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Research Article

Detection of Coronary Plaque and Sensing Risks Factors of Heart at early stages using various Image Processing and Segmentation Techniques

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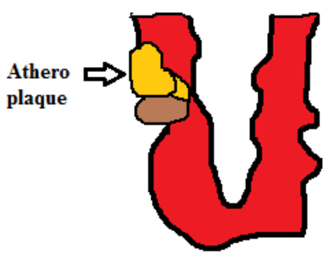
Abstract

Cardiac arrest known as myocardial infarction is one of the common disease occurring in the human heart, usually causing death. Currently some of the clinical modalities are insufficient to detect at early stages. This paper shows the early detection of plaque non-invasively through CCTA images. In this paper, noise removal is being done by enhancement technique followed by global thresholding with segmentation using K-means Clustering. Further ROI extraction by stenosis using canny gradient operator with non maximum suppression with threshold values 75 to 90 and hysteresis is done. The proposed mathematical model explains the rate of change in blood flow using fluid dynamic concept by Hagen Poiseuille law and vascular wall shear stress method for quantification of healthy and diseased coronary arteries. After that we have classified the levels of heart attack as initial, mild and severe using ANFIS(Adaptive Neuro Fuzzy Inference System) tool with membership function. Computer simulation results assist in predicting the risk factors of heart attack at an early stage.

Keywords: *ANFIS, Blood flow, Coronary artery, Edge gradient, Fluid dynamics, Heart attack, Stenosis.*

1. Introduction

Heart disease commonly caused due to atherosclerosis, an accumulation of fatty substances on the inner lining of coronary arteries causing blockage of blood flow.



When the flow of blood is totally blocked, the result is heart attack. According to the research, this disease was declined somewhat since 1990, lot of deaths caused and affected adversely. 17 million people are affected according to World Health Organization. Recently in London, Dr Anoop Shah introduced a new blood test technique to detect the heart attack. Heart attacks are occurred when coronary arteries are partially blocked or clogged. Blockage is caused due to the regular fixation of athero-plaque which is a waxy material. Due to this, arteries become narrower and harden itself which means there is a lack of oxygen known as myocardial ischemia and reduction of blood flow leads to the damage of heart. It causes in every men and women in any age groups.

The main objective of this research is to detect the atherosclerosis plaque and risks of heart in non invasive manner at early stages for further diagnosis. Now days, image processing plays a vital role in reducing the overheads of clinicians, they can understand the diagnosis of patients in better manner. This paper proposes various image processing modalities to extract relevant information through CCTA images for the prediction of disease. Starting from preprocessing, median filters are applied to remove the noise and get the enhanced image.

The most important step is segmentation which is done through global thresholding technique followed by K-means clustering to extract the crucial information for the coronary arterial branches. Stenosis, post processing context which considers the region of Interest or blockage is detected by canny edge gradient operator by applying gradient magnitude function with non maximum suppression and hysteresis. Proposed mathematical model is used for analyzing the change in blood flow rate through cardiac blood vessels. This mathematical model has been designed using fluid dynamics concepts including Hagen Poiseuille law (S.Agarwal *et al*,2013) and

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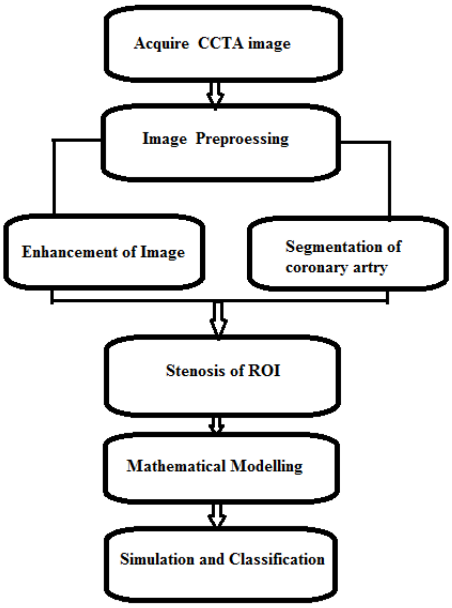
vascular wall shear stress method. Degree of stenosis (blockage) has been measured by calculating the cross sectional area of blocked and unblocked coronary artries using ellipse curve fitting method. After that classification has been done using ANFIS tool for characterization of severity of heart attack as initial, mild and severe.

2. Research Workflow

The following research workflow shows the steps to predict the risk factors of heart attack at early stages:



2.1 Acquisition of Data

Experimentation have been done on computed tomography angiogram(CTA) images which is gathered from Dr.Balabhai Navanati Hospital, Mumbai and Cardiac Life Center, Ludhiana.The image is of normal age group male and female of approx 40 to 65 years.

2.2 Preprocessing of Image

2.2.1 Enhancement of Image

Image Enhancement is the visual perception of an image to improve the quality. In this various median filters are applied on gray level formation CCTA image for the removal of noise and better visualization as given in (S.Agarwal *et al*,2013) shown in figure1.

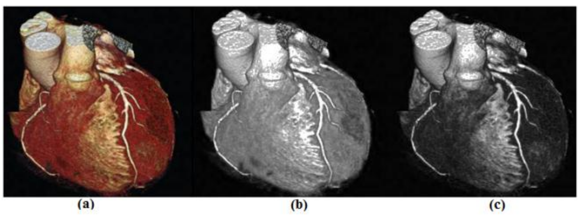


Fig.1 (a) a real ccta image of 40 years old healthy man. (b) gray label image (c) median filter image

2.2.2 Segmentation of Coronary Arteries

Segmentation is the crucial component in image processing. It is to extract the coronary artery structure from computed image by applying global thresholding modality through K-means clustering to segment color in automated fashion using L*a*b color space as shown in figure2.

There are also some other segmentation techniques like watershed and texture segmentation applied to show different behavior of this CTA image as shown in figure3.

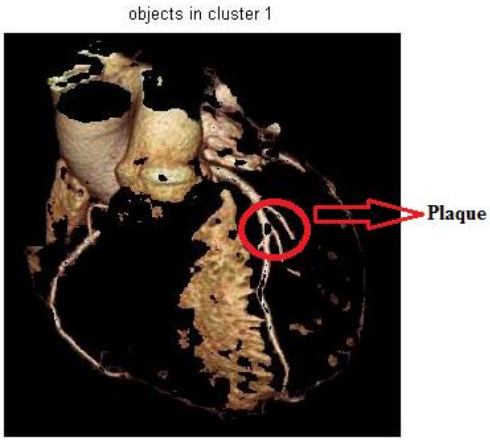


Fig.2 Plaque detected through K-means clustering

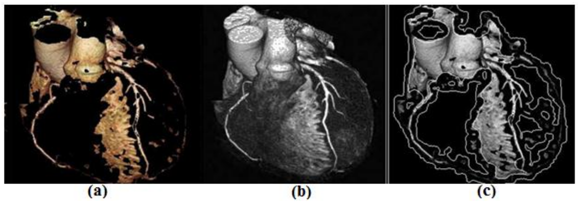


Fig.3(a) cluster1 image (b) gray label image (c) texture image

Clustering is a way of grouping of objects. K-clustering treats each object as having a location in space known as L*a*b color space, it visually distinguish one color from another. It finds partitions such that objects within each cluster are as close to each other as possible and as far as from other objects of cluster as possible.

K- clustering requires that you specify the number of clusters to be partitioned and a distance metric to quantify how close two objects are to each other.

K-means clustering algorithm defines K-center for each cluster. These centers should be placed in cunning way as there are many different results in different location. Next step is to take each point belonging to a given dataset associated to nearest center. If no point is left, first step completed and now recalculate the centers, then a new binding has to be done between same dataset points and nearest data centers. Finally it aims at calculating euclidean distance between the centers.

$$\mathbf{J(V)} = \sum_{i=1}^{Ci}\sum_{j=1}^{Cj}(\|x_i - v_j\|^2) \qquad (1)$$

Ci= number of data points in ith cluster
Cj= number of data centers

2.3 Stenosis of Coronary Branches

Stenosis is the condition where the arteries contracts or in other words narrowing of arteries, which in severe cases creates complete blockage. We have considered stenosis or blockage as ROI detection and applied canny gradient edge operator with threshold value from 70 to 90 on segmented image for preserving high spatial frequency regions corresponding to edges as shown in figure 4 and figure 5.

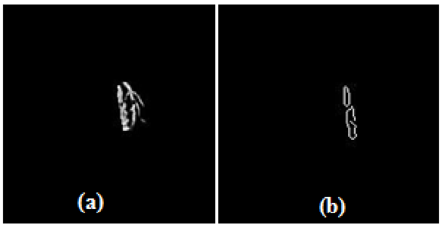


Fig.4 (a) ROI image. (b) canny edge gradient image

Fig.5 Thresholded image of cluster1 with value 84

The gradient magnitude and direction of the segmented image are calculated at each point.

$$|\mathbf{G}| = \sqrt{\mathbf{Gx^2 + Gy^2}}$$

$$\boldsymbol{\theta} = \mathbf{arctan}\left(\frac{\mathbf{Gy}}{\mathbf{Gx}}\right) \quad (2)$$

2.4 Mathematical Modeling of blood flow

Blood is an incompressible non- Newtonian fluid but such liquid motions are complicated. As in Newtonian fluid viscosity only changes with the change in pressure or temperature, it has constant viscosity which is exactly opposite in non Newtonian fluid as explained in (S.Agarwal *et al*, 2013). The contraction and relaxation of ventricles and atria visualizes blood flow in coronary arteries in (C.Corciova *et al*,2012) The viscoelastic model of Skalak and Schimid-Schonbien (Fibich *et al*,1993) is followed by the following research in which pressure changes in linear form related to strain, such that

$$\Delta \boldsymbol{P} = \boldsymbol{\alpha E} \quad (3)$$

Where $\Delta P = P_A - P_V$; pressure differences of atria and ventricles. Now blood flow which is incompressible, non homogeneous and non Newtonian fluid depends on vessel diameter and resistance in cardiac-vascular system as described in Hagen Poiseuilli's law.

$$Q = -\frac{\pi a^4}{8\mu l}\Delta P \quad (4)$$

Where Q represents blood flow, l represents length of artery, a represents diameter of artery and μ represents blood viscosity.

The relation between vessel diameter and resistance is inversely proportional as explained in below Eq.

$$R = \frac{P_A - P_V}{Q} = \frac{8\mu l}{\pi a^4} \quad (5)$$

where R represents fluid resistance.

Blood flow is also dependent on coronary artery`s wall that produces stress explained in (C.Corciova *et al*,2012) given below

$$\text{Vascular wall shear stress} = \mu\frac{\delta v}{\delta r} \quad (6)$$

Poiseuille's law is used to determine shear stress rate as

$$\gamma = \frac{8\mu}{a} \text{ or } \gamma = \frac{32\,\mu}{\pi a^3} \quad (7)$$

2.5 Degree of Stenosis

2.5.1Cross Sectional Area of Arteries using Curve Fitting Method

The difference between healthy and diseased arteries is explained by area of segmented coronary arteries by using ellipse curve fitting method from (Milos *et al*,2007) as a second order central moment.

$$\frac{1}{1+\sum_{i,j=0}^{i+j\le 4}\left(\mu'_{ij}-\mu_{ij}\right)^2} \quad (8)$$

Where μ is the central moment of the shape and corresponding ellipse fit. Now area of curve fitting is calculated using Eq.9 given below as shown in table 4.

$$A_0 = \pi * r1 * r2 \quad (9)$$

Where r1 is semi major axis and r2 is semi minor axis.

2.5.2 Error Rate to Detect % Stenosis

The symbol of blockage or stenosis can be shown by the variations in the area of artery. How much blockage inside the cardiac artery is quantified by Eq.10 to measure risk factors of heart attack as shown in Table 4.

$$\%\ \text{Stenosis} = \frac{A_N - A_B}{A_N} \times 100 \quad (10)$$

Where AN is the normal artery area (without blockage) and AB is abnormal artery area (with blockage).

3. Result and Computations

The evaluation has been done based on the mathematical model for cardiac blood flow system which includes both diseased and healthy factors. Computerized simulation has been done on MATLAB (R2010).

3.1 Clinical Parameters

This research includes diseased as well as healthy Left Coronary artery (LCA) and Right Coronary artery (RCA) CCTA images of both women and men. Simulated results are based on following clinical parameters such as length, diameter of coronary arteries, velocity and blood viscosity blood flow rate.

Table 1 Simulation of blood flow rate based on clinically approved parameters

Coronary artery	Sex	Diameter (mm)	Length (mm)	Blood viscosity (10-3)
LCA	M	4.6± .6	9.6± 4.4	3.67±0.44
RCA	M	3.5± .7	123 to 141	3.67±0.44
LCA	F	4.1± .8	8.5±4.2	3.30±0.20
RCA	F	3.2± .9	120 to 134	3.30±0.20

RCA= Right coronary artery, LCA= Left coronary artery, F= Female, M=Male.

3.2 Blood Flow Rate in Healthy or Diseased Artery

Table 2 Normal and patient specific clinical parameters

Coronary artery	Sex	Length (mm)	Diameter (mm)	
			Healthy coronary	Diseased coronary
LCA	M	9.4	4.5	3.6
RCA	M	127	4.5	3.8
LCA	F	8	4	3.4
RCA	F	125	3.5	3.5

On the basis of Table 2, we have measured fluid resistance and blood flow rate of corresponding coronary arteries from Eq.(4) and Eq.(5) respectively.

Table 3 Comparison between fluid resistance and blood flow rate

Fluid resistance		Blood flow measurement(ml/sec)	
Healthy artery	Diseased artery	Healthy artery	Diseased artery
0.0013	0.0026	0.3974	0.9562
0.024	0.0338	7.064	9.4591
0.0008	0.0022	0.2533	0.5773
0.0252	0.0323	6.3552	8.950

3.3 Area Calculation and Degree of Stenosis Detection

Table 4 Area measurement and % blockage

Coronary artery	Sex	Area without blockage (mm2)	Area with blockage (mm2)	%Blockage (stenosis)
LCA	M	0.012	0.008	36.37%
RCA	M	0.011	0.006	50%
LCA	F	0.008	0.005	55.54%
RCA	F	0.006	0.003	20%

3.4 Computer Simulation Results

3.4.1 Measurement of Blood Resistance

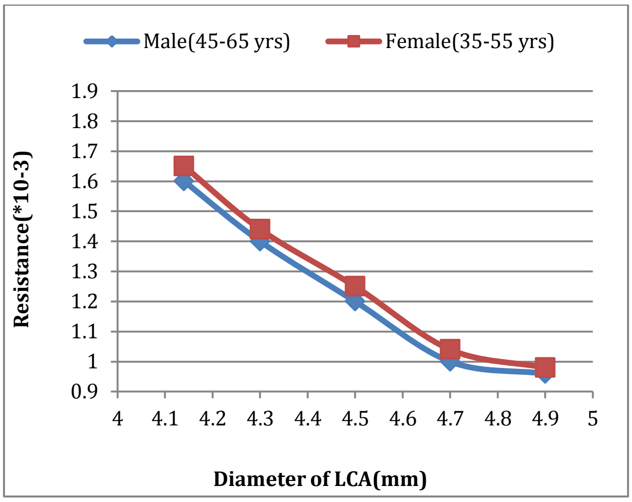


Figure 1: Resistance in healthy left coronary artery (LCA)

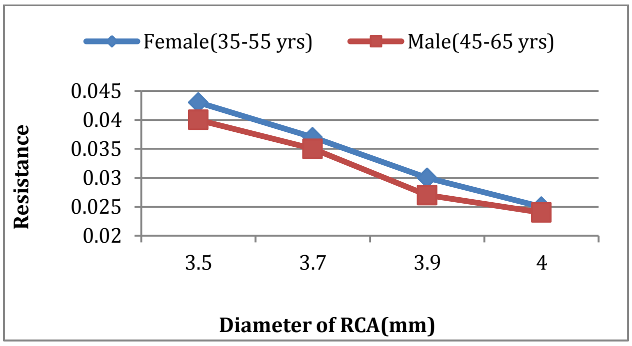


Figure 2: Resistance in healthy right coronary artery (RCA)

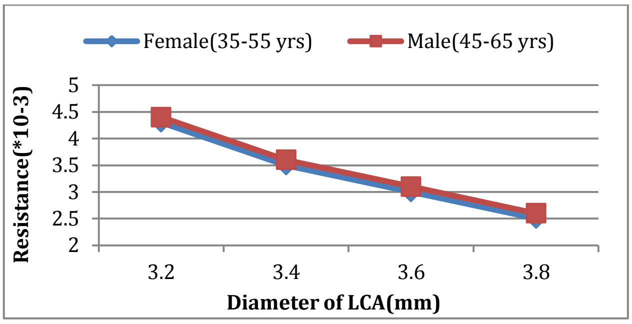


Figure 3: Resistance in unhealthy left coronary artery (LCA)

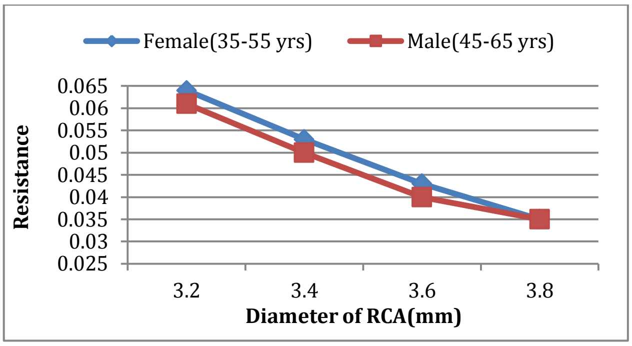


Figure 4: Resistance of unhealthy Right coronary artery (RCA)

Figure 1,2,3,4 Resistance against diameter of healthy and diseased coronary arteries of men and women from Eq.(5)

3.4.2 Measurement of Blood Flow Rate

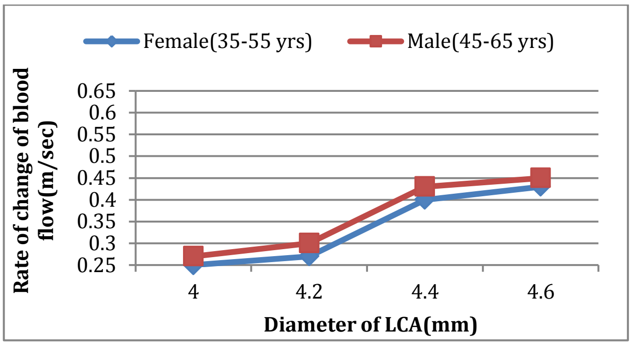


Figure 5: Blood flow in healthy Left coronary artery (LCA)

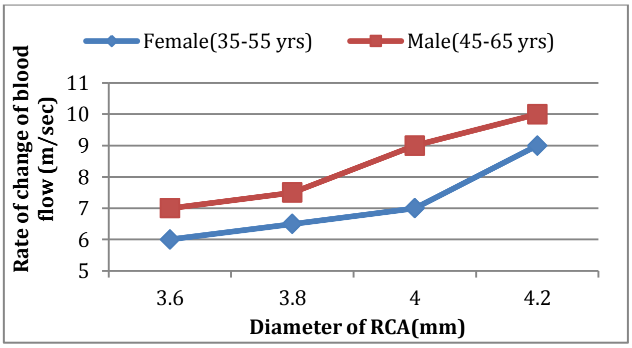


Figure 6: Blood flow in healthy Right coronary artery (RCA)

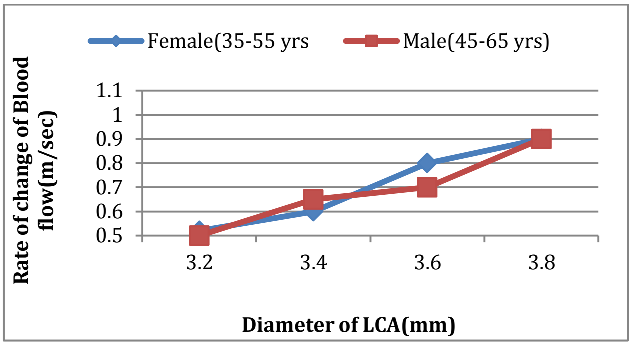


Figure 7: Blood flow in unhealthy Left coronary artery (LCA)

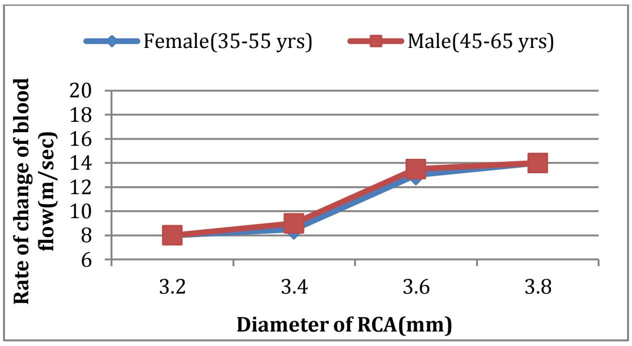


Figure 8: Blood flow in unhealthy Right coronary artery (RCA)

Figure 5,6,7,8 Blood flow against diameter of healthy and diseased coronary arteries of both men and women using Eq.(4)

3.4.3 Measurement of Wall Shear Stress Rate

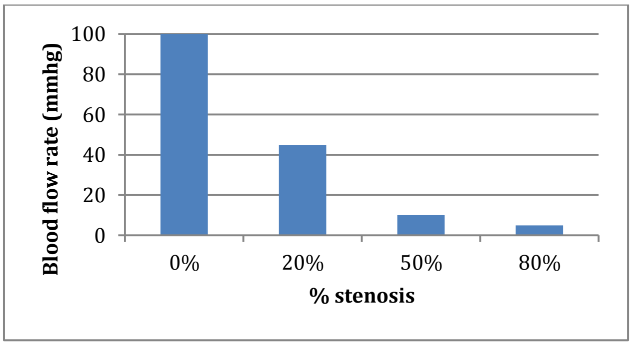


Figure 9: Graph between blood flow and stenosis

3.4.4 Classification

Risk factors of heart attack can be classified on the basis of 3 levels as shown in Table 5.

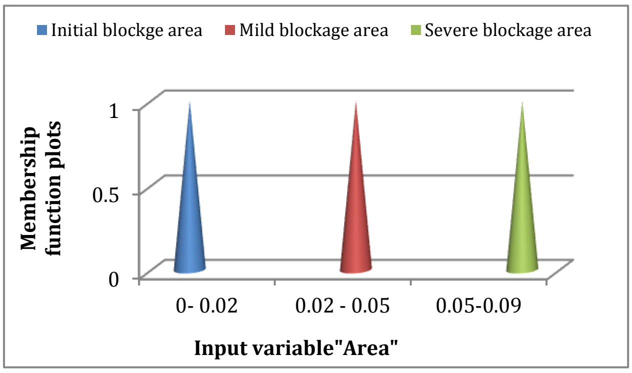
Table 5 Levels of heart attack

Levels	% Blockage
Initial	0 to 20%
Mild	20 to 50%
Severe	Above 50%

In this research work, we use a classifier named as ANFIS (Adaptive Neuro Fuzzy Inference System) to classify levels of heart attack on the basis of healthy and diseased cases. ANFIS based classifier works as a diagnostic tool to help doctors in the classification of heart attack disease. The ANFIS is a inference model put in the framework of adaptive systems to facilitate learning and adaption from (I.Guler *et al*,2005) Classification has been done on 5 training dataset and 5 testing dataset images as shown in Table6 and results for ANFIS tool with membership function results are shown in Figure 10.

Table 6 Dataset for training and testing images

Category	No. of training images	No. of testing images
Healthy artery	5	5
Diseased artery	5	5



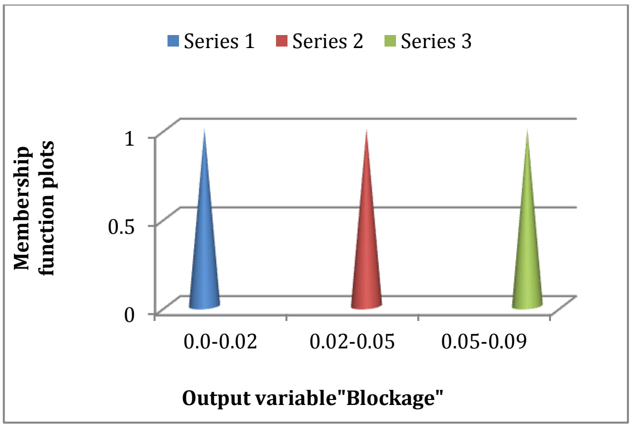


Figure 10: Prediction of heart attack levels through membership function

Table 7 Levels of risk factors of heart attack in terms of blockage

Coronary artery	Sex	Area without blockage (mm2)	Area with blockage (mm2)	%Blockage (stenosis)	Level of blockage
LCA	M	0.011	0.007	36.36%	Mild
RCA	M	0.010	0.005	50%	Severe
LCA	F	0.009	0.004	55.55%	Severe
RCA	F	0.005	0.004	20%	Initial

Conclusion

This research proposed a semi automated approach for enhancement and segmentation of coronary branches as well as quantification of degree of stenosis. The modeling of blood flow gives the worthy conclusions with an observation that variations in cardiac vessel diameter make wide changes in blood flow rate. ANFIS classifier differentiated between healthy and diseased cases for early prediction of risk factors of heart attack. According to the further needs there should be enhancement in the area of better findings.

Acknowledgement

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References

I. Guler, E.D.Ubeyli (2005) Adaptive neuro fuzzy inference system for classification of EEG signals using wavelet coefficient Journal of Neuroscience Method.

C.Corciova, M.Turnea, F.Corciova (2012) Analysis of blood flow in Coronary Artriel Tree Using Mathematical Models, Proceedings of the 1st International Conference on Health Science and Biomedical Systems (HSBS'12) ISBN: 9781-61804-097-8.

G.Fibich, Y.Lanir, N.Liron (1993), Mathematical Model of blood flow in a coronary capillary, Am. J. Physiol. 265(Heart Circ. Physiol. 34): H1829-H1840.

S.Milos, N.Amiya (2007),Direct ellipse fitting and measuring based on shape boundries, Proceedings of the 2nd Pacific Rim Conference on Advances in image and video technology.

S.Agarwal, S.Mukherjee (2013), Modelling and Simulation of Blood Flow for Early detection of Coronary Artery Blockage using CCTA images, Proceedings of ISCI-2013, Indian Institute of Technology, Madras, p_id.