Journal of Basic and Applied Engineering Research
p-ISSN: 2350-0077; e-ISSN: 2350-0255; Volume 3, Issue 6; April-June, 2016, pp. 487-492

http://www.krishisanskriti.org/Publication.html

Extraction of Coronary Artery Blockage and Determining Risk Factors of Heart Attack at the Earliest using Image Enhancement and K Means Clustering Segmentation Technique

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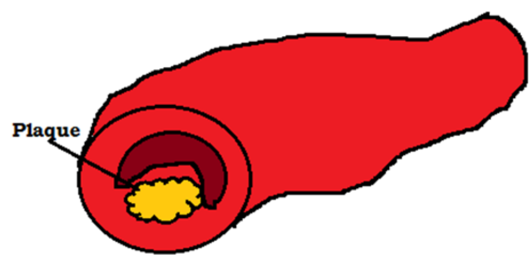
Abstract—*One of the common disease emerging presently is heart attack which is causing deaths also known as myocardial infarction. Cardiac arrest also known as heart attack, currently some of the clinically techniques are not enough for detecting such disease at early stages. This paper includes the detection and extraction of plaque also known as coronary artery blockage in scientific terms non-invasively through CTA image and also to determine the risk factors of cardiac arrest at the earliest. This paper includes various image enhancement and segmenting techniques used for extracting the plaque. Noise removal has been done using enhancement techniques with global thresholding, further segmenting the coronary branches using K-means clustering. Then region of interest is being extracted by stenosis using canny edge gradient operator with double threshold and non maximum suppression with threshold values 74 to 96 and then hysteresis is done. Further a mathematical model is designed to explained the rate of change of blood flow through the fluid dynamics using hagen poiseuille's law and calculated wall shear stress for healthy as well as diseased heart.*

1. INTRODUCTION

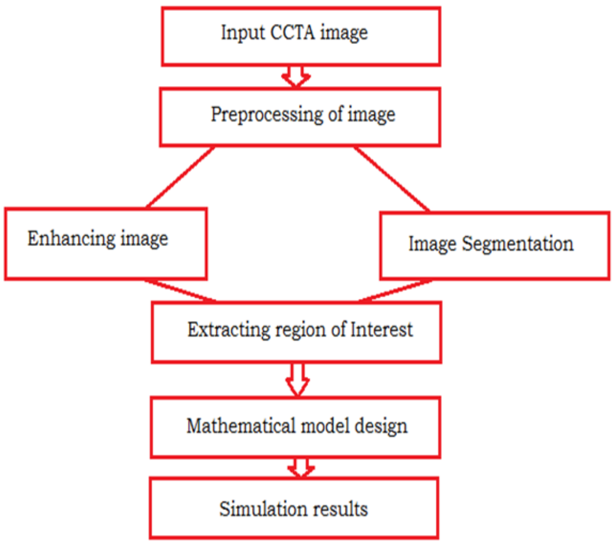
Cardiac arrest is one of the common heart disease caused due to the blockage of coronary arteries also known as atherosclerosis which is an accumulation of fatty substances causing blockage in that artery which leads to heart attack. This blockage occurs when it completely blocks the flow of blood in coronary artery. Heart attack is the disease which was declined in 1990s, a lot of deaths adverse affectively. According to the recent study, an American association found that women aged 40 or younger were disproportionately at risk to develop heart attack, chest pain, or need treatment for blockage in arteries. Heart attacks cause commonly due to smoke and high blood pressure, diabetes and various other reasons and when the arteries are partially blocked or clogged. Due to the regular clog of plaque also defined as waxy material, blockage occurs. This causes arteries to grow narrower and harden itself which shows the lack of oxygen also known as myocardial ischemia and reduce the flow of blood which leads to the damage in the heart. It generally cause in men and women in various age groups.



The objective of this research includes the extraction of athero-plaque from coronary artery and detection of early risk factors of heart non-invasively for further treatment. In recent days, image processing plays an important role in reducing burden and over head for the clinicians for the diagnosis, they can now understand the problems and treatment given to the patients in better mannar. This paper defines various image enhancement and segmentation techniques to extract the important and relevant information through CTA images for the earliest prediction of risk factors of heart attack. In this context, everything is based on the below research methodology, starting from acquiring input image to the simulation results, beginning from the preprocessing of image, various median filters including sobel, gray level slicing, etc. are applied to remove the noise and get the enhanced image for further segmentation, which is done through K-means clustering using global thresholding technique to extract vital information from coronary arteries. Now further extracting the region of interest through stenosis which is a post processing context done by canny edge gradient operator by applying gradient function with double thresholding and non maximum suppression and hysteresis. Mathematical model is designed for analyzing changes in the blood flow rate in cardiac vessels using fluid dynamic concept with hagen poissuille's law [4] and calculating wall shear stress.

2. REASEARCH METHODOLGY

The below research methodology defines the workflow to extract the region of interest and detect the risk factors of heart attack at the earliest.



2.1 Acquiring Input Data

Input data has been acquired in the form of computed tomography angiogram image from Dr.Balabhai Navanati Hospital, Mumbai and Cardiac Life Center, Ludhiana. This image is of normal male and female age groups of approximately 45 to 60 years.

2.2 Image preprocessing

2.2.1 Enhancing image

Image enhancement has been widely used in the field of image processing for the subjective evaluation or we can say the visual perception of an image to improve its quality. In this context, various median filters like sobel, gray level slicing etc, are applied on CTA image for the better visualization and removal of noise as given in Agarwal et al.[4] shown in Fig. 1.[1]

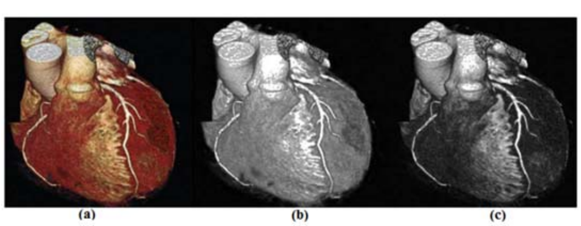


Fig. 1. (a) a real ccta image of 45 years old healthy man. (b) gray label image (c) median filter image.

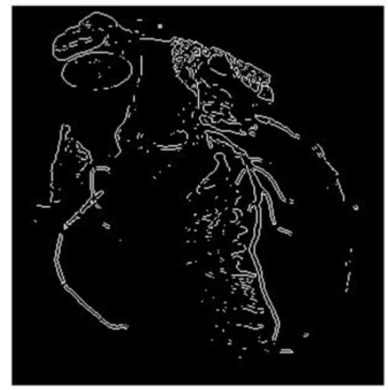


Fig. 1.(d) Sobel filter image

2.2.2 Image Segmentation

The vital component of image processing is the segmentation of coronary arteries to extract the coronary structure from CTA image through K-means clustering with global thresholding technique to segment color in an automated fashion using L*a*b color space as shown in Fig. 2(a). Plaque is detected through this technique as shown in Fig. 2(b).[1]

Some of the other segmentation modalities like watershed and texture segmentation are also applied to show different behavior of computed image as shown in Fig. 3.[1]

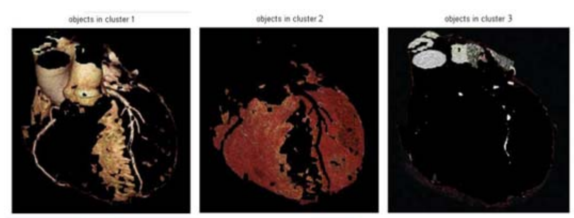


Fig. 2(a). K-means clustering applied using L*a*b color space.

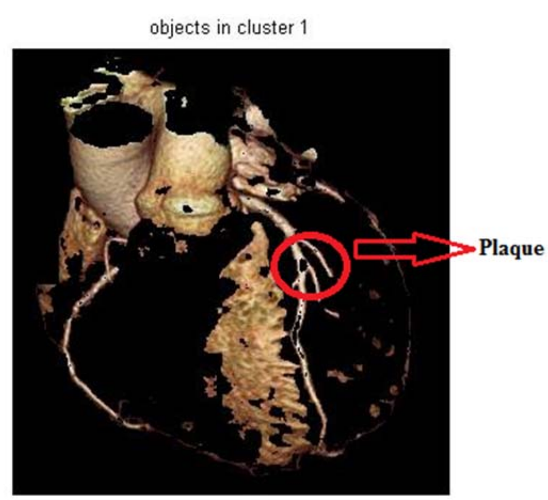


Fig. 2(b). Plaque detected through K-means clustering.

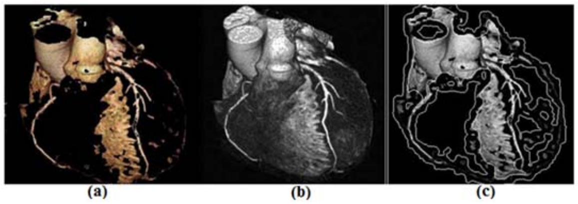


Fig. 3.(a) cluster1 image (b) gray label image (c) texture image

K-means clustering defines each object having a location in the L*a*b color space which categorizes it in 3 layers i.e. Luminosity layer and 2 chromaticity layers that visually distinguishes one color from another. Clustering defines a way of grouping of objects such that each object within a cluster are as close to each other as possible and as far as from other objects of cluster as possible.

K-means clustering specifies the number of clusters to be partitioned and a distance metric is defined to quantify how close two objects to each other and how two clusters are far from each other.

Algorithm for K-means clustering:

Step1: defines k center for each cluster.

Step2: take each point that belongs to given dataset associated to nearest data center.

Step3: if no point left then first step completed and recalculate new centers

Step4: calculate Euclidean distance metric between data centers

The centers should be placed in a cunning way so as to obtain different result in different directions.

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

Ci= number of data points in ith cluster.

Cj= number of data centers.

2.3 Extraction of ROI through stenosis

A condition which leads to the contraction of arteries is known as stenosis. In this type of situation arteries contracts which leads to complete blockage of blood through coronary arteries. Extraction of region of interest has been done by ROI detection followed by canny edge gradient operator with threshold value from 75 to 90 applied on CTA image after segmentation of preserving connection between high spatial regions related to edges as shown in Fig. 4 and Fig. 5.[1]

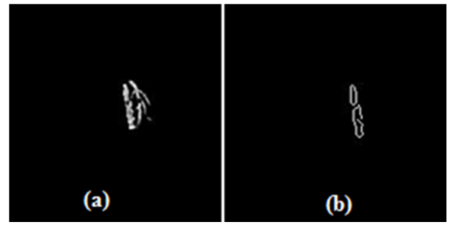


Fig. 4.(a) ROI image. (b) canny edge gradient image.

Fig. 5. Thresholded image of cluster1 with value 84.

Calculation of gradient magnitude and direction of CTA image after segmentation are done at each point.

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

$$\theta = \mathbf{arctan}\left(\frac{\mathbf{Gy}}{\mathbf{Gx}}\right) \qquad \text{Eq.(2)}$$

2.4 Mathematical model

According to the clinical study, blood is non Newtonian fluid and such fluid motions are complicated so it is assumed to be incompressible. As Newtonian fluid has constant viscosity and it only changes with the change in temperature or pressure which is exactly opposite in non Newtonian fluid explained in Agarwal et al.[4]. Computation simulations are used in which blood flow is visualized by the contraction between atria and ventricles in coronary arteries as shown in corciova et al.[2]. As the coronary ateries are analyzed theoretically so it is based on the model of Skalak and Schimid(Fibich et al.[3]) which is also known as viscoelastic model which is followed by the research which explains pressure changes in linear form related to strain, such that

$$\Delta \boldsymbol{P} = \boldsymbol{\alpha E} \qquad \text{Eq.(3)}$$

Where ΔP is the pressure difference of atria and ventricle and $\Delta P = P_A - P_V$;. This non Newtonian fluid which is known as blood which is incompressible and non homogeneous depends on the diameter and resistance of the vessel in cardiac system is described in Hagen Poiseuilli's law.

$$Q = -\frac{\pi a^4}{8\mu l}\Delta P \qquad \text{Eq.(4)}$$

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

The relationship between resistance and diameter is inversely proportional as shown below.

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

where R represents fluid resistance.

Stress is produced by the blood flow which is dependent on coronary artery wall explained in corciova et al.[2]

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

Shear stress is also determined by Poiseuille's law as given below

$$\gamma = \frac{8\mu}{a}\ or\ \gamma = \frac{32\ \mu}{\pi a^3} \qquad \text{Eq.(7)}$$

3. SIMULATION RESULTS

The computations have been done on the basis of mathematical model for cardiac system which includes healthy and diseased factors. The evaluation and simulation have been done on MATLAB(R2010).

3.1 Clinical Parameters

Evaluation and Simulation results are based on clinical parameters such as length, velocity, diameter of coronary artery and blood viscosity. The following research includes healthy and diseased Left coronary artery (LCA) as well as Right coronary artery (RCA) of both men and women.

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	4.56± .60	9.59± 4.40	3.68±0.45
RCA	M	3.50± .70	122 to 140	3.68±0.45
LCA	F	4.2± .7	8.51±4.3	3.31±0.21
RCA	F	3.20± .91	121 to 135	3.31±0.21

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

3.2 Blood Flow Rate in Healthy or Disease Artery

TABLE 2: NORMAL AND PATIENT SPECIFIC CLINICAL PARAMETERS

Coronary artery	Sex	Length(mm)	Diameter (mm)	
			Healthy coronary	Diseased coronary
LCA	M	9.41	4.4	3.7
RCA	M	128	4.6	3.79
LCA	F	9	4.1	3.5
RCA	F	126	3.4	3.4

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
0.0012	0.0025	0.3975	0.9563
0.023	0.0339	7.065	9.452
0.0007	0.0023	0.2533	0.5772
0.0253	0.0322	6.3553	8.951

3.3 Computer Simulation Results

3.3.1 Measurement of Blood Resistance

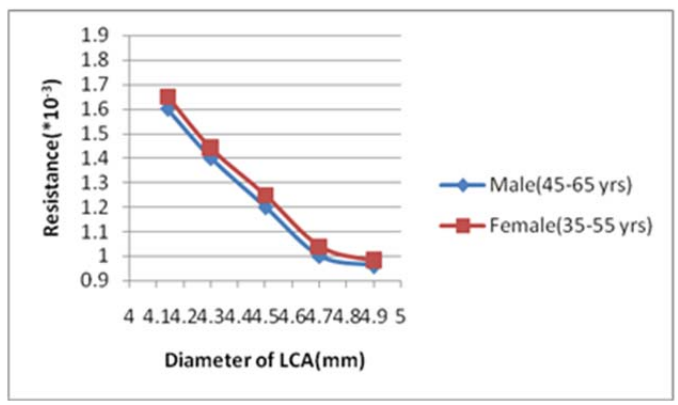


Fig. 1: Resistance in healthy left coronary artery(LCA)

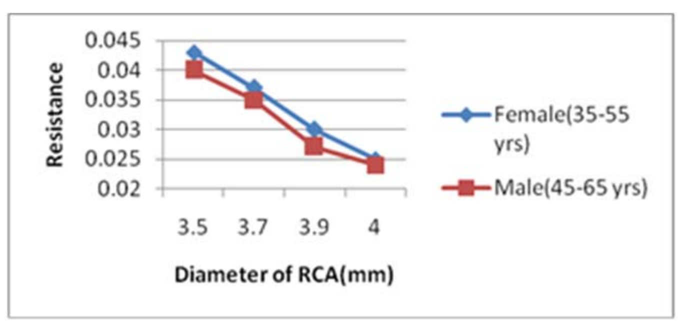


Fig. 2: Resistance in healthy right coronary artery(RCA)

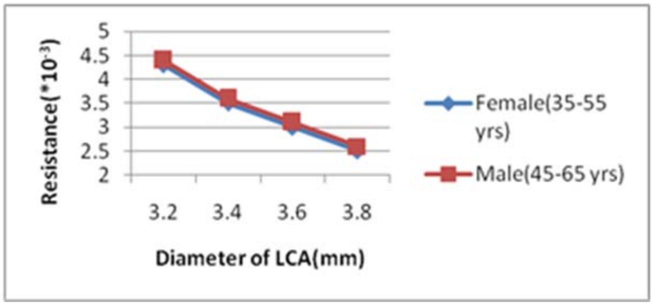


Fig. 3: Resistance in unhealthy left coronary artery(LCA)

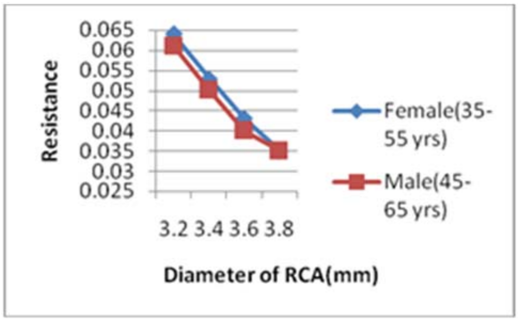


Fig. 4: Resistance of unhealthy Right coronary artery(RCA)

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

3.3.2 Measurement of Blood Flow Rate

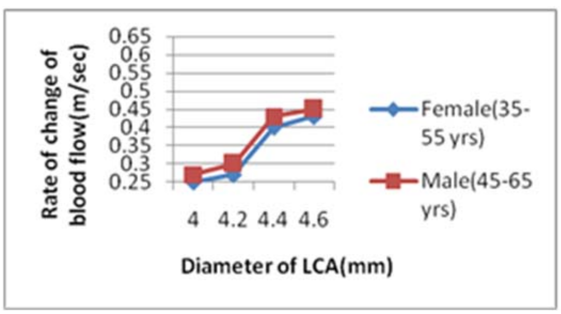


Fig. 5: Blood flow in healthy Left coronary artery(LCA)

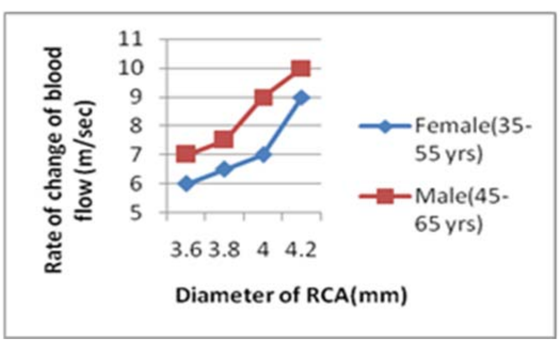


Fig. 6: Blood flow in healthy Right coronary artery(RCA)

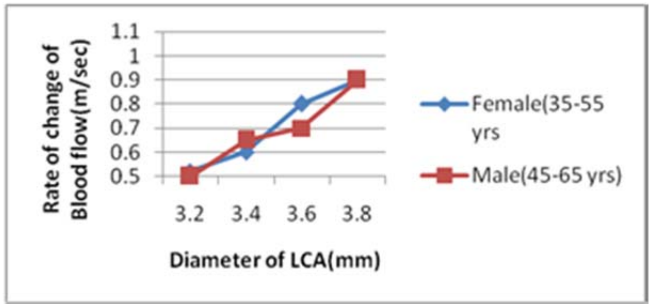


Fig. 7: Blood flow in unhealthy Left coronary artery(LCA)

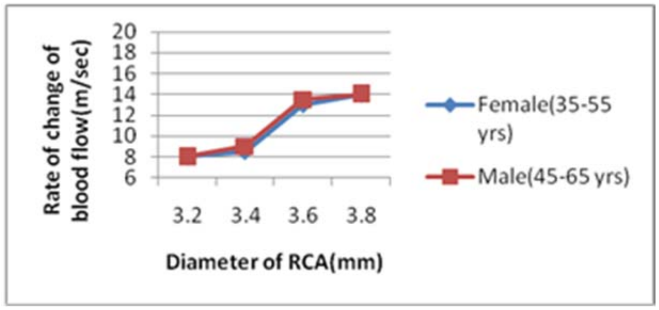


Fig. 8: Blood flow in unhealthy Right coronary artery(RCA)

Fig. 5,6,7,8 Blood flow against diameter of healthy and diseased coronary arteries of both men and women using Eq.(4)[1]

3.3.3 Measurement of Wall Shear Stress Rate

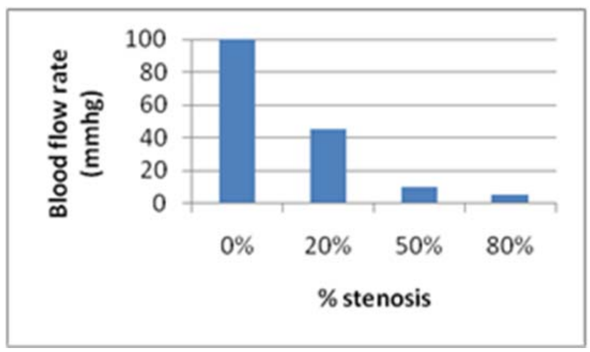


Fig. 9: Graph between blood flow and stenosis.

4. CONCLUSION

The following research proposes a well automated closure for imaging modalities such as enhancement and segmentation modalities for detecting plaque in coronary branches and quantifying degree of stenosis. The mathematical model of blood flow gives exemplary results with an observance that change in vessel diameter makes wide change in blood flow rate. According to the future use there should be better advancements in terms of better findings.

5. ACKNOWLEDGEMENT

This research consumed huge amount of work, dedication and determination. Still implementation was not possible without my project guide Ms. Jyotika Pruthi, Assistant professor, The Northcap University, Gurgaon and my sincere regards to Dr. Balabhai Navanati Hospital team members, Mumbai and Dr. Manpreet Singh Bindra, Cardiologist, Cardio Life Care, Ludhiana for their guidance and help for carrying out this research.

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