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Early Detection and Segmentation of Coronary Artery Blockage using Advanced Imaging Modalities for Predicting Risk Factors of Heart Attack

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Abstract— Myocardial infarction, commonly known as heart attack, is a leading cause of human death world wide. Hence, it requires early detection of the disease non-invasively through real CT angiogram images. In this paper, median filter has been applied on input images for noise removal followed by global thresholding with frangi vesselness filter using dilation morphology for segmentation of coronary arteries. Cardiac stenosis, considered as ROI, has been detected by using canny edge gradient operator with threshold values 75 to 90. The proposed mathematical model explains 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 intial, 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.

Index Terms— ANFIS, Blood Flow, Coronary Artery, Edge Gradient, Fluid Dynamics, Heart Attack, Stenosis

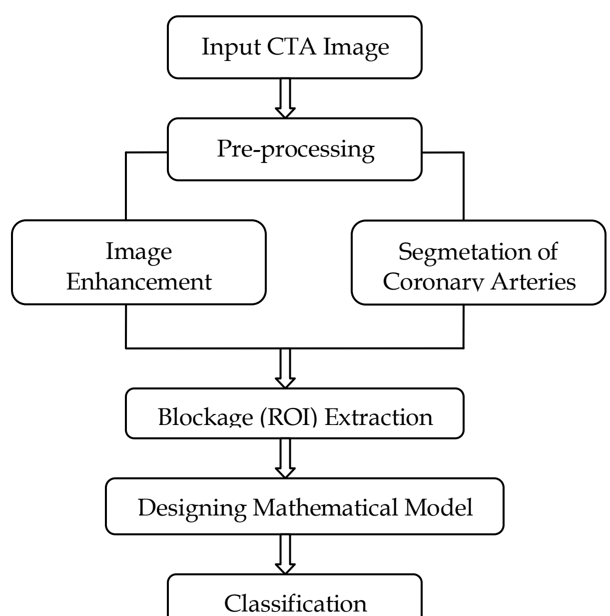
1 INTRODUCTION

Heart attack, in medical terms Myocardial Infarction (MI), is a major cause cause of human death in all over the world. According to recent statistics of WHO (World Health Organization) around 17 million people die per year due to heart attack which is of 30% of all the deaths. Heart attack occurs due to blockage of coronary arteries by building up of waxy material known as atherosclerotic plaque. Due to this plaque, cardiac arteries become narrower and harden and blood flow is reduced which results to damaged heart muscles. Heart attack can happen in any age group of men and women.

The objective of this research study is early detection the risk factors of heart attack in various age groups with non invasive manner for quick diagnosis. Today, health care systems deeply rely on medical information system by extracting knowledge from medical images with advances of digital image processing. This paper proposes various image processing methods to extract relevant information from real computed tomography angiogram images for predicting the disease. In this context, preprocessing has been done by applying median filter for removing noise from the CTA image. Here segmentation is a crucial step which has been done by applying Global Thresholding technique followed by Hassian based Frangi's Vesselness Filter with dilate morphological operator for segmentation of coronary arterial branches. In post-processing context, consider Coronary stenosis or blockage as ROI (Region of Interest) that has been detected by applying Canny Edge Gradient Operator with threshold values 75 to 90. Proposed mathematical model is used for analyzing the rate of change of blood blow through cardiac blood vessels. This mathematical model has been designed using fluid dynamics concepts including Hagen Poiseuille law [5] and Vascular Wall Shear Stress method. Degree of stenosis (blockage) has been measured by calculating the cross sectional area of blocked and unblocked coronary arteries 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 METHODOLOGY

This research work proposes the following successive steps for early prediction of heart attack:



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2.1 Data Acquisition

Experiments have been done on small batches of real Computed Tomography Angiogram images (CTA) taken *from Dr. Balabhai Nanavati Hospital, Mumbai and Cardiac Life Center, Ludhiana*. These images are of normal as well as patient specific of both males (age group 40 to 65 yrs) and females (age group 35to55 yrs).

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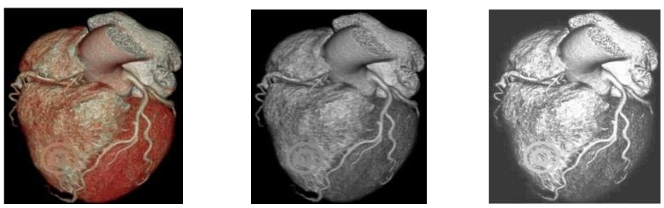
2.2 Pre-processing

2.2.1 Image Enhancement

The aim of image enhancement technique is to improve image quality for better visualization. In this research study, median filter has been applied on input gray label CTA images for noise removal as given in Agrawal et al. [10] as shown in figure 1 (c).



(a) (b) (c)

Fig. 1. (a) Real CTA image of 40 years old healthy man (b) Gray Label Image (c) Median Filter Image

2.2.2 Segmentation of Coronary Arteries

Segmentation from medical images is a crucial step in this study. To segment coronary arteries from CTA images, we have applied global threshold technique followed by Hassian matrix based Frangi Vesselness Filter with dilate morphological operator as result shown in figure 2.

Hassian matrix is the second order partial derivative square matrix which describes local curvature of the image. For a given input image, eigen values of Hessian matrix are calculated on the basis of vesselness filter Oksuz et al.[1] and Frangi et al.[8].

$$H = \begin{bmatrix} \partial^2 I/\partial x^2 & \partial^2 I/\partial x \partial y & \partial^2 I/\partial x \partial z \\ \partial^2 I/\partial x \partial y & \partial^2 I/\partial y^2 & \partial^2 I/\partial y \partial z \\ \partial^2 I/\partial x \partial z & \partial^2 I/\partial z \partial y & \partial^2 I/\partial z^2 \end{bmatrix} \quad (1)$$

where I refers to the input image and ∂ refers to derivatives of the image. Vessel structure is brighter than background so grey label invariants λ are calculated by following dissimilarity measure ratios:

$$R_A = \frac{|\lambda_2|}{|\lambda_3|} \quad \text{and} \quad R_B = \frac{|\lambda_1|}{\sqrt{|\lambda_2 \lambda_3|}} \quad (2)$$

We can calculate vessel values of "second order structureness" by proposed vesselness function as in Eq.3

$$S = \|H\|_F = \sqrt{\sum_{i \le 3} \lambda_i^2}, \quad \text{if } \lambda_2 > 0 \text{ or } \lambda_3 > 0 \quad (3)$$

where α, β and c are threshold values to measure R_A, R_B and S.

(a) (b)

(c)

Fig. 2. (a) Median Filtered Image (b) Thresholded Image (c) Segmented coronary arteries using vessel filter

2.3 Stenosis Detection in Segmented Arteries

Stenosis is a condition in which arteries become narrower and blood flow is reduced. We have considered stenosis or blockage as ROI detection, and applied Canny Gradient Edge Operator with threshold values 75 to 90 on segmented image for preserving high spatial frequency regions corresponds to edges as shown in figure 3 and figure 4. At each point in the image, the resulting gradient magnitude and direction are computed by Eq.5 and Eq.6:

$$|G| = \sqrt{Gx^2 + Gy^2} \quad (4)$$

(4

$$\Theta = \arctan\left(\frac{Gy}{Gx}\right) \quad (5)$$

(a) (b (c)

Fig. 3. (a) Healthy Left Coronary Artery (LCA), (b) Canny Edge Gradient

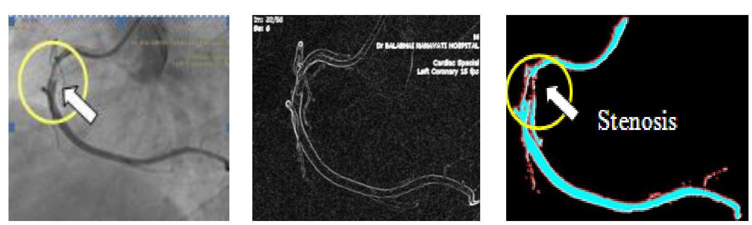


Image (c) Image after threshold value 84

(a) (b) (c)

Fig. 4. (a) Unhealthy Right Coronary Artery (RCA) of 55 years old man (b) Canny Edge Gradient Image (c) Stenosis detected on threshold value 80

2.3 Mathematical Modeling of Blood Flow

Blood is a non-Newtonian fluid and to model such liquid motion equations becomes complicated so we have assumed that blood is incompressible Newtonian fluid as explained in Agrawal et al.[10]. Blood flow in Coronary artery is strongly influenced by contraction and relaxation of ventricles and atria in Corciova et al.[3]. This study follows viscoelastic model of Skalak and Schmid-Schonbein (Fibich et al.[5]) in which pressure changes in linear form related to strain, such that

$$\Delta P = \alpha E \quad (6)$$

where $\Delta P = P_A - P_V$; pressure difference of Atria and Ventricles.

Now, blood flow, non homogeneous non-Newtonian fluid, is dependent on vessel diameter and resistance in cardiovascular system as explained in Hagen Poiseuille's law:

$$Q = -\frac{\pi a^4}{8\mu \ell} \Delta P \quad (7)$$

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

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

$$R = \frac{P_A - P_B}{Q} = \frac{8\mu\ell}{\pi a^4} \quad (8)$$

where R represents fluid resistance.

Blood flow is also dependent on coronary artery's wall that produces stress explained in Corciova et al.[3] given below

$$\text{Vascular Wall Shear Stress} = \mu \frac{\delta v}{\delta r} \quad (9)$$

Poiseuille's law is applied to find out shear stress rate as

$$\gamma = \frac{8\mu}{a} \quad \text{or} \quad \gamma = \frac{32\mu}{\pi a^3} \quad (10)$$

2.4 Degree of Stenosis Detection

2.4.1 Cross Sectional Area of Arteries using Curve Fitting Method

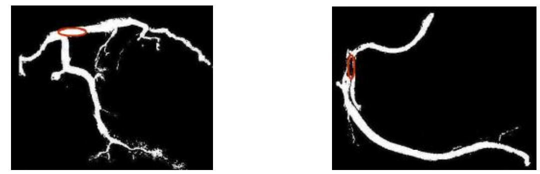
Area of segmented coronary arteries is calculated for differentiating healthy and diseased arteries by using ellipse curve fitting method from Milos et al.[9] as a second order central moment

$$\frac{1}{1 + \sum_{i,j=0}^{i+j<=4} \left(\mu'_{ij} - \mu_{ij}\right)^2} \quad (11)$$

where μ is central moment of the shape and corresponding ellipse fit. Then we have calculated the area of curve fitting by Eq. 12 as result shown in Table 4.

$$A_0 = \pi \times r_1 \times r_2 \quad (12)$$

where r_1 is semi major axis and r_2 is semi minor axis.



(a) (b)

Fig. 5. (a)~(b) Represents Ellipse Fitting method on Healthy and Diseased Coronary Arteries

2.4.2 Error Rate to Detect % Stenosis

Variations in the area of artery can be a symbol of stenosis or blockage. How much blockage inside the cardiac artery is quantified by Eq. 13 to measure risk factors of heart attack as shown in Table 4.

$$\% \text{ Stenosis} = \frac{A_N - A_B}{A_N} \times 100 \quad (13)$$

where A_N is normal artery area (without blockage) and A_B is abnormal artery area (with blockage).

3 RESULT AND DISCUSSIONS

We have evaluated a mathematical model for myocardial blood flow system which includes healthy subject as well as patient subject's factors. Computerized simulations have been implemented on MATLAB 7.9(R2009B) software and DICOM software.

3.1 Clinical Parameters

This research has been done on small batches of healthy as well as diseased Left Coronary Artery (LCA) and Right Coronary Artery (RCA) angiogram images of both men and women. Simulation of blood flow rate is based on following clinically approved parameters such as length and diameter of coronary branches, blood viscosity and its velocity.

TABLE 1
CLINICALLY APPROVED PARAMETERS TO CALCULATE BLOOD FLOW RATE

Coronary Arteries	Sex	Diameter (mm)	Length(mm)	Blood Viscosity (10-3)
LCA	M	4.5 ± .5	9.7 ± 4.3	3.57 ± 0.43
RCA	M	3.6 ± .8	124 to 140	3.57 ± 0.43
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

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LCA=Left Coronary Artery, RCA=Right Coronary Artery, M= Male, F= Female

3.2 Blood Flow Rate in Healthy and Diseased Arteries

TABLE 2
NORMAL AND PATIENT SPECIFIC CLINICAL PARAMETERS

Coronary Arteries	Sex	Length (mm)	Diameter (mm)	
			Healthy Coronary	Diseased Coronary
LCA	M	9.4	4.5	3.6
RCA	M	127	4.2	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. 8 and Eq.7 respectively.

TABLE 3
COMPARISION 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	0.3954	0.9562
0.024	0.0338	7.064	9.4951
0.0008	0.0022	0.2533	0.5773
0.0252	0.0343	6.3552	8.590

3.3 Area Calculation and Degree of Stenosis Detection

TABLE 4
AREA MEASURMENT AND % BLOCKAGE

Coronary Artery	Sex	Area Without Blockage (mm2)	Area With Blockage (mm2)	% Blockage (Stenosis)
LCA	M	0.011	0.007	36.36%
RCA	M	0.010	0.005	50%
LCA	F	0.009	0.004	55.55%
RCA	F	0.005	0.004	20%

3.4 Computer Simulation Results

3.4.1 Measurement of Blood Resistance

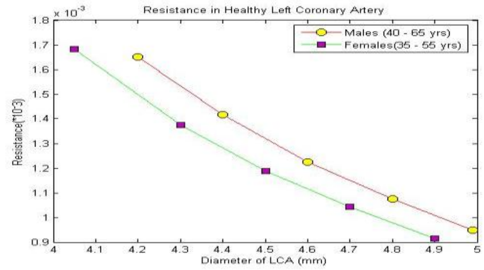

Fig. 6(b) Healthy LCA

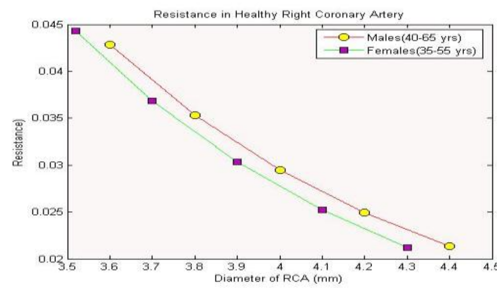

Fig. 6(b) Healthy RCA

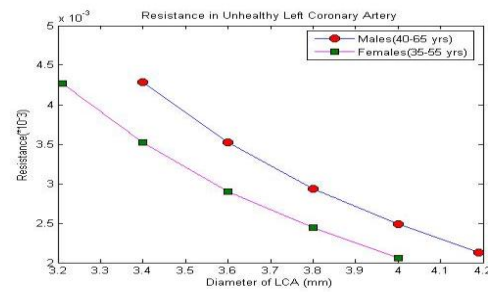

Fig. 6(c) Unhealthy LCA

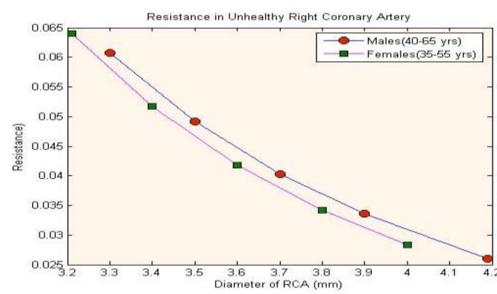

Fig. 6(d) Unhealthy RCA

Fig. 6 (a)(b)(c)(d) Resistance against diameter of healthy and diseased coronary arteries of men and women (from Eq. 8)

3.4.2 Measurement of Blood Flow Rate

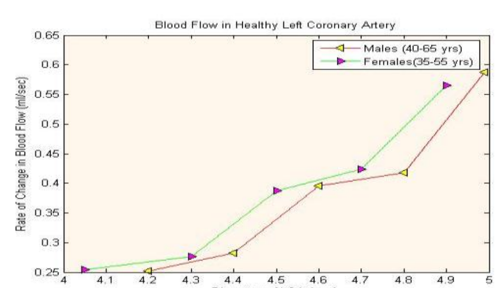

Fig. 7(a) Healthy LCA

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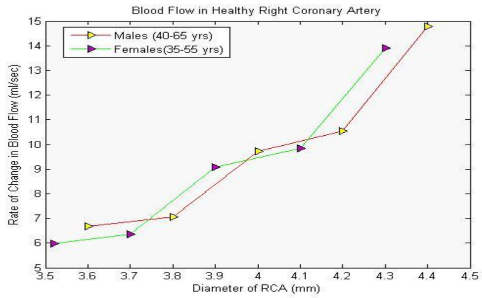


Fig. 7(b) Healthy RCA

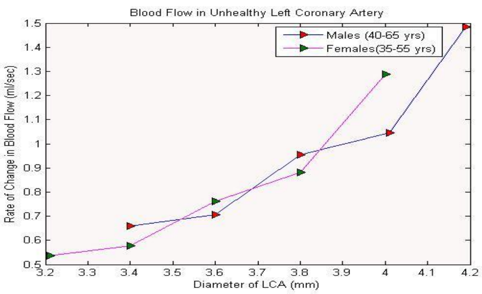


Fig. 7(c) Unhealthy LCA

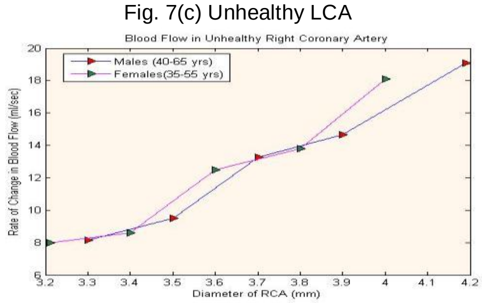
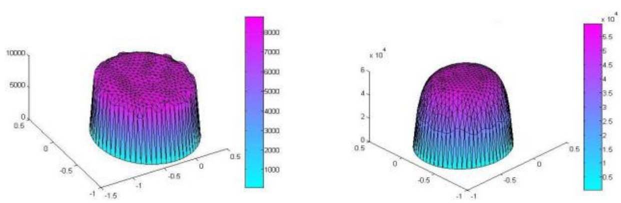


Fig. 7(d) Unhealthy RCA

Fig. 7 (a)(b)(c)(d) Blood flow against diameter of healthy and diseased coronary arteries of both men and women (from Eq. 7)

3.4.3 Measurement of Wall Shear Stress Rate



(a) (b)

Fig. 8 (a)(b) Simulation of wall shear stress rate in 2nd order polynomial (using MATLAB PDE tool) of healthy and diseased coronary arteries respectively (from Eq. 9 and Eq. 10)

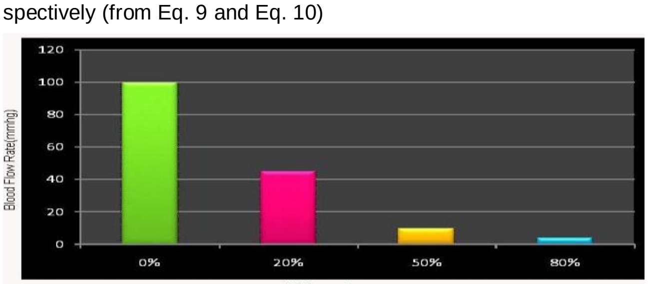


Fig. 9. Graph between Blood Flow and Stenosis

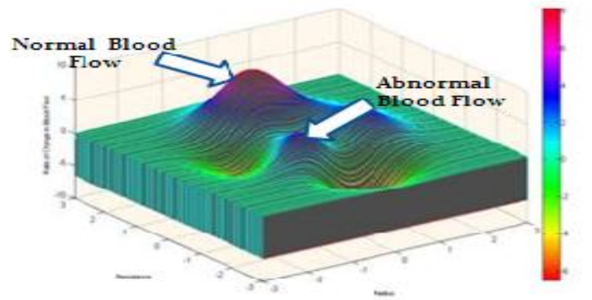


Fig 9. Mesh Graph of Normal (Without Blockage) and Abnormal (With Blockage) Blood Flow

3.4.4 Classification

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

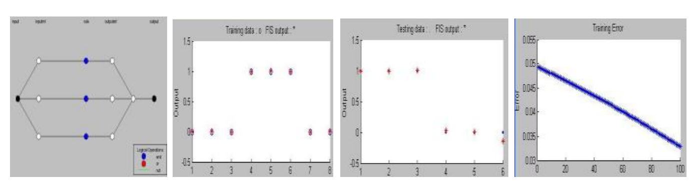
TABLE 5
LEVELS OF HEART ATTACK

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

In this research work, we used 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 fuzzy inference model put in the framework of adaptive systems to facilitate learning and adaptation from Guler et al.[2]. Classification has been done on 5 training and 5 testing dataset as shown in Table 6 and results of ANFIS tool with membership function results are shown in figure 10 and 11.

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



(a) (b) (c) (d)

Fig. 11. (a) Neural Structure of Input Data (b) Training Dataset (c) Testing Dataset (d) Training Error Rate

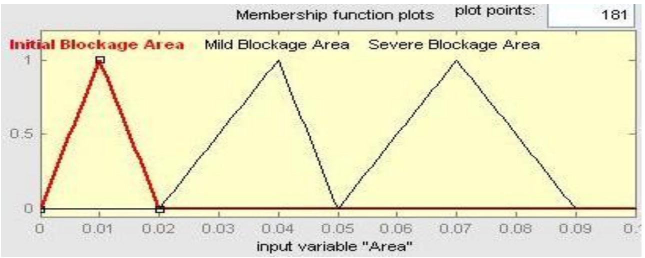


Fig. 12 (a)

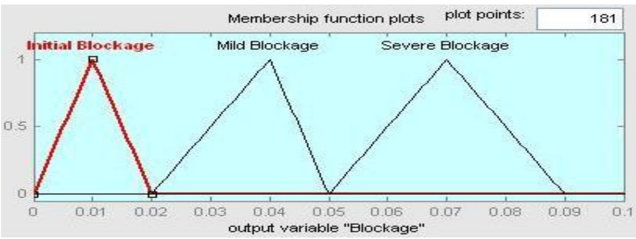


Fig. 12 (b)

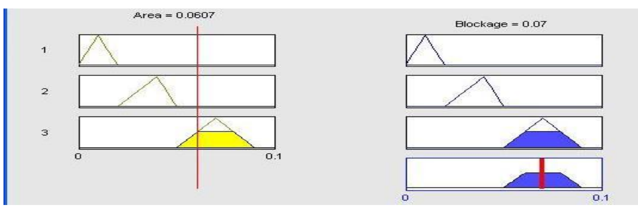


Fig. 12 (c)

Fig. 12. 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 With Blockage (mm2)	Area Without Blockage (mm2)	% Blockage (Stenosis)	Levels Of Heart Attack
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 study has proposed a semi-automated approach for segmentation of coronary arteries as well as quantifies the degree of stenosis. Modeling of blood flow gives valuable results with an observation that variations in cardiac vessels's diameter make vast changes in blood flow rate. ANFIS classifier with membership function classifies healthy and diseased cases for early prediction of heart attack. Further, study needs improvement in the area of computerized simulations for better findings.

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