, and the filter is slid over the image to eliminate speckle. The filter measures the signal content from the noise in each straight kernel and replaces the pixels with noise-free intensity [21, 22].

**Step 2: Seed point selection**

A random selection of location is needed inside the endocardium to generate an initial contour. The field experts are independent to choose a point from which the Radial fitting curve starts. The procedure after seed point selection is automatic which is followed by initial contour generation and segmentation using Local Chan Vese Model.

**Step 3: Initial contour generation**

An Endo fitting curve called Radial charge fitting curve is used for generation of initial contour within the endocardium. The curve is based on Gauss law and by which the endocardium is hypothesized to be an electrostatic conductor. From the seed point, the curve is generated with a radial sweeping in 4 cycles [14]. According to Gauss law, an electrostatic conductor is charge free and hence the endocardium is presumed to have nil pixel intensity. This charge search will end after nearing the boundary.
Step 4: Endocardium Segmentation using Local Chan Vese Model

Local Chan Vese Model (LCV) is well known for segmentation of intensity inhomogeneity images. The model is based on techniques of curve evolution, local statistical function and level set methods [13]. The energy function of LCV model comprises 3 parts namely the global term $E^G$, local term $E^L$ and regularization term $E^R$. The energy function of LCV is shown in equation (3.1)

$$E^{LCV} = \alpha E^G + \beta E^L + E^R$$

The global term is based on global information. To represent the intensity inhomogeneity effect, local term is incorporated with local statistical information. To improvise the segmentation and to avoid isolated regions, regularization term is included. The parameters $\alpha$ and $\beta$ represent positive values and are used to maintain a tradeoff between global term and local term. The parameter $\beta$ is set as 1 and $\alpha < \beta$ for intensity inhomogeneity images.

In LCV model the termination criterion for curve evolution is based on local term and global term. As the terms minimize and reach zero, the curve evolves to the true boundaries. For each iteration, the length of the evolving curve $L(c(t))$, is compared with $\xi_{length}$ which becomes greater than the length of the evolving curve. This is done for fixed number of iterations $T_{it} = 10$ and $\xi_{length} = 5$. The condition for curve evolution is given by equation (3.2)

$$[L(c(t)) - L(c(t-1))] \leq \xi_{length}$$

In the proposed work of endocardium segmentation as the initial contour generated by radial charge fitting curve is close to the boundary, $T_{it}$ is reduced to 2 and $\xi_{length} = 5$. The number of iterations are reduced than with direct application of Local Chan Vese Model.

Step 5: Measurement of parameters LVEDD, PWD and IVSD

Left ventricular hypertrophy is a chronic cardiac disease characterized by increase in Left Ventricle Mass (LVM) and / or increase in Relative Wall Thickness (RWT). The equations (2.1) and (2.2) can be used for calculating LVM and RWT. Apical 4 chamber view of echocardiography image is used for measuring the parameters LVEDD, PWD and IVSD in the proposed work. A sample measurement of the said parameters is shown in Figure 4.

IV. ASSESSMENT OF RESULTS

A total of 153 gray scale sequences of Apical 4 chamber view including both male and female with cases having Concentric LVH, Concentric LVR, Eccentric LVH and no LVH are collected from Pranav Hospital, Salem, Tamil Nadu. The expert’s disease diagnosis statement is obtained for all the images. The images are obtained for research with the consent of patients. The images are collected from GE Vivid 7 Ultrasound machinery. The simulation of these Echocardiographic images is performed in Matlab R2012, on a personal computer with Intel Core 2 Duo processor, 2.93 GHz, 2 GB Random Access Memory (RAM). All the Echocardiography images have undergone the process of noise removal, seed selection, initial contour generation using Radial Charge Fitting curve, endocardium segmentation using Local Chan Vese Model and parameter quantification. The segmentation results through Local Chan Vese Model with Radial Charge Fitting curve has produced the results with few iterations and thus reducing the computational complexity. Out of those 4 cases the results of – one female with Concentric LVH, one male with Concentric LVR, one female with Eccentric LVH and one male with no LVH are shown respectively in Figures 5, 6, 7, 8. The measurements given by Dr. S. Murugapandian, Cardiologist, Pranav Hospital is shown for comparison. The parameter quantification through the proposed endocardium segmentation has 98.76% accuracy.

Case 1: Concentric LVH
(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (19 iterations) (f) Parameter Quantification

The image shown in Figure 5 is the Apical 4 Chamber view of Rohini, aged 56. The patient has Concentric LVH for a period of 3 years. Figure 5 (a) is the original image with noise and 5 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 5 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 5 (d) and 5 (e). Accurate segmentation results are obtained with 19 iterations. The image in 5 (f) shows the parameters measured after segmentation. Concentric LVH is characterized by both increased LV mass and RWT.

Case 2: Concentric LV Remodeling

Figure 6: Apical 4 Chamber view of Concentric LVR (end diastole)

(a) Noisy image (b) Noise filtered image with Entropy filter (c) Seed selection (d) Initial contour using Radial charge fitting curve (e) Segmentation using Local Chan Vese Model (22 iterations) (f) Parameter Quantification

The image shown in Figure 6 is the Apical 4 Chamber view of Govindan, aged 62. The patient has Concentric LVR for a period of 6 years. Figure 6 (a) is the original image with noise and 6 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 6 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 6 (d) and 6 (e). The segmentation is obtained with 22 iterations. The image in 6 (f) shows the parameters measured after segmentation. Concentric LV Remodeling is characterized by normal LV mass and increased RWT.

Case 3: Eccentric LVH

The image shown in Figure 7 is the Apical 4 Chamber view of Lalitha, aged 43. The patient has Eccentric LVH for a period of 2 years. Figure 7 (a) is the original image with noise and 7 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 7 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 7 (d) and 7 (e). The segmentation is attained with 18 iterations. The image in 7 (f) shows the parameters measured after segmentation. Eccentric LVH is characterized by increased LV mass and normal RWT.

Case 4: No LVH (Normal)

The image shown in Figure 8 is the Apical 4 Chamber view of Ramkumar, aged 35. The volunteer has normal LV geometry. The volunteer has consented to have the echo test for research purpose. Figure 8 (a) is the original image with noise and 8 (b) is the image after the application of Entropy based straight kernel filter. The noisy pixels are eliminated from the endocardium using the filter for better visualization of the chambers. A random seed selection done in both the left and right ventricles is shown in 8 (c). The results after initial contour generation and segmented image using Local Chan Vese Model are shown in figure 8 (d) and 8 (e). The ventricles are segmented in 20 iterations. The image in 8 (f) shows the parameters measured after segmentation. The normal heart is characterized by normal LV mass and normal RWT. In the case of normal heart, the geometry of left ventricle is characterized by normal values shown in Table 1. It can be visualized from figure 8 that all the chambers of the heart are normal sized and not enlarged.
ventricle mass is calculated by using the Penn convention formula shown in equation (2.1). Relative Wall thickness is the ratio of Posterior Wall thickness and Left Ventricular end diastolic dimension. From Table 2, the values obtained by endocardium segmentation and that collected from medical expert are very close. The LV mass for case 1 is 177.25 gm by the proposed segmentation and that by expert’s report is 180.16 gm. The normal range of LV mass for female is 162 gm and RWT is 0.42. From table 2, it is evident that both LV mass and RWT are greater than the normal range. Hence the disease is classified as Concentric LVH. The diagnosis is similar in the case of proposed work and by expert. In case 2, for Concentric LV Remodeling, LV mass is normal but RWT is greater than the normal level. The Relative Wall thickness is same for both the proposed work and expert’s report. The LV mass differs by ± 4 gm. Eccentric Hypertrophy is a special case in which RWT is normal but LV mass is greater than 162 gm for female and 224 gm for male. In the case considered, the LV mass obtained is 194.51 gm and 198.75 gm by proposed endocardium segmentation and expert’s report respectively. In case 4, the volunteer has normal cardiac geometry and all the values are within the specified range. The measurements LVEDD, IVSd and PWT obtained by the proposed endocardium segmentation and expert’s report are very close and differ by ± 0.1 cm.

Table 2: Parameter Quantification & Comparison with Expert’s Report

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values obtained from endocardium segmentation</th>
<th>Values obtained by expert</th>
<th>Disease Diagnosed from proposed work</th>
<th>Disease Diagnosed by expert</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 1: Concentric LVH – Rohini aged 56</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>LVEDD (cm)</td>
<td>4.1 cm</td>
<td>4.2 cm</td>
<td>Concentric LVH</td>
<td>Concentric LVH</td>
</tr>
<tr>
<td>IVSd (cm)</td>
<td>0.97 cm</td>
<td>1.0 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWT (cm)</td>
<td>1.25 cm</td>
<td>1.3 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LV Mass (gm)</td>
<td>177.25 gm</td>
<td>180.16 gm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RWT (cm)</td>
<td>0.60</td>
<td>0.62</td>
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<td><strong>Case 2: Concentric LVR - Govindan aged 62</strong></td>
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<tr>
<td>LVEDD (cm)</td>
<td>3.95</td>
<td>4.0</td>
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<tr>
<td>IVSd (cm)</td>
<td>1.1</td>
<td>1.2</td>
<td></td>
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</tr>
<tr>
<td>PWT (cm)</td>
<td>1.08</td>
<td>1.1</td>
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</tr>
<tr>
<td>LV Mass (gm)</td>
<td>161.87</td>
<td>164.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RWT (cm)</td>
<td>0.55</td>
<td>0.55</td>
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<tr>
<td><strong>Case 3: Eccentric LVH – Lalitha aged 43</strong></td>
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<tr>
<td>LVEDD (cm)</td>
<td>5.21</td>
<td>5.2</td>
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<tr>
<td>IVSd (cm)</td>
<td>0.86</td>
<td>1.0</td>
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<tr>
<td>PWT (cm)</td>
<td>0.92</td>
<td>0.9</td>
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<tr>
<td>LV Mass (gm)</td>
<td>194.51</td>
<td>198.75</td>
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<tr>
<td>RWT (cm)</td>
<td>0.35</td>
<td>0.35</td>
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<tr>
<td><strong>Case 4: No LVH (Normal)- Ramkumar aged 35</strong></td>
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<tr>
<td>LVEDD (cm)</td>
<td>4.26</td>
<td>4.3</td>
<td></td>
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<tr>
<td>IVSd (cm)</td>
<td>0.72</td>
<td>0.8</td>
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<tr>
<td>PWT (cm)</td>
<td>0.8</td>
<td>0.8</td>
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<tr>
<td>LV Mass (gm)</td>
<td>106.82</td>
<td>110.37</td>
<td></td>
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</tr>
<tr>
<td>RWT (cm)</td>
<td>0.37</td>
<td>0.37</td>
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</table>
The closeness between expert’s report and the proposed parameter measurement is shown in Figure 9. All the 4 cases are shown for the parameters LVEDD, IVSd and PWT. The Y axis shows the values in centimeter and X axis shows the parameters.

V. CONCLUSION

Endocardium segmentation using Local Chan Vese Model with Radial Charge fitting curve is done to quantify the parameters needed for Left Ventricular Hypertrophy, a serious cardiac disease. The parameters namely LVEDD, IVSd and PWT are measured from 153 Apical 4 Chamber view gray scale images and are compared with that of expert’s report. The results obtained through Local Chan Vese Model with Radial charge fitting curve have minimal computational complexity as the method has automatic contour generation very close to the endocardium boundary. Also the parameter measurements from the segmentation results are very close to the expert’s measurements and has produced 98.76% accuracy. The proposed work is to aid the medical experts with automation in endocardium segmentation and parameter quantification of Left Ventricular Hypertrophy.

![Graph](image)

Figure 9: Comparison between Expert’s report & proposed segmentation

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References


