Coronary Artery Disease Detection Using CT Angiography

BY

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In the name of ALLAH, the Beneficent, the Merciful

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ABSTRACT

There is an ever-increasing interest in the development of automatic medical diagnosis systems due to the advancement in computing technology and also to improve the service by medical community. The knowledge about health and disease is required for reliable and accurate medical diagnosis. Digital information is acquired at different scales, quickly and efficiently by means of image processing techniques. So the algorithms can be developed for computer-aided medical diagnosis based on image processing technology. In this thesis, a design and algorithm of coronary artery disease detection system using computed tomography angiography images for the screening of coronary artery disease is proposed. The thesis proposes algorithms for image preprocessing, noise removal and area calculation and evaluation to detect coronary artery disease. The developed method is tested on different available databases i.e. collected from two hospitals. Three parameters are used to check the validity of proposed algorithms i.e. visual inspection, accuracy, and calculation time. The proposed method for coronary artery disease detection achieves an average accuracy of 83.8%.

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Chapter 1

INTRODUCTION

1.1 Overview

Heart diseases are most common cause of death in all over the world. There are a large number of diseases, problems and abnormalities related to heart and blood circulatory system. We can list the major or commonly found diseases as coronary heart disease, atherosclerosis, stroke, chest pain (angina pectoris), congestive heart failure, irregular heart beat (arrhythmia), congenital and rheumatic heart disease.

Coronary heart disease is more commonly found in all over the world out of all above mentioned diseases. We can observe it as in Figure1.1.

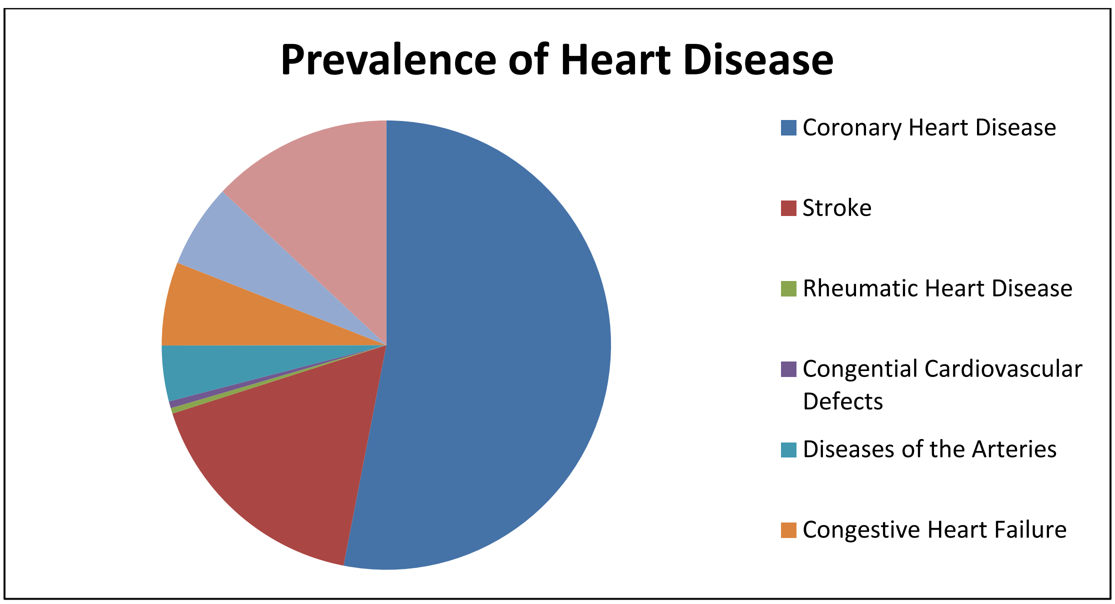

Figure 1.1 *Percentage of all heart diseases*.

Coronary Heart Disease has 53% possibility in heart patients. Studies have revealed that out of 9 women and 6 men 1 is suffering from Coronary heart disease (CHD).Different regions of the world has different mortality rates due to Coronary Artery disease.

According to authentic research different regions of the world has following death rates as described in Table 1.1.

Age	Hispanic	Asian	Native Amer	White	Black
>65	1335	870	1128	2181	2079
45-64	165	95	224	425	244

Table 1.1 *Death rates due to coronary artery disease*.

Major cause of Coronary artery disease is formation of plaque (Formation of lipid or cholesterol layer inside the artery). Plaque inhibits the blood flow to the heart muscle, as coronary arteries are the one which supply blood to the heart muscle for its proper working. It may block the blood flow ways partially or sometimes completely (In heart attack condition). Explanation of the plaque and its role in blockage of arteries can be understood by looking at the following Figure1.2.

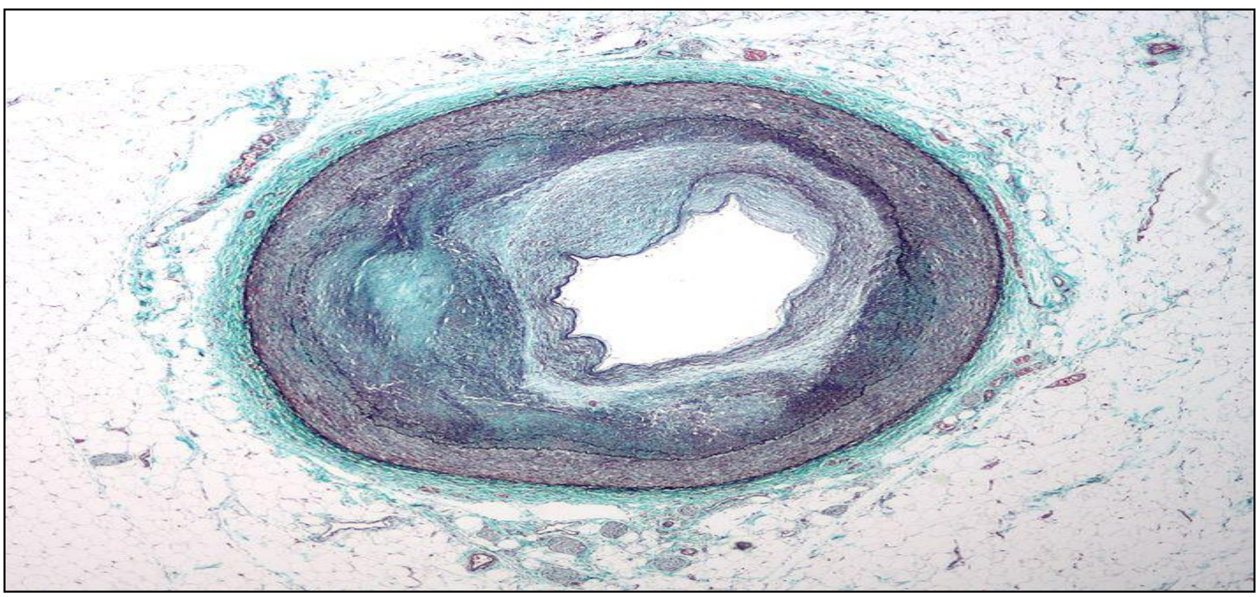

Figure1.2 *Plaque inside artery*.

Or more precisely we can say that there may occur a chance that the artery is partially blocked or fully blocked. It can be shown as in Figure1.3.

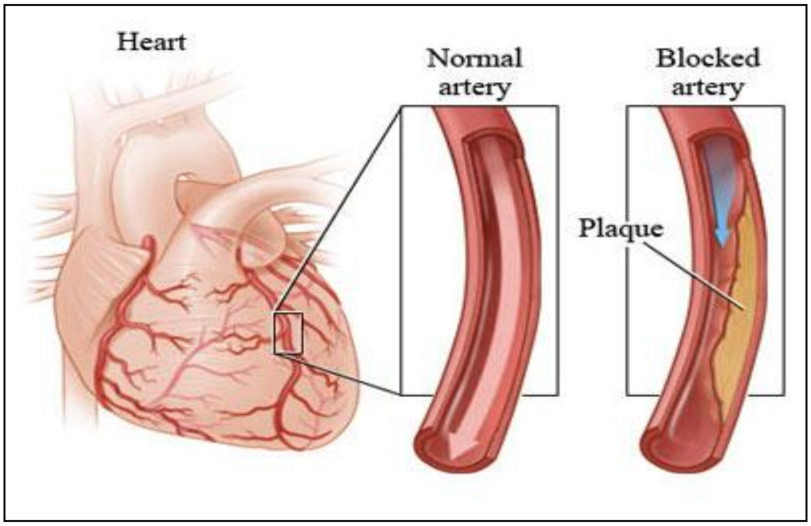

Figure1.3 *Normal and blocked artery.*

There are a large number of causes due to which this disease can occur e.g. smoking, high fat and cholesterol level, high blood pressure, hypertension and of course obesity. One person can control his habits and all above mentioned factors with a healthy diet and regular exercise. There are also some risk factors which cannot be controlled by a person himself or can be mentioned as uncontrollable factors. These include heredity, gender, race and age.

Large numbers of techniques are here to detect the defective or abnormal portion of coronary artery (CA) used by Cardiologists (Heart Doctor).Cardiologists use all the possible ways to assess the severity of disease and the major objective is correct diagnosis. In this phenomenon of diagnosing the problem Biomedical Imaging techniques and procedures are being adopted. Of great importance is how the narrow and constricted arteries can be detected for further examination and treatment. Cardiologists observe the images closely and conclude the results. No methodology can beat the human services but there is always a room for improving the things, procedures and methods for human ease. Coronary heart disease (CHD) is same as Coronary Artery Disease (CAD). Following techniques are used for CAD diagnosis, where major categories are invasive and non invasive techniques.

And imaging technologies can be categorized as echocardiogram, coronary catheterization, intravascular ultrasound, computed tomography angiography (CT Angiography), positron emission tomography, magnetic resonance imaging and electrocardiogram (ECG).

Computed Tomography Angiography belongs to non invasive technique of heart imaging. Here all the focus of Coronary Artery Disease detection is by using these CT angiographic images.

1.2 MOTIVATION

To examine the CT angiographic images is the new emerging research area in Medical Image Processing and Biomedical Imaging. It's more convenient to observe this technique before using a catheterization technique as it can help cardiologists to determine the exact location of blocked area in coronary arteries which can be used for further treatment. One basic advantage of CT angiography over other techniques is that no tube like structure passed into the body of patient and after this test patient can do his routine work normally.CAD is the most common disease all over the world. By detecting the disease automatically will improve the advancements in biomedical imaging and this work can be used in medical institutions and also by medical professionals.

1.3 SCOPE OF THE RESEARCH

Doctor to patient communication and understanding is extremely low in Pakistan. In addition to this CAD is most common throughout the world especially after forty years of age. In Pakistan we have very small number of people expert in cardiac field, in fact only a single cardiology center can be found on division level. Hence any research in this domain can be helpful at local or national level. Other advantages can be ease for professionals, effective solution for detection of blocked arterial tree, low computational cost and of course a non invasive method for detection. The main goal of this research thesis is to provide reliable and accurate image processing methodologies (pre processing techniques), extraction of coronary arterial tree, and then calculation of area of arterial tree.

1.4 STRUCTURE OF THESIS

This thesis consists of six chapters. Chapter 2 includes the medical introduction to Coronary Artery disease, its major types, causes, and describes the different abnormality and changes occurs within the anatomy of heart when effected by heart disease .Chapter 3 familiarizes the reader with related work presented in the literature. The proposed methodology for detection of abnormal patient images by using CT Angiographic images are explained in chapter 4. A comprehensive explanation of the proposed and implemented methods, procedures and algorithms are explained in this chapter. Chapter 5 shows all the experiments performed and their final results. And finally in chapter 6 conclusion and future wok is discussed.

1.5 SUMMARY

CAD is the major cause of death in all over the world. Globally every year millions of people are affected by this disease and most of the times blockages in coronary arteries lead to heart attack and most of the people do not came back to their life, hence a sudden death occur all the time as severity takes place in this disease. Therefore to assist in the diagnosis of CAD images can be used as developing tools. An algorithm is implemented which can detect the deceased images by using area factor of arterial tree.

Chapter 2

CARDIOVASCULAR SYSTEM AND DISEASES

2.1 Heart Location

Behind the tail and above the diaphragm which is located in between the lungs, heart from the pericardium is present about the size surrounded by a handful, and the weight is about 250-300 grams. The midsagittal plane left about 1.5 cm, located in the heart center. Further, on back side of the heart esophagus and the spine lie. An overall view is given in Figure 2.1[1].

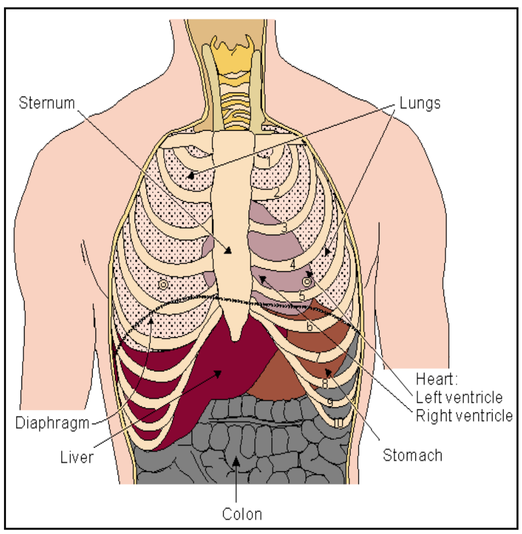

Figure 2.1 *Location of the heart in chest.*

2.2 STRUCTURE OF HEART

The walls of the heart consist of four chambers made up of Myocardium: the right and left atria and ventricles. The free wall of right ventricular is thinner while septum and left ventricular are much thicker. The cardiac muscle fibers have spiral orientation as shown in Figure 2.3. Structure of cardiac muscle fiber and are divided into four groups. The heart has four valves. Tricuspid valve lies between the right atrium and ventricle and mitral valve lies between the left atrium and ventricle. Between the right ventricle and the pulmonary artery lies pulmonary valve, while the aortic valve lies in the outflow tract of the left ventricle. The right atrium and right ventricle are there for the delivery of systemic blood returns through tricuspid valve to go. Right ventricle passes blood through the pulmonary valve to the lungs. We can observe it in Figure 2.2 and Figure 2.3[1]. Oxygenated blood containing more amounts of oxygen returns to the left atrium, through left ventricle, and from there through the mitral valve also. In the end, systemic delivery of blood to the aorta and aortic valve exits through [1].

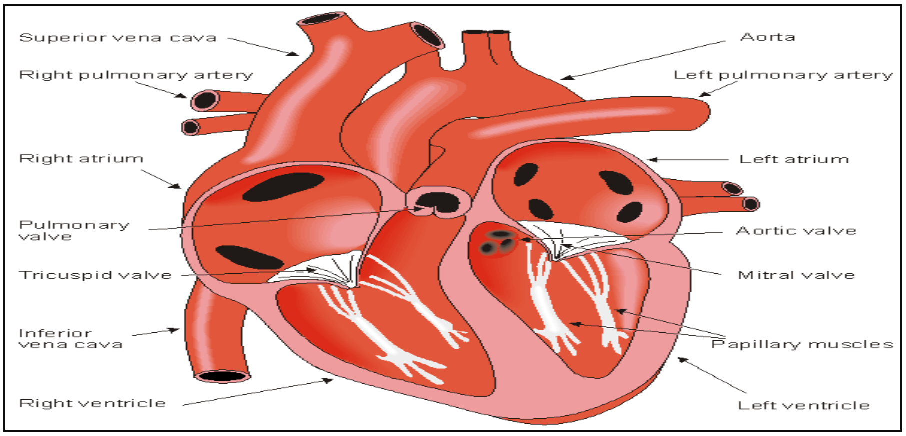

Figure 2.2 *The structure of the heart and related vessels.*

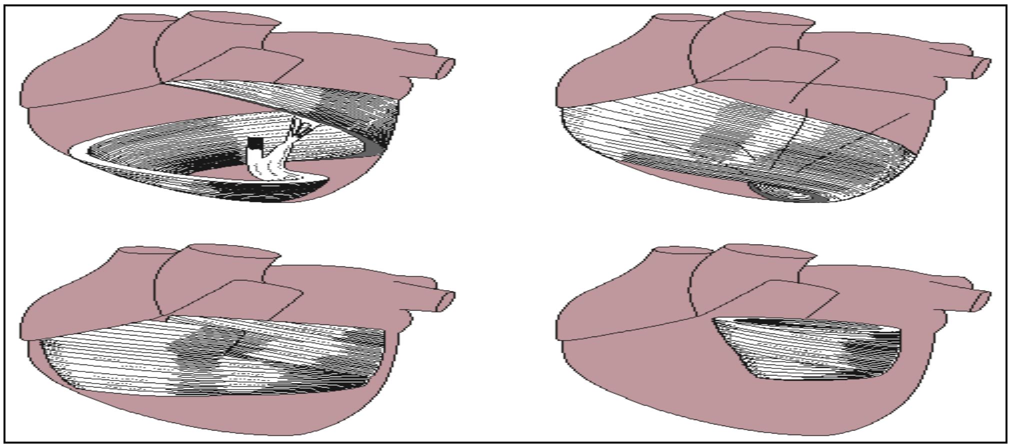

Figure 2.3 *Structure of cardiac muscle fibers.*

2.3. PHYSIOLOGY OF HEART

The heart can beat on its own without the need for exogenous commands. Excitation of the heart is triggered by electric impulse rather than neutral transmitters whereas as contraction of heat is triggered by elevation of intracellular calcium influx.

2.3.1. ACTIVATION OF THE HEART BY ELECTRICAL IMPULSES

2.3.1.1. Heart Muscle Cell

In the myocytes, electric activation ensues by flow of sodium ions across the cell membrane. The potential needed for proper working or action potential is 100 mV for both nerve and muscle. A phase follows cardiac depolarization, which is then followed by repolarization. As repolarization ends the potassium ions outflows from membrane, the time of the action impulse is about 300 ms [2] as shown in Figure 2.4.

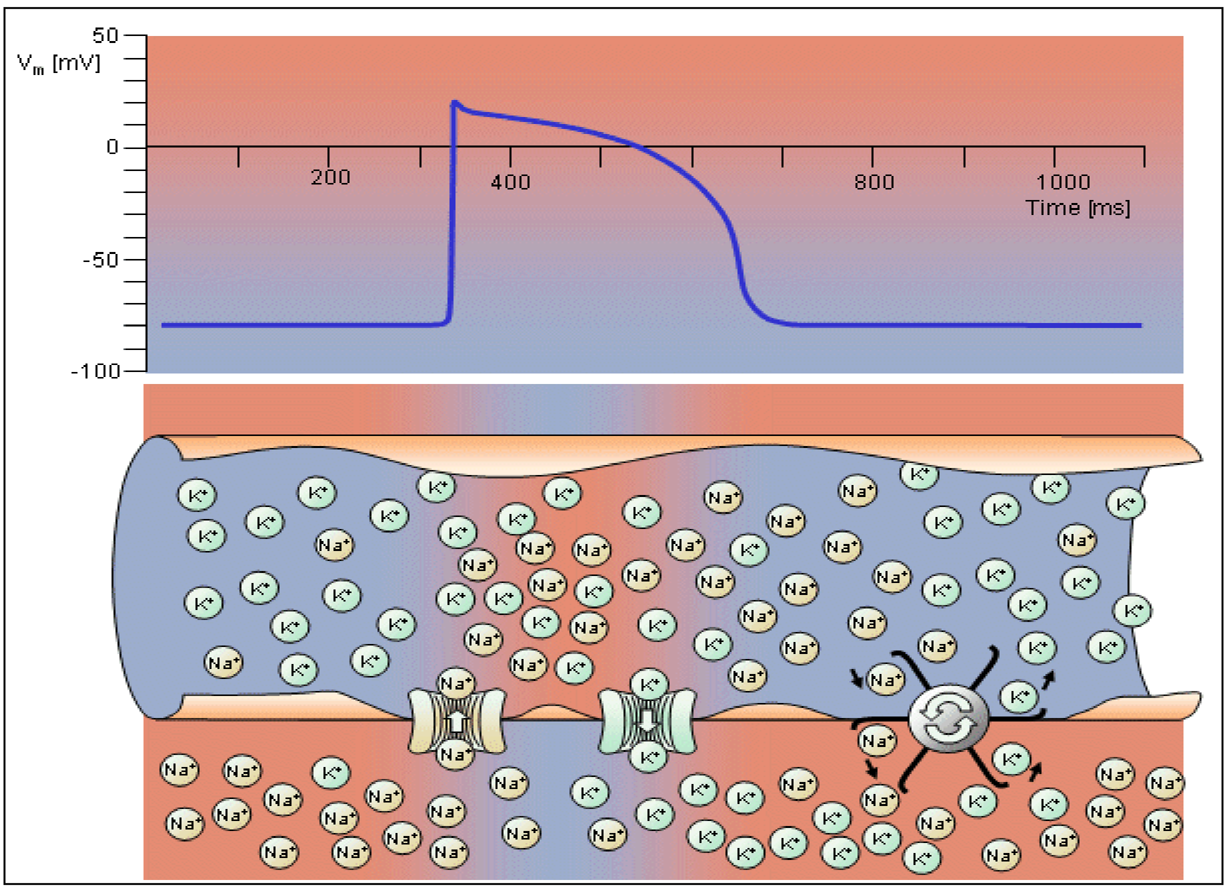

Figure 2.4 *Electrophysiology of the cardiac muscle cell*.

2.3.1.2. The Cardiac Cycle

The cardiac cycle or cardiac event starts from the beginning of one heart beat and completes with the beginning of the next heartbeat. Each cycle is started by the impulse of spontaneous action potential produced in the sinus node located higher in the lateral wall of the right atrium at the opening of the vena cava above, and the action potential propagates through the atria from here and then through the AV bundle into the ventricles. Hence there can be observed a delay of more than 0.1 seconds during the propagation of the cardiac impulse from the atria to the ventricles because of this special event, the support of the atria into the ventricles. Here ventricular contraction occurs after the contraction of atria, while blood is pumped into ventricles until unless full ventricular contraction starts. In all, the atria can be considered as the basic pump for ventricles and ventricles after that became a source for blood supply throughout the human body.

2.3.1.3. Diastole and Systole

The diastole is a period of relaxation, during which the heart fills with blood, followed by a period of contraction called systole. Figure 2.5 shows the different events during the cardiac cycle for the left side of the heart [3]. The pressure changes in the aorta, left ventricle, and left atrium are shown in top three curves respectively. The changes in left ventricular volume are depicted by fourth curve, the fifth cure showing the electrocardiogram, and the sixth a phonocardiogram.

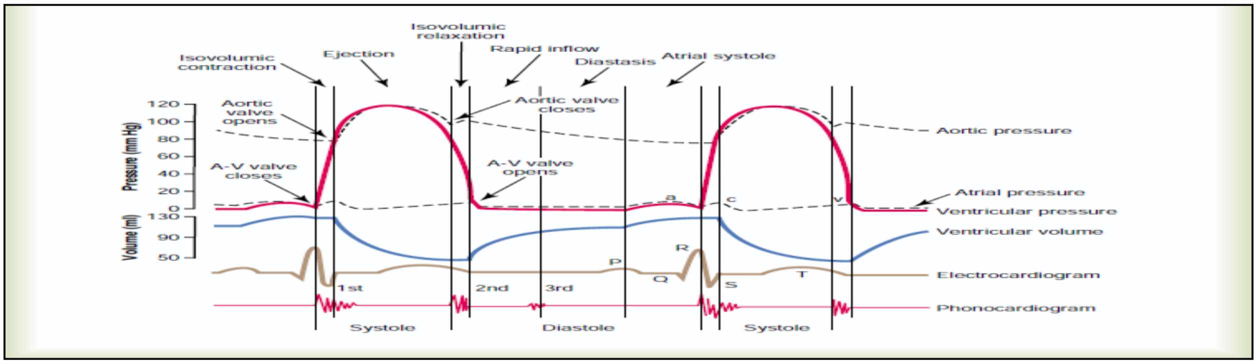

Figure 2.5 *Events of the cardiac cycle.*

2.3.1.4. Function of the Atria and Ventricles as Pumps

Blood is accumulated in left atrium and ventricle during atrioventricular systole because atrioventricular valves are closed. During atrioventricular systole condition pressure is decreased. In 2.5 we can see that pressures are increasing modestly. Blood enters into ventricles according to last in first out (LIFO) principle. Whereas ventricular volume curve is shown in figure 2.5 and called fast period for filling ventricles.

2.4. FUNCTION OF VALVES

2.4.1. Atrioventricular Valves

The basic function of both the ventricles is to pump the blood in circulation. To fulfill this mechanical work function of ventricles is associated with structure of ventricle [8]. During systole A-V valves (the tricuspid and mitral valves) prevent backflow of blood from the ventricles to the atria, and during diastole the semilunar valves (the aortic and pulmonary artery valves) inhibit the backflow from the aorta and pulmonary arteries into the ventricles [3].

2.4.2. The Conduction System of the Heart

The sinus node which consists of specialized muscle cells is found in the right atrium at the superior vena cava and its shape is just like a crescent of about 15 mm length and 5 mm widths as shown in Figure 2.6. The SA nodal cells produce an action potential which has a rate of about 70 per minute that propagates throughout the atria, but cannot propagate directly.

The atrioventricular node (AV node) is found near the boundary between the atria and a ventricle and it contains an intrinsic frequency of about 50 pulses/min. Specialized systems are used for propagation of AV node to ventricle by a conduction system composed of a common bundle. More precisely it constitutes the right and left bundle branches. Repolarization occurs after depolarization of each ventricular muscle region [4]. The waveforms observed for specific cardiac tissues can be understood by the following Figure 2.7.

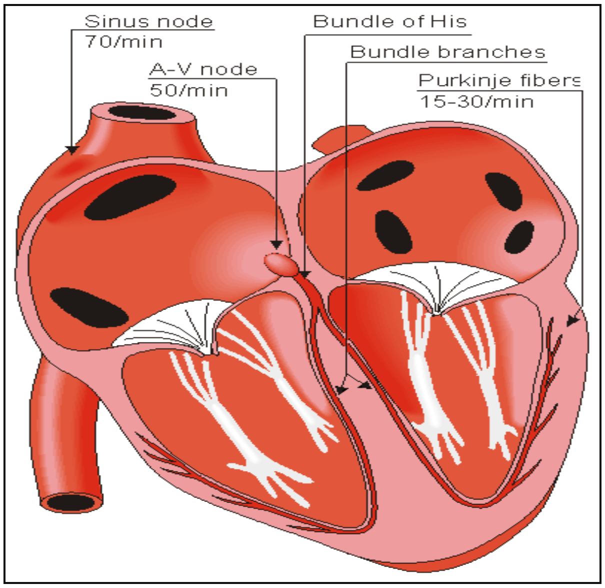

Figure 2.6 *The conduction system of the heart.*

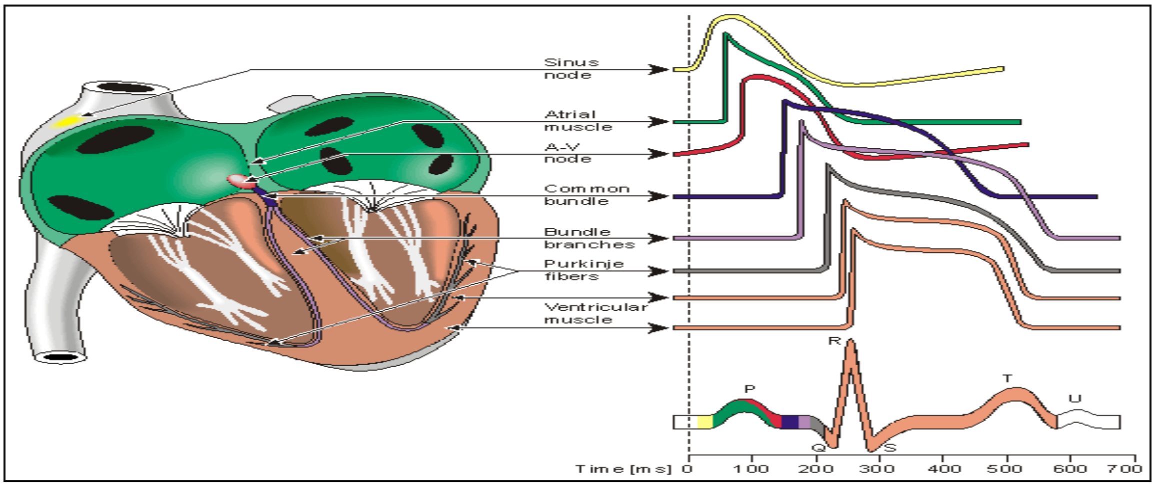

Figure 2.7 *Normal heart waveforms.*

Keep Dürer and his colleagues studied the spread of excitation in the classic human heart separating the heart of a man who had died of various diseases of the brain and no history of heart disease. Within 30 minutes from the autopsy and perfuse the heart was removed. No less than 870 leads are inserted into the heart muscle, and then the electrical activity recorded by a recorder and its work at a lower speed by the ECG, Hence the value of the interested part was 960 mm / s, by producing a time resolution better than 1ms [5].

2.5. DIFFERENT HEART DISEASES

2.5.1. Rheumatic Heart Disease

One or more attacks of rheumatic fever causes Rheumatic heart disease, it is also major cause of heart failure. It usually occurs in children due to a special type of infection called a streptococcal infection. Sometimes, the infection affects the heart, weakening of heart, scarring the valves and also causing damage to pericardium. Heart valves are often scarred so they do not open and close properly [6].

2.5.2. Cerebrovascular Disease

This disease is related to brain blood vessels. When blood supply to some part of brain is inhibited a stroke occurs.

2.5.3. Inflammatory Heart Disease

It is the inflammation of myocarditis, pericarditis, endocarditis or the myocardium. Inflammation may be caused by known reasons which can either be infectious agents or due to unknown sources.

2.5.4. Cardiomyopathy

These are diseases of heart muscle. It may be genetic, due to infection or other reasons. Idiopathic dilated cardiomyopathy is one of the most common types of this kind of disease, in which size of heart became bigger. The rest includes ischemic, heart muscle loss; may be dilated, and may be heart muscle is thickened.

2.5.5. Valvular Artery Disease

Various conditions can lead to injury, such as valvular stenosis, regurgitation or prolapse. The person who born with valvular disease, or may be affected by conditions such as fever, tissue infections, and certain medications or radiation treatment for cancer have chances of valvular artery disease.

2.5.6. Hypertensive Heart Disease

2.5.6.1. Aneurysm

The swelling or damage in the wall of a blood vessel. Inflammation in arteries occur at any age and at, and can be life threatening if remain unnoticed. In addition, the stomach and nerves at the base of the brain are the most commonly affected areas. Cases may cause high blood pressure or a weak portion in wall of blood vessel.

2.5.6.2. Atherosclerosis

It is the condition in which the walls of arteries become very hard, thick and stiff because of the fatty deposits and cholesterol levels high in blood vessels and are called plaques. As a result the blood flow becomes limited. Atherosclerosis can occur throughout the body and when happens in the arteries of the heart it is known as coronary artery disease while in the legs it is called peripheral arterial disease. Atherosclerosis as a result also includes stroke, heart attack and kidney failure.

2.5.6.3. High Blood Pressure (Hypertension)

It is the excessive force of blood pumping through your blood vessels. It is also cause of many other diseases related to heart, for example heart failure, kidney problems and also stroke.

2.5.6.4. Peripheral Arterial Disease

This disease refers to a condition caused by atherosclerosis, in which vessels found in legs are affected by blockage or narrowing of blood vessels.

2.6. ISCHEMIC HEART DISEASES

2.6.1. Angina

When there is reduced blood supply to heart sometimes a pain can be felt in chest portion which is named as angina. Angina is a result of atherosclerosis that is the narrowing or blockage of the blood vessels that supply blood to the heart. The common pain of angina is in the chest radiating to the left arm, shoulder or jaw. In angina, the pain is related to exertion and is relieved by rest.

2.6.2. Transient ischemic attacks (TIA)

TIA arises when there is a short time blockage of blood supply. When blood is lost in brain there occur some complications and it can also affect the brain function suddenly. There may be some temporary numbness, weakness on one side of the body, weight loss, and dizziness, speaking problems, double vision and very harsh headache. It may cause blindness of one or both eyes. But all these will recover quickly and permanent damage is not common.

2.6.3. Coronary artery disease

Coronary artery disease as a disease is most common type of heart diseases and also popular for heart attack and heart failure. Atherosclerosis that is narrowing or blockage of the blood vessels is the major cause of coronary artery disease. In this disease the arteries are partially or fully blocked which are supplying blood to pericardium.

2.6.4. Coronary heart disease

It is a disease of the arteries which are supplying blood to the heart and as a result a large number of complications are produced, e.g. angina, heart failure and heart attack.

2.6.5. Heart Attack

When blood supply to the heart is stopped, heart attack (myocardial infarction) is said to occur. A heart attack refers to as central chest pain which is very severe. Moreover additional symptoms over here can be sweating; short breath and also feeling faint. Sudden death may occur if an abrupt loss of heart's ability to pump blood is affected and also sometimes serious heart beat abnormality is observed.

2.6.6. Congential Heart Disease

Malformations of the heart's structures by birth are congenital heart disease. This may be due to a gene inherited from our parents or harmful exposure to certain medications or alcohol. It may be inherited when infant is in the womb. Examples include abnormal valves, heart chambers abnormality and also holes in the heart. Most common congenital heart defect is ventricular septal defects as in [9].

2.6.7. Heart Disease

When the heart muscle becomes very delicate and damaged to pump enough blood to the body, a condition known as chronic heart disease occurs. Heart is still working even in the presence of heart disease, but because it is less effective in the blood supply and you receive enough oxygen. Adults tend to be more affected by heart and exercise tolerance is decreased, shortness of breath and swelling may be observed on ankles. A large number of evidences tell us that sympathetic nervous system activation is mostly found in people with heart problems [10].

2.7. CORONARY ARTERY DISEASE

Coronary artery disease is a narrowing or blockage of the coronary arteries, usually induced by atherosclerosis, refers to the blood flow to the heart muscle by abnormal blood vessel function and tone and also by physically blocking an artery. In the absence of enough blood supply, the heart nutrients and oxygen important things needed to function properly are not supplied to heart and problems occur most of the times. Also causes angina which is chest pain. In this case, the heart muscle is prevented altogether, or if the heart needs more energy to be more supply of blood, heart attack occurs. Narrowing of arteries is shown in Figure2.8[6].

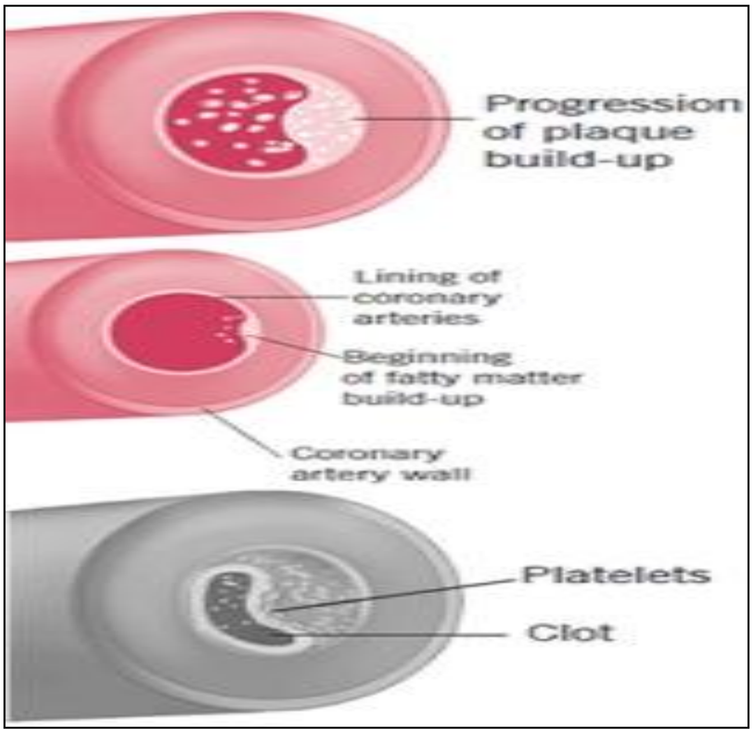

Figure 2.8 *Normal or plaque regions.*

2.7.1. NARROWING OF CORONARY ARTERIES

It is a disease of young age. Before adolescence, the blood vessel walls begin to show stripes of fat. However, the fat builds up, causing slight injury to blood vessel walls during elderly years. Also the substances moving through blood stream, including inflammatory cells, cellular waste products, proteins and calcium cling to the vessel walls. The fat and other substances together form a material called plaque. Additionally, plaques of different size ensue in the interior of arteries. Mostly the plaque deposits are soft on the inside with fibrous top that includes external hard muscle. The soft, fatty inside becomes apparent in the case of a hard muscle outer surface cracks or tears. Platelets are coming to the area, and blood clots form around the plaque. The endothelium also interrupts and refuses to function properly, causing the muscle to squeeze the artery at inappropriate times [7]. This induces the artery to further reduce. Sometimes the blood clot breaks, and the blood supply is restored. The blood clot suddenly blocks the blood supply to the heart muscle, causing acute coronary syndromes.

2.8. ACUTE CORONARY SYNDROMES

2.8.1. Unstable angina

It is normally being different from stable angina. Unstable angina is the one that may occur more frequently and easily at rest; also it is more severe and long lasting. Though it is usually relieved by oral medications, yet may proceed to a heart attack as it is unstable. Often the treatment of unstable angina requires more intense medical procedure.

2.8.2. Non-ST segment elevation myocardial infarction (NSTEMI)

Heart attack, or MI, we show the main changes in ECG, but the chemical symbols of the blood shows that the damage to the heart muscle in NSTEMI, up to limited extent. Here chances for damage are very low and the blockage occur will be partial and temporary most of the times.

2.8.3. ST segment elevation myocardial infarction (STEMI)

Heart attack or MI (Myocardial infarction) occurred due to a blockage in the blood supply for longer time. It changes the value of principle chemical markers, changes the ECG (Electro Cardio Graph), and also the area of heart muscle is affected.

Collateral circulation is caused by blockage of coronary artery due to narrowing or plaque formation inside the walls of artery. Formation of new blood vessels that refill the flow of blood around blocked artery is called as collateral circulation. However, at times of exercise and exertion these blood vessels do not supply enough blood to the heart muscle. As a result oxygen and nutrients are not provided to heart in a sufficient amount. When heart's demand of blood is not fulfilled, oxygen rich blood is not provided and ischemia occurs. As a result oxygen shortness affects heart. Stable angina or stable coronary artery ensues if medicines or rest is given to ischemic patient in less than 10 minutes. Collateral circulation can be observed in Figure 2.9 [6].

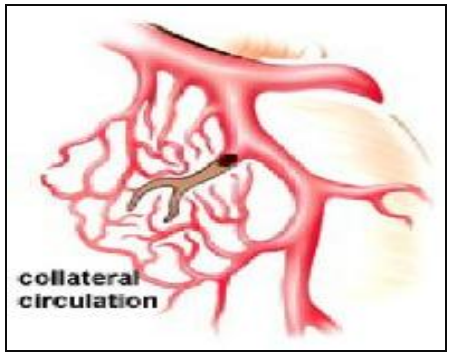

Figure 2.9 *Collateral circulation.*

2.8.2. SYMPTOMS OF CORONARY ARTERY DISEASE

One of the most common symptoms of coronary artery disease is angina (also called angina pectoris).Other symptoms that may occur with coronary artery disease include, dizziness, nausea, sweating, weakness, irregular heart beat and shortness of breath.

2.8.3. RISK FACTORS FOR CORONARY ARTERY DISEASE

Male gender, advanced age**,** family history of heart disease and race can be considered as the unavoidable risk factors for coronary artery disease**.** Modifiable risk factors include smoking, diabetes, overweight, physical inactivity and high cholesterol.

2.9 METHODS OF DIAGNOSIS

Physical exam: During the physical examination, there may be a medical professional to use the organs of the chest to check for abnormal sounds called whooshing spot, which may be indicative of poor blood flow gradually increased due to the movement of the plaque. A patient will feel and observe the normal pulses for legs and feet or vice versa, if the pulses are weak and not normal it is indicating a blocked artery.

2.9.1. Diagnostic Tests: These includes following tests:

- **Electrocardiograph tests**: The electrical activity produced by the heart when heart is not working and with exercise can be evaluated by Electrocardiogram.
- **Laboratory Tests**: Different blood tests can be used to diagnose the CAD.
- **Invasive Testing**: Cardiac catheterization involves putting catheters into the blood vessels of the heart for viewing the arteries.
- **Nuclear Imaging:** It will detect the radiations coming from different parts of the body after the administration of a radioactive tracer compound such as cardiolite (sestamibi) or a material known as thallium are injected into blood. Where less blood is supplied to heart area can be monitored by specially designed cameras.
- **Ultrasound Tests**: High frequency Ultrasound waves having high frequency used to create graphic images of the heart's pumping its structures and blood flow direction.
- **Radiographic Tests** X-ray techniques, CT scan and MRI can be used. C-reactive protein (CRP), lipid profile complete screening and calcium score screening heart scan can be used for predicting the risk of CAD.
- **Electrophysiology Test** It will measure the Rhythm of the heart, Pathways and electrical activity of the heart.
- **Myocardial Biopsy** A piece of heart tissues is removed for the examination.
- **Pericardiocentesis** Fluid in the sac surrounding the heart is removed with a needle.
- **Electrocardiogram (ECG)** Electrical signals are recorded as they passed through heart. It can also tell us that patient may suffer with some heart attack before.
- **Echocardiogram** This test uses sound waves for generating images of heart echocardiogram uses sound waves for producing images of heart. Through this technique Functioning of the walls of the heart are measured either they are contributing normally to the pumping of heart or not. Parts that are moving weakly indicate the coronary artery disease.
- **Cardiac catheterization or angiogram**. A special dye is injected into the arteries of the heart through a long, thin, flexible tube (catheter) that is threaded through an artery, usually

in the leg, to the arteries in the heart. It is known as cardiac catheterization. Also called conventional angiography.

- **CT scan** Technologies computed Tomography (CT), such as electronically safe place (EBCT) Rapid CT relief to see the roots. EBCT (ultrafast CT scan) calcium found in fat in narrowing of the coronary arteries. If calcium deposits are high coronary artery disease will be there. In CT albums, where in contrast to the color of the injection occurred during the CT scan, also can produce coronary arteries images.
- **Magnetic resonance angiography (MRA)** This procedure detects the areas of narrowing and also blockages, here MRI technology is used altogether with an injected contrast dye [4].

2.10. TREATMENT

2.10.1. Angioplasty

Blocked or narrowed coronary arteries are opened with the help of Angioplasty. It improves blood flow, relieves chest pain, and thus may be helpful in preventing the heart attack. Sometimes after the angioplasty to keep the arteries open a stent (small mesh tube) is placed in arteries.

2.10.2. Coronary artery bypass grafting (CABG)

In this type of treatment technique surgery is done where arteries from other body parts are used to open the blocked arteries type of surgery in which the arteries from other parts of the body are used to bypass the blocked arteries. With this technique one can prevent the chances of heart attack, have a rescue from chest pain and also improvement in blood flow to heart.

2.10.3. Bypass grafting

It can be used for the treatment of blocked arteries of legs. In this surgery, a normal blood vessel is used to bypass a narrowed or blocked artery in the leg. The healthy blood vessel redirects blood and improves flow to the leg.

2.10.4. Carotid Endarterectomy

It is also known as surgery of carotid artery. Here plaque is removed from neck’s carotid artery. Blood flow to the brain will be normal after opening of arteries and will be helpful in preventing a stroke.

2.10.5. CT Angiography (CTA)

Angiography can be performed by using any of the following techniques.

- x-rays with catheters
- computed tomography (CT)
- magnetic resonance imaging (MRI)

Coronary computed tomography angiogram (CTA) uses advanced CT technology, along with intravenous (IV) contrast material (dye), for obtaining high-resolution, three-dimensional pictures of the heart and major vessels. The CT scanner is a large, box-like machine with a hole, or short tunnel, in the center as in Figure2.10 and 2.11[60].

Figure2.10 *CT scanner*.

Figure2.11 *CT Scanner 2*

2.11 Working of CT scanner

It works like other x-ray examinations. Different body parts absorb the x-rays in varying degrees. While using CT scanning, large number of X -rays and a set of electronic x-ray detectors are set around the patient, sufficient amount of radiation absorbed by the body. Meanwhile, the exam table moves through the scanner, so that the X-ray beam follows a spiral path in a circular fashion. A large number of programs for processing large volumes of data to create two - dimensional cross-sectional images (slice) of the body are written and implemented, after that results can be seen on monitor screen. The CT technique is called helical or spiral technique. With a routine life example we can compare it with a loaf of bread, cutting the loaf into thin slices. After that values are set and a demand for 3-D image is placed, which displays 3-D images inside body with high precision. A dye is introduced into the bloodstream during surgery; it clearly defines the blood vessels by making them appear bright white. Blood vessels in the different organs of the body can be examined by using the CTA including neck, chest, heart, brain and abdomen. This test can be used to diagnose and evaluate many diseases of blood vessels and related conditions such as:

- Aneurysms
- Injury
- Aneurysms
- Blockages produced from blood clots or plaques.
- Birth related abnormalities and various parts of the body which are affected by abnormal blood supply and also blood vessels.
- Disorganized blood vessels and blood supply to tumors.

This exam can also be used to check the blood vessels which undergo procedure of surgery such as:

- Detection of aneurysms, in the aorta or in other arteries and other abnormalities.
- Identify the atherosclerotic disease in the carotid artery of the neck and in the arteries of legs
- Identify a small aneurysm or arteriovenous malformation inside the brain.
- Detect disease in the arteries to the kidneys and thus can be helpful in kidney transplant.

- Detect injury to one or more arteries in the body after trauma.
- Evaluate arteries feeding a tumor prior to surgery or other procedures.
- Coronary bypass or stunting can be referred if the severity of disease is observed.
- Pulmonary embolism detection and pulmonary examination can be done to explore arteries in lungs.
- Also helpful in looking arteries in children and abnormalities of blood vessels which are known from birth.
- Patient should be advised to wear loose fitting and comfortable clothing and should not have any metal objects during the exam. It will be advised to the patient not to eat any food or drink few hours before the procedure.

2.11.1 Treatment Procedure

Before the procedure, an intravenous (IV) catheter into a vein is passed; most of the times in arm or hand catheter are inserted. Injection pump connected to the IV will give contrast material at a controlled rate and the procedure is automatic. Sometimes the people with some kind of skin allergies mostly in small babies and patient with fragile skin are injected by using syringes.At first for the evaluation of material movement inside the body a small amount of material is injected to see how long it takes to reach required area. While scanning, the table is moved relatively from the starting point and can be moved faster through opening of machine to have the results of CT angiography. New scanners are very powerful and can give fruitful results while using a limited area scan, for example chest of a baby, with single rotation it will be done and table movement is not required. When CT angiography is in work of the coronary arteries or aorta in the chest, electrocardiogram (ECG) leads (sticky patches) will be placed on the chest to record heart beat during scanning. The patient will be monitored during and after the scanning as medication is given to patient to do the procedure. Images can be blurred or problematic if patient do not have control over his breath, hence it is advised to hold the breath during the examination. We can explain it as image quality damaged up to such a way that one has captured image of a rapidly moving object. As children cannot remain still hence sedation may be given to them to have a good CT scan. After the exam, the intravenous catheter will be removed. Also a bandage will be placed over the needle puncture site.

The complete CT angiography exam may be completed within a few seconds. Actual time in the scanner room will be far more than a few seconds because the technologist has to prepare all the instruments and machine, he has to position the table and machine in proper manner, he has to do some images to verify the correct starting and ending points. Also he has to put an IV and lot of technical work to do.

It may also be able to be performed in children. As the children are more sensitive to the rays than adults so less amount of the rays will be used according to the body weight, or the radioactive shields may be preferred. Special instruction will be given to the patient if any contrast material will be used during the procedure. Radiologist will interpret the results. Sometimes follow up examination may be required if the abnormality still exists.

2.12 Advantages and Disadvantages

2.12.1. Advantages

- Without doing surgery, we can know about disease.
- CT angiography detects narrowing or obstruction of blood vessels thus will be helpful in correct therapy.
- CT angiography can give more precise details of small blood vessels as compare to the MRI.
- Having a comparison to catheter angiography it is more reliable, less complicated and fast. No catheter has to be placed in groin region. Even general anesthesia and sedation is not required at all.
- CT angiography is a very powerful way to detect structural abnormalities, arterial blockages and even the symptoms for heart attack
- Catheter angiography is more expensive as compared to CT scanning.
- More comfortable way as no catheter is passed and dye can be inserted through arm.
- After a CT examination no radiations remains inside the body of patient.
- No immediate side effects have been reported so far.

2.12.2. Disadvantages

- A patient with history of X-ray allergies should tell his doctor before the examination, doctor should advise him to take special precautionary medication, such as a steroid, for a few hours or the day before CT angiography to lessen the chances of allergic reaction. Another option is to undergo a different exam that does not require iodinated contrast material.
- Patients with renal diseases and kidney problems are not encouraged for this test because high concentration of iodine can be an extra load on kidneys while urine filtration.
- If there is any possibility that women are pregnant, they must inform their doctor.
- Mothers should not breastfeed their babies for 24-48 hours, after contrast medium is given.

2.12.3. Limitations of CT Angiography

Iodine rich material may be harmful for the patients. Some people are very sensitive to radiation exposure and nay have some reaction afterwards. A person who is very large, may not fit into the opening of a conventional CT scanner, or may be over the weight limit usually 450 pound for the moving table's angiography should be avoided. In severe diabetic patients it is also avoided.

Chapter 3

TECHNIQUES FOR THE DETECTION OF CORONARY ARTERY DISEASE USING CT ANGIOGRAPHY IMAGES

Heart diseases can be detected by using a large number of ways. Also a large number of tests are available for the correct detection of abnormality. CT Angiography is very popular among those tests just because of its non invasiveness and after the test no recovery time required for patient. Risk factors are also very low in this procedure, exposure to radiation is not good for health but this kind of risk can be lowered using proper measurements and precautions. There are some related techniques and previous procedures used in this domain so far.

3.1. Coronary Centerline Detection Using CT Angiography

3.1.1 Image preprocessing

First of all image preprocessing was done by using which a large number of techniques were applied to make the images ready for further processing.

3.1.2. Methodology

Hoyos et al. had extracted the coronary-artery by using one initialization point per vessel. In this algorithm he used eigenvalues and inertia matrix in a multistage framework. By using elastic model of snakes they estimated the location. They used 8 training CT datasets, they find these results.

Overlap with reference:

Considering the Whole length = (OV) 79.1%, until the First failure (OF) =50%, in clinically relevant segments (radius > 1.5 mm, OT) 83%.

Average distance from reference:

Taking the complete length = 4.30 mm, restrains to portions where the semiautomatic centerline remains within the vessel 0.35 mm, while in clinically related portions it was 4.12 mm. He used 16 testing datasets, the results were represented as:

OV =79.2%, OF =38.3%, OT =81.1%, AD =4.05 mm, AI =0.39 mm and AT =4.49 mm.

3.1.3. Stopping Criteria

They used two criterions for stopping the algorithm, they checked on the basis of proximal and distal end of an artery. They checked either the radius of voxel is 90% of the artery; they labeled it as proximal end and stopped the algorithm. Similarly if the radius is 30% of voxel it would be treated as distal end.

3.1.4. Conclusions and Discussion

It was very difficult to make a final decision without an expert's vision as anatomic facts are very important for any final conclusion. Distal end detection is very carefully done as sometimes spaces may occur just because of low contrast and penetration of arteries to heart muscle.

3.2 Using Robust Detection in 3D CT Angiography Using Coronary Artery Tracking

Computed Tomography angiography is considered a gold standard for the detection of coronary artery disease. This diagnostic method is used for detection of disease, to know the severity of disease and also how to do treatment. Hence to produce a method which require minimum human interaction and can point out the precise results is very important in medical professions. Zhao et all [11] proposed a work in which they computed coronary artery tree using vessel junction detection. The method uses sequential Monte Carlo framework in which a seed point was decided and tree was detected by tracking the way from seed point.

To produce a coronary artery tree the localization of vessel junctions has great importance, and these junctions are automatically broke down into segments of vessels which also further used for detecting the disease and blockage in segments [12].

Very extensive research has been done in domain of vessel segmentation. A large number of reviews are proposed on vessel segmentation techniques in [13] [14]. Robustness of the Bayesian tracking algorithm has been proved. To determine the solution space these methods use the local optimization technique. Gaussian mixture intensity and use of 2D ellipses in filter framework used k means clustering algorithm to determine junctions at every step. [15] [16].

Another algorithm was proposed in which Gaussian distribution was used to determine Gaussian intensity distribution of vessel while to remain good quality of segmentation tube shape was used. During tracking Gaussian does not always clearly describe the vessel appearance. There is a limitation regarding this kind of methods and that is when contrast dye is injected into body, it will not give the true colors of lumen [16].

In vessel likelihood measure they used an algorithm which account for intensity histograms and also background and foreground models. By doing some changes in this model if radius is used in intensity model, it will also track very thin vessels. But this approach does not go well for problem of junction detection [17].

3.2.1 Algorithm 1: Recursive Tracking Framework

They proposed recursive tracking framework as their fist algorithm, in this algorithm they used the Coronary CT Angiography (CTA) images as input and they used to push the seed point to junction queue. They used DIP static test and started single branch tracking of coronary artery if junction was detected using DIP static test they used K mean clustering technique for junction tracking, they evaluated junction direction and found principal thick branch while ignoring the thin small branches which were put again to junction queue and they finished the single branch detection.

Tracking results are as follows for above mentioned algorithm in Figure 3.1.

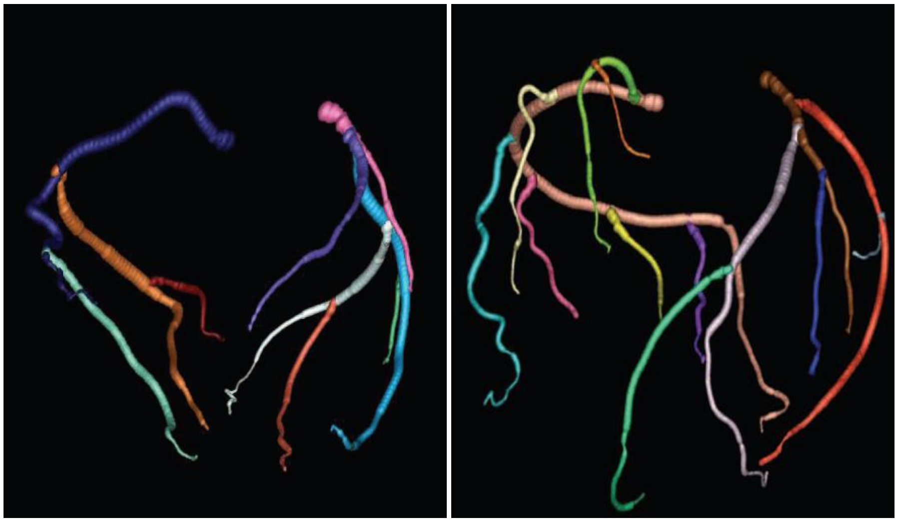

Figure3.1 *Tracking Results.*

3.3 Automatic Extraction of the Arterial Tree from 3-D Angiograms

Higgins et al suggested that (3-D) coronary angiography three dimensions produced by fast, high-resolution X-ray CT scanner called Dynamic Spatial Reconstruction (DSR) enables complete visualization of the coronary vascular tree by using only a single scan [18]. That single scan was taken from a non selective injection using contrast dye [19]. Unfortunately, the operator interface software using time to analyze 3-D manual angiography. Recently method developed called coronary angiography and it is most powerful scan for detecting coronary arteries revealed by research [20]. This paper describes a more efficient procedure for coronary artery extraction automatically while using 3-D DSR angiography.

3.4 A Novel Approach for Detection of Tubular Objects and Its Application to Medical Image Analysis

In this algorithm Bauer et al has introduced a new method for the detection of tubular objects in medical images. Detection filters conventional tube / local use lineness derivatives at multiple scales while introducing a linear scale space, but this linear scale space can leads to an undesirable scattering structures adjacent to each other, this leads to unwanted situations such as targeting in which two tubes are considered as a single tube. To have a rescue from this situation, they introduced to change the multi- scale gradient vectors by the Gradient Vector Flow, because it allows diffusion gradient edge of the retaining information. The application Frangi vesselness and the resulting vector field enables prediction of the center lines of tubular articles, regardless of dimension and different contrast tubes. Comparisons and analysis with relative methods to sets of clinical and synthetic data show a high strength to image noise and external disturbances of tubular objects.

In literature most of the algorithms using tube detection filters describe that the tube like structures are bright objects as a foreground while background is dark, as described in [21, 22, 23, 24, 25, 26]. According to concept of space scale theory if we use the radius factor for tubular structures, these structures form height ridges as we know that radius of these objects changes [27].

3.5 A 3D Approach for Extraction of the Coronary artery and Quantification of the Stenosis

Mazinini et al proposed segmentation and quantification of stenosis is an important task in the evaluation of coronary artery disease. A key challenge is to measure the true diameter of vessels. Moreover curve, uncertainty in the segmentation of different tissues in the narrow vessel is a major issue affecting the accuracy. This technique has proposed an algorithm for extracting the coronary artery and to measure the amount of stenosis. Markov fuzzy classification method applied to model the uncertainty arising from the problem of partial volume effect. The algorithm employs: segmentation, extract the center line orthogonal to estimate the aircraft center line, measure the degree of stenosis. To assess the accuracy and reproducibility, the approach has been applied to a virtual vascular and the results are compared with the actual diameter. They found the results of 10 sets of patient data visually by a qualified radiologist. The results revealed superiority of the proposed method compared to the conventional threshold method (CTM) on two sets of data.

A large number of hybrid automatic techniques have been developed for the detection of coronary artery tree which must have the common intensity level [28, 29, 30]. Most commonly observed disadvantage of this method is to define seed points manually which require human interaction. They proposed an automatic method for defining seed points on the basis of region growing technique.

A stenosis interval is defined generally by using extracted coronary arteries by the radiologists. Actually centerline of vessel is extracted during stenosis interval. The shape of an object can be easily represented by centerline and it is also an important feature for the assessment of shape. A large number of methods has been reported for extracting centerline [31, 32, 33]. There are also some techniques used for thinning. These algorithms rely on simplest points for extracting centerline [34].These are the results judged by radiologists in Figure3.2.

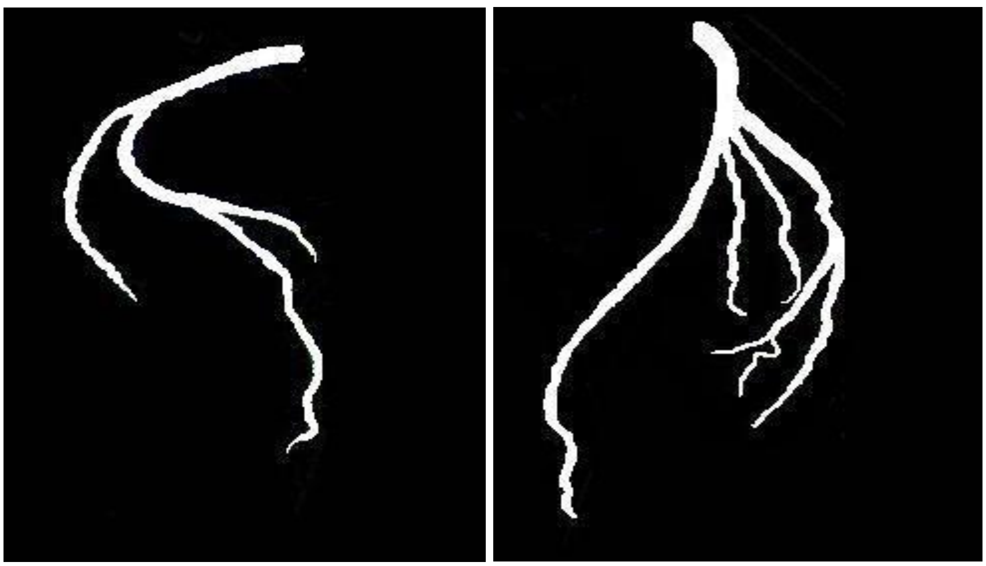

Figure3.2 *Right and left coronary artery of heart.*

3.6 Detection of Coronary Artery Tree Using Morphological Operator

In this research Eiho et al introduced the technique for automatic detection of coronary artery tree on coronary cineangiogmm. The approach used in many types of operations and also morphological operations. Here morphological top hat operator is used to improve the dimensional shape of the artery. The morphological erosion and another technique called half thresholding used to eliminate points which were considered as coronary area and in fact they did not belong to coronary artery other than the coronary area. Then they extracted the full coronary artery tree using angiography after observing a one point on the artery. Coronary tree parts are extracted by using thinning operation. In the last step watershed transformation is performed using image binary skeleton of morphological operations and the spread of the coronary artery. Accordingly, a clear line of the coronary artery is automatically available. Some experimental studies confirm the ease and accuracy of the detection limit of the coronary artery by the proposed method [35, 36, 37].

3.7 Extraction of Vascular Tree on Angiogram with Fuzzy Morphological Method

Sun et al proposed this method. They concluded that vessels are very important components of blood circulatory system and segmentation algorithms can be used for better analysis of this system. A new method was used using morphological operators with fuzzy logic. By using this method coronary artery tree was extracted. Morphological Top-Hat operator was used to improve the contrast between the vessel and background which was a very cumbersome problem. Noise was removed by using fuzzy morphological opening operator along with the structuring element so that noise can be removed and reduced along the arterial path and along direction of vessel; it was also helpful for removing background noise. Threshold of the image after fuzzy morphological filter produced the vascular tree. Experimentation studies showed that the method presented can hardly obtain the entire consecutive vascular tree structure whereas deals with vessel with different diameter by the identical operator. It was also fast and automatic way of extraction of vascular tree using angiogram using fuzzy morphological method [38].

3.8 Related Work

Over the past years, different computer algorithms have been proposed to segment coronary artery tree by using angiograms. A general review of the techniques and algorithms about segmentation of vessel can be done by looking at different research papers [39]. Among them mathematical morphological methods is one of the most commonly used pattern recognition techniques [40]. Mathematical morphology is a nonlinear theory on images or signal processing techniques. Mathematical theory originates from the set theory and processes image based on the viewpoint of set theory and follows all the rules of set theory. The major work of morphological image operators when implemented and observed is to make different kinds of structuring element (SE) also tells that this method, how to apply it with structuring element on image, that can be directly related relates to the image how to analyze[41, 42]. Useful information can also be obtained through the usage and implementation operation. The morphological gray scale dilation and erosion are two main morphological operators which work opposite to each other but produce totally different results on their implementation. The morphological gray opening, erosion followed by dilation, is an important nonlinear filter related with the shape and dimension of the structuring element used and whenever we use it vice versa it produce totally different results.

One of the most important properties used for extraction of arterial tree is opening operator which is used in common that it can remove the bright objects which can not contain the used structuring element and remain those being capable of accommodating the structuring element. Two groups of structuring element are usually applied to extract vascular tree on angiogram, which method is made to delineate different property of the image respectively. One of them is the structuring element (SE) where a larger value is applied to it as compared to vessel width value so that we can also attain the background information needed, after that resultant image is subtracted so that we can have only interested part of image. Through subtracting the result image by opening operator, on which the vessel is removed, from the original image, the vascular tree could be enhanced. This technique named as top hat operator for filtering purposes, in which the disk-shaped or square structuring elements are usually chosen. Then other techniques follow it to attain the resultant vascular tree, for example the types of technique are region growing and dynamic programming while the parameter taken is intensity difference in all neighboring pixels of the image. In simple words we can say threshold of the enhanced image when top hat operator is also applied on it result will be only a segment of vessel, which is also discontinuous, in different characters of the segmented part are used to refine the result to connected vessel tree [44]. Another group of the structuring element is those designed to be contained by the vascular structure, which is used catch the information of vessel directly. The vessel is always found in a continuous linear fashion. Thus the linear structuring is natural way introduced to extract the vascular tree on angiogram.

Thackray and Nelson [43] used a large number of operators belonging to morphological operator's class for the extraction of arterial tree segments, while all the segments were taken as specific vessel segment. An adaptive thresholding technique was also used while the image type for extraction by this way was the intensity images. Here also lies a limitation in their system as it cannot sort out the connections between the vascular tree and we know that width of vessels and its range changes along the vascular path and they are only using a set of morphological operators.

Zana and Klein used different linear structuring elements for extraction of interested area inside the retinal images while the angiogram was used for experimentation [49]. However, they take different strategy for big vessels and small vessels. It should be pointed out the two qualities about the gray opening. To extract vessel on angiogram, the second group structuring elements used, as mentioned above, must be small enough to be contained by the vessel. On the other hand, the intensity of any point on the result image by opening operator will be lower than that on original image. However, the entire medical image is ill posed. The light intensity and contrast along the vascular tree changes hence the results of opening will also suffer. Moreover, the size and dimensions of arterial tree will vary in different parts of angiogram. Thus no appropriate structuring element can be contained by any vessel structure while having the ability removing the noise of background at the same time. For their view too much additional processing after morphological filter or different processing for different vessel part contrary showed the weakness of the filter method or the structuring elements adopted for segmentation of vessel on angiograms. It also means that the capabilities of morphological filter do not take effect on segmentation of vessel on angiogram evidently.

They produced the results depicted in Figure 3.3.

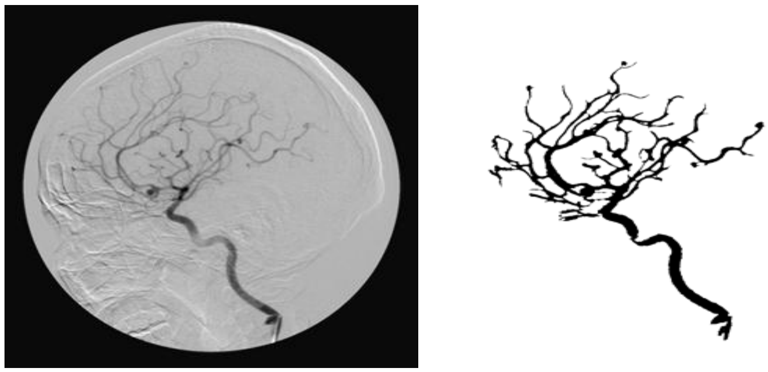

Figure3.3 *Original image and result of proposed algorithm*.

3.9 Extraction of Coronary Artery Tree Using Morphological Operators

Oroz et al proposed measures several substructures heart artery tree from Multislice CT data sets of heart; one of the important goals is to improve diagnosis of coronary artery disease. This research explained all the work based on morphological operations where reconstruction algorithm is used and image data is 2D while background is 3D coronary arterial tree. This algorithm uses substructures knowledge of coronary arteries. The background to the left and right coronary arteries was passed in 9 CT-data of good results, particularly concerning speed and robustness.

3.9.1 Introduction

Computer aided surgery is a therapeutic tool for correct visualization and analysis in most of the diagnostic systems used for vessel segmentation [45]. Although a large number of techniques have been produced but vessel segmentation still needs more improvement as in all the methods we must have human interaction, image acquisition and a large number of other factors. Segmentation is achieved by combining morphological operators, thresholding techniques and also using region growing methods as in [46].

With very interesting results and segmentation techniques the algorithm also selects unwanted area which did not belong to coronary artery although a very useful interface is provided in [47].

Hence with these problems they propose an algorithm for vessel segmentation dividing their goal into two major components so that they can emphasize on their approach. They extracted the coronary arterial tree in first part whereas in second part detection of disease and place of plaque has been reported [48]. Their results can be shown in Figure3.4 and in Figure3.5.

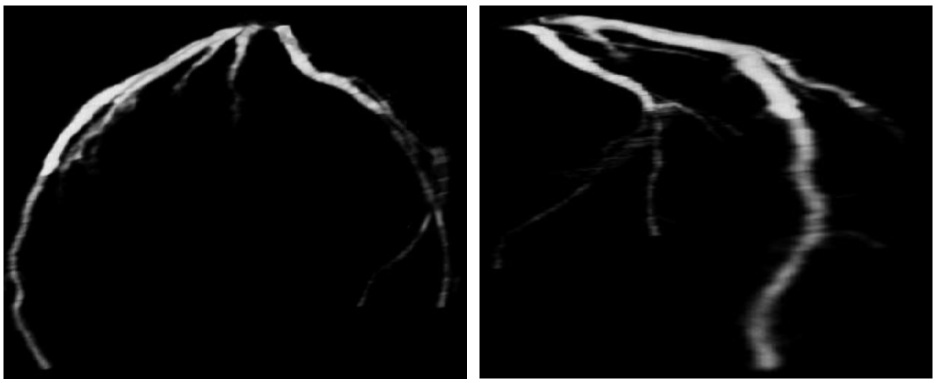

Figure3.4 *Left coronary artery without lesion.*

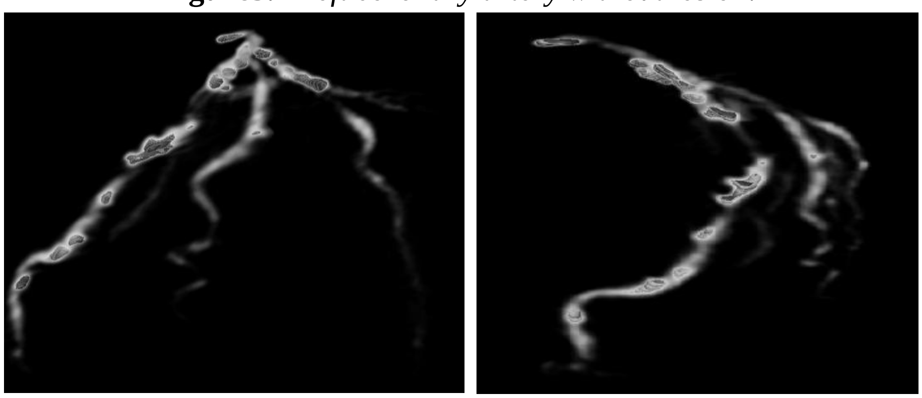

Figure3.5 *Left coronary artery with loads of calcification.*

3.9.2 Morphological Algorithm for Causal Tubular Structures Extraction

This algorithm uses a non linear image processing technique named mathematical morphology which can be used for extraction of coronary artery tree in CT images. This algorithm uses the pre defined knowledge of shapes and constricted tubular structures of coronary artery tree.

3.9.3 Proposed Architecture

1. The expert has to select seed points at first in start of implementation of algorithm where coronary tree is present.
2. This segmentation procedure is performed in the seed slices of 2D point.

3. A set of points possible seeds will be produced automatically for the segmentation morphological i+1 and iterations continue in this way.
4. Steps 2 and 3 repeated until unless no potential seed left for the propagation of tubular structures and it cannot be elongated further.

3.9.4 Implementation Technique

The implementation of algorithm is done by introducing some operations which were named as morphological operators. They named an image as o generic value with G and they defined two main morphological operations which are dilation and erosion and when both of these operators are used together they produce another kind of operators called opening and closing operators. Opening operations filter out light structures from the images while closing operations have an impact opposite to opening.

3.9.10 Coronary Artery Segmentation from CT-Images

This segmentation algorithm is tested on 3D data sets. The input images used in this algorithm are taken from a Toshiba camera of category Aquilion while it is a 16 CT scanner and its resolution is 0.5 mm and a slice of 0.5 mm space (isotropic). Five cases presented lesions are nonexistent. The original size of image has dimensions of 512x512 data in the horizontal plane, and between 200 and 300 slices z-axis where no pre processing was done in images.

The length and number of coronary artery segments visible differ most importantly across data of those patients where especially in pathological cases are considered. While implementing the algorithm they limited the analysis of the left coronary arteries also the left anterior descending part (LAD) and left circumflex coronary artery (LCX) coronary arteries and their branches. Hence results of the coronary exploration were evaluated on their appearance by a specialist. The 3D reconstruction algorithm TBS was tested on a variety of data. Image resolution is 0.5 and 0.5 mm pieces of space sculpture (isotropic) and Toshiba Aquilion 1:06 CT was acquired by the scanner, if the five small lesions are not reported. The number and duration of the disease of the artery segment varies especially if the patient is significantly differing from the data set. The left anterior down (LAD) and left circumflex artery (LCX) artery and its branches are limited to an analysis of the left coronary artery. Internally the extraction result of the disease was evaluated by visually examining.

3.9.11. Single seeded Coronary Artery Tracking in CT Angiography

In this research Lavi et al proposed a safe place (CT) have a greater advantage is noninvasive technique for imaging coronary artery and has become a well designed evaluation system disease in recent Emerging technologies. The main problems due to which we cannot detect the arterial tree very correctly are that veins are very closer to each other, proximate chambers and gray level changes along the arterial path.

A large number of algorithms have been developed for vascular structure segmentation and also for coronary arteries. Level sets, fast marching and deformable models have been used for this particular task as in [50, 51, and 52]. Most commonly used methods are morphological operators, line enhancement filters and region growing [53, 54, 55, and 56]. A very basic review of vessel extraction has been discussed in [57]. There is also another algorithm named cockscrew algorithm as in [59].

A coronary artery centerline rapid detection automatically allows direct network of the coronary artery lumen and wall and thus allows presence of a single artery in time duration of 2-3 minutes. Florin et al proposed a new approach for coronary artery extraction based on ray and a filter [58]. The proposed research is a new way for the extraction of coronary arteries.

Most of the techniques still need human interaction up to some extent. Whenever we need a business application, there must be some compromise between robustness and automation. Involving users in addition to the increase in the speed limit through the combination of this fact must be kept in mind when making a delivery to the customer and according to the work of the users.

3.9.11.1. Methodology

The proposed algorithm fall into the category of methods based monitoring. However, other categories of multiple techniques are incorporated in the algorithm to achieve the necessary results with characteristics of the segmentation of coronary artery. Artery followed before spreading based on two levels. Both regional and local properties are currently under study. All decisions are made on partitions before, and after based on a comparison of the property before existing presets or average characteristics examined during propagation.

3.9.11.2. Initial Filtering

While doing initial filtering Bottom-hat initial filter is applied to a layer of fat wrapping the heart. A bottom-hat filter is made by plotting the morphological closing binary image of the black and white image itself. This phase filter improves not hollow inside of the fat layer the fat and therefore contributes to a differential contrast product lying within the fat layer i.e. arteries coronary contrast agent to come find anywhere, for example the cavities of the heart. The bottom hat filter is a way to prevent the track from entering unnecessary areas. The resultant coronary artery achieved was as in Figure3.6.

Figure 3.6 *Coronary Artery Tree.*

3.9.12 Adaptive Threshold Technique

Adaptive threshold technique is incorporated to cope with the lower level of intensity value along arterial path. Threshold will be adjusted due to changes in size at the front and angular deviations of any of the local or regional points. A gradual decrease in height of 50 HU is allowed. Exceed the threshold of change is avoided by dividing the voxels by their intensity.

3.9.12.1. Mean value Properties

The average property of vessel diameter and the direction will be considered during the propagation. And average values of vessel are considered.

3.9.12.2. Decision Making

A system of empirical credit has been made that, tip diameter, the angular deviation and the reduced levels of gray are classified enough. Avoid propagating return will be credited as well. Spread after they were identified by comparing the directions of local and regional progress. Results based on values before the credit system explained above. Each of the two fronts, produced in the division, is distributed according to his character. The minimal angular deviation is observed for the credited being calculated and shown by the line in a graph which is a corrected function whereas a cosine function is also calculated by a line which is shifted by a value of -0.2. And these results are based on smallest angular deviation observed whether it is local or regional.

3.9.12.3. Stopping Criteria

Many criteria are here to stop monitoring the aorta artery correctly in achieving its original or on a side of the distal end of the other side. The growth rate, which is second derivative of the scale before, will be monitored for the aortic trunk of the accelerated identification diameter. Before minimum size and maximum deflection angle are used for detection of the distal end.

3.9.12.4. Last step

Last step is to do aortic root segmentation; it was done by watershed segmentation.

Chapter 4

DESIGN AND IMPLEMENTATION

4.1 SYSTEM FOR DECTECTION OF CORONARY ARTERY DISEASE

The proposed Coronary Artery Disease Detection System (CADDS) uses a procedure for the enhancement of a CT Cardiac images preceded by extraction of characteristic features. The major steps involved in the coronary artery disease detection system include as in Figure 4.1Flow diagram of coronary artery disease detection system.

1. CT Cardiac Angiographic Image Acquisition.
2. CT Cardiac Angiographic Image enhancement.
3. Feature Extraction.

Figure 4.1 *Flow Diagram of Coronary Artery Disease Detection System*.

4.2 CT CARDIAC ANGIOGRAPHIC IMAGE ACQUISITION

Dataset of CT angiographic images collected from Armed Forces Institute of Cardiology, rawapindi and also from Al Razi hospital, Lahore. It was very difficult to collect the data of different patients because of the reasons that the CT Angiography is comparatively a new technique to Cardiac imaging and also because of privacy reasons. Publically no data set is available for research purpose .I got data of seven patients while one normal person from above mentioned two hospitals. I got the data in a machine software format but to make it easy for image processing techniques I converted the images into PNG format. In total 52 images were collected for the research purpose. We can observe the normal and patient's images as in Figure4.2 and Figure 4.3.

Figure 4.2 *Normal Images*.

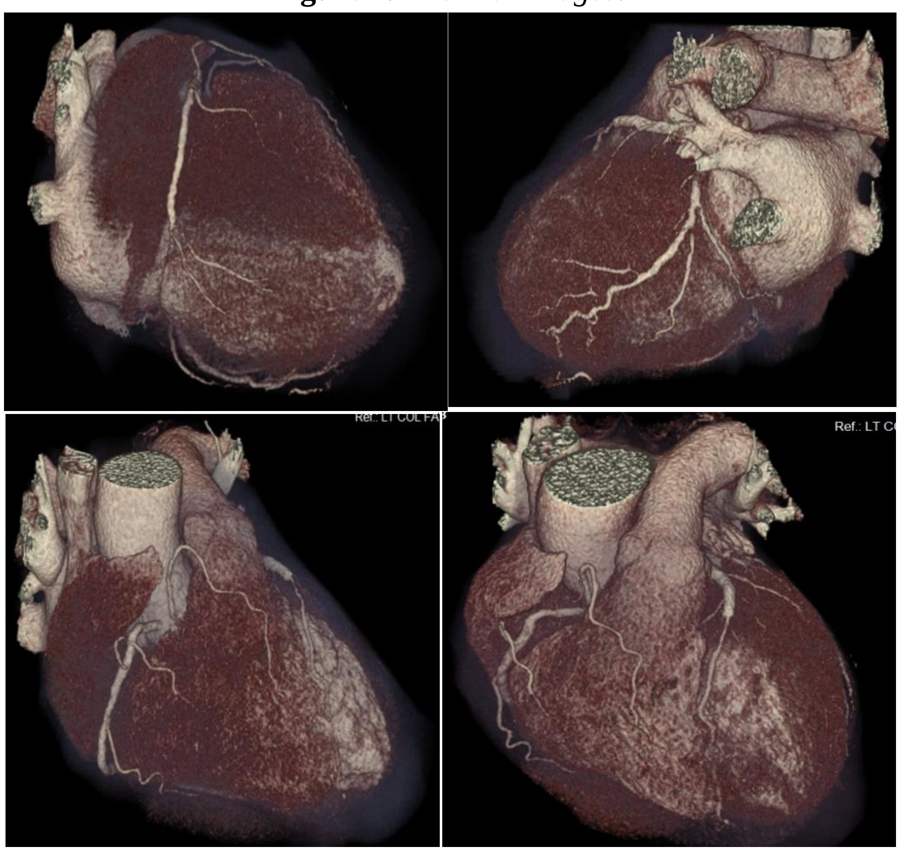

Figure 4.3 *Patient Images.*

4.3 IMAGE ENHANCEMENT (PREPROCESSING)

Enhancing an image means to make an image more useful for required application. There are a large number of techniques used for image enhancement. For example in start we do very basic gray level transformations after that histogram equalization is done in which intensity level of all the pixels is modified under a range of minimum and maximum value. Filtering is also very important in enhancing an image and mostly the filters used belong to categories of average filters and median filters.

Image enhancement can be done in both of the two domains. In spatial domain pixel values are being changed directly whereas in frequency domain Fourier transform of the image is modified. Log transformations and Gamma corrections are also very important methods in this era.

Thresholding is very common method for image enhancement and also for most of the preprocessing techniques used in large number of applications.

A gray level image is simple image which has only shades of gray color, these shades may be lighter or brighter depending upon the intensity value. Gray image provides less information for each pixel and that is the difference between such images and any other sort of color image. Red, green and blue components all have equal intensity in RGB space so it is only necessary to specify a single intensity value for each pixel in gray color, as contrasting to the three intensities needed to specify each pixel in a color image. The grayscale image provides 256 possible different shades of gray from black to white. Its intensity is stored as an 8-bit integer giving. The difference between successive gray levels is considerably better than the gray level resolving power of the human eye if their levels are spaced evenly then. Often grayscale images are entirely sufficient and too good for many tasks so there is no need to use more complicated and harder-to-process color images.

Image enhancement involves the methods and techniques applied to the image to make it more convenient for the application of an algorithm or to attain the fruitful results, whatever we want to have from that image. An image in fact provides information, but sometimes we don’t all the information and only a region of interest can be the real useful information. To make it a useful image input a large number of pre processing techniques have been applied. For example smoothing of images, noise removal from images, contrast enhancement in which foreground is made more brighten and enhanced from background so that region of interest can be more precisely processed using the proposed algorithm. First step in pre processing is to convert the colored image (RGB) to grayscale image to make it easier for further processing. Result is described in Figure 4.4.

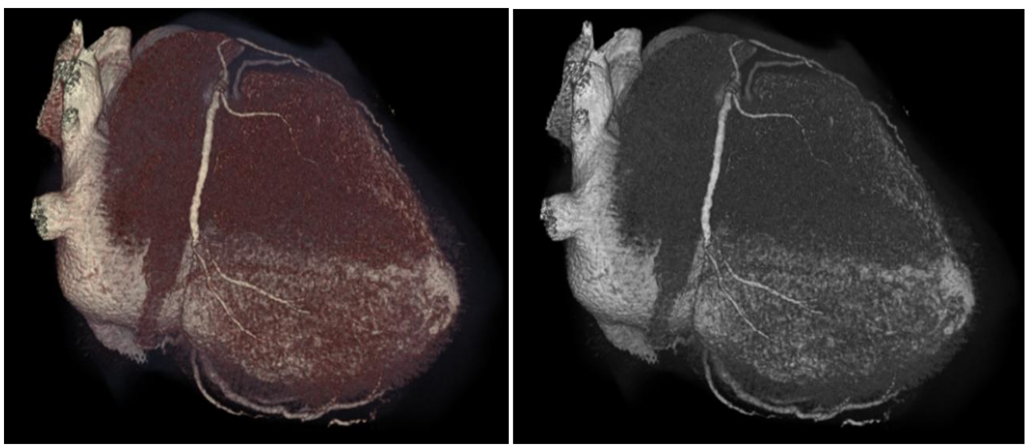

Figure 4.4 *RGB Image and Grayscale Image.*

4.4 FEATURE EXTRACTION

After Converting the RGB image to grayscale we have to extract the feature with which we can detect the arterial tree and the sudden changes in arterial tree which show that plaque or fats has affected the coronary artery area which is the major cause of blood flow blockage.

In first step the grayscale image is converted into binary image. To make this algorithm easier to implement, the MATLAB GUI (Graphical User Interface) is used. It can point our region of interest with a single mouse click and then we can compare the arterial area of three different points.

4.4.1 Binary Threshold Technique

To obtain the binary image threshold technique is applied. A specific value is set as a threshold, the pixel values greater then threshold is changed to 1 whereas pixel values lower than threshold are turned to 0.

In next step binary threshold technique is applied on the image and the threshold was set to be as 0.4. Binary threshold is a technique in which gray scale image is given as an input and resultant image will be a black and white image called binary image. It works by converting all the pixel values above a certain threshold value as brightest and assign them value 1 while all other values below that level will be considered as darkest and a value 0 assigned to those pixels. As shown in Figure 4.5.

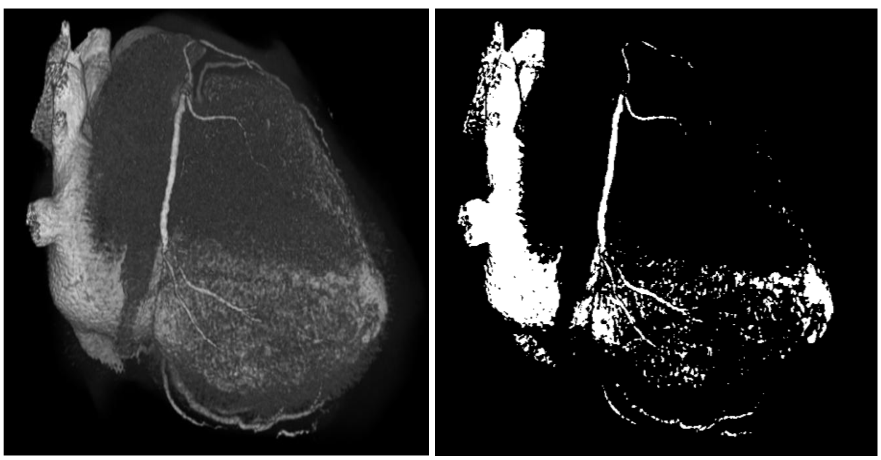

Figure 4.5 *Grayscale image and binary image.*

4.4.2 Noise Removal (Removal of unwanted small objects)

Binary resultant images have some small unwanted objects. Objects connected by 4-connectivity and are fewer than 100 pixels produces another objects are labeled and then simply removed by “bwopenarea” matlab command.

Noise removal is one of the very important and cumbersome problems while extracting our important information from an image. In this algorithm I used morphological open operations for the removal of noise on the basis of size. By using this technique all the small objects were removed which were making the image noisy. The opening operators are also used for enhancement of images. The equation for morphological open operation is as Equation 4.1

$$A \circ B = (A \ominus B) \oplus B \qquad \text{Eq. (4.1)}$$

Here we can observe noise removal from binary image as in Figure 4.6.

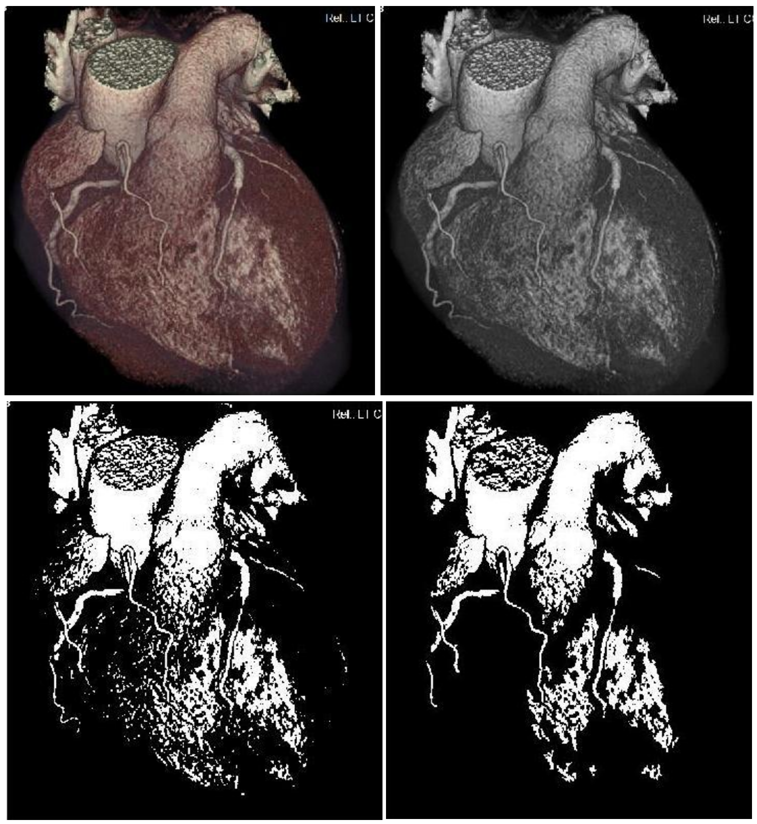

Figure 4.6 *Binary image and noise removal using opening operator. (a) Original image. (b) Gray level image. (c) Binary image. (d) Noise removal.*

Here threshold for removing the small object was an object having less than 70 pixels.

4.4.3 Using Morphological Reconstruction

In Morphological operations a structuring element is applied to an input image, which makes output image having the same size as of input image. In morphological operations, the value of each pixel in the output image is based on a similarity of the corresponding pixel in the input image with its neighbors. The boundaries of regions of foreground pixels *i.e.* white pixels, gradually enlarges by dilation typically. Consequently areas of foreground pixels grow in size

while holes within those regions become smaller or fully covered. The gaps are filled by dilating it. Morphological operation helps to fill the gaps but overall size of object also get increases.
The equation for morphological dilation is

$$A \oplus B = \{z \mid (\overline{B})_z \cap A \neq \Phi\} \qquad \text{Eq. (4.2)}$$

After removing the noise from image using morphological reconstruction algorithm, the lighter borders of an image are removed so that additional area cannot be added into the real area of arteries. The resultant images are shown in Figure 4.7.

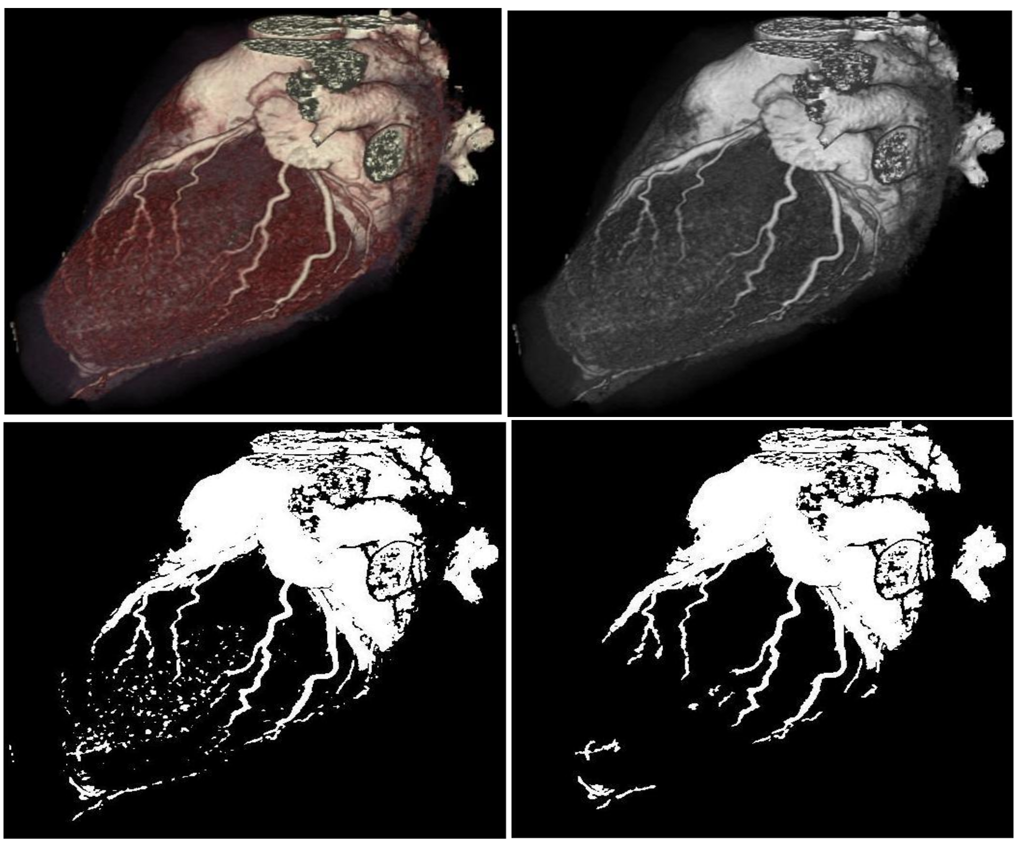

Figure 4.7 *Morphological Reconstruction. (a) Original image. (b) Grayscale image. (c) Binary image. (d) Morphological reconstruction.*

4.4.4 Defining Region of Interest (ROI) Using GUI

Graphical user interface (GUI) works at the point of interface where a computer and user are involved. All the elements which can be explained graphically except the text characters can be defined here e.g. icons, scroll bars, dialog boxes, menus etc. GUI's are usually approached by using the pointing devices which are pen, mouse or stylus. Here in our work we used mouse as a pointing device.

GUI is defined so that the arterial area can be pointed with single click of mouse and it compares the areas of the points which were selected. ROI is selected on the basis of ‘x’ and ‘y’ coordinates and also how much number of pixels it has to count to calculate the area. The points of arterial area are labeled which are afterwards compared with each other. GUI pointer can be shown in Figure 4.8.

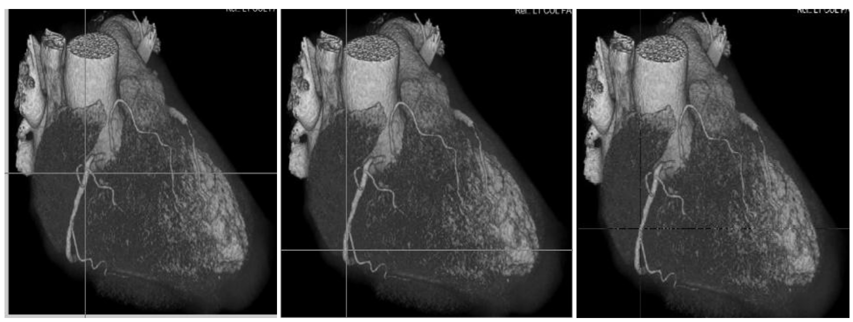

Figure 4.8 *GUI Pointer.*

4.4.5 Defining size of Basic ROI

The size of ROI is defined as [50×50] i.e. 50 pixels in horizontal direction and 50 pixels in vertical direction. It may also be varied but if we make it more and more pixels to account for area calculation and area comparison then computational cost is so much increased which make the algorithm slower.

4.4.6 Making ROI for specific labeled regions

The three points as ROI’s as roi1, roi2, roi3 are labeled .With 50 iterations of each labeled ROI, areas are calculated and specified the points on the basis of which arteries has to be tracked and results has to be made either the image used is of a normal person or a patient with narrow and shrunk arteries.

4.5 Feature Evaluation

Evaluation of arterial area is done by taking the ratios of first ROI and also first ROI and third ROI by counting the number of pixels. The ratio by comparing it with main artery in the image is evaluated.

4.6 Classification

After analyzing a number of images we concluded the following range with which we can classify all the results that either the image belongs to normal person or a patient. Range is selected on the basis of ratios which we calculated earlier.

If equation 4.2 is satisfied

$$\textbf{Ratio1} > \textbf{1.7 or Ratio2} > \textbf{1.5} \qquad \text{Eq. (4.2)}$$

There would be great chance for having a sudden difference in arterial area which shows that some blockage or plaque has been there in artery.

and if equation 4.3 is satisfied.

$$\textbf{Ratio1} < \textbf{1.7 or Ratio2} < \textbf{1.5} \qquad \text{Eq. (4.3)}$$

Artery will be normal.

Chapter 5

RESULTS AND ANALYSIS

5.1 EXPERIMENTAL PARAMETERS

This chapter shows all experimental results and analysis done in this thesis. Three parameters for the proposed algorithms were examined.

1. Accuracy
2. Computational Time
3. Visual Inspection

These are the most commonly used parameters to check the validity of an algorithm. Comparison of proposed method with other algorithms is also computed according to these parameters.

5.2 DATASETS

To diagnosis a disease, the important step is to obtain the effective dataset for reliable evaluation of features have been verified by experts. An accurate algorithm will always gives the same results as prescribed and observed by the doctors should while it will take an input image and after implementation of algorithm it will give an output image. In the evaluation, the consistency is measured and compared between the algorithms. The conducted experiments described in this chapter are performed using two different datasets.

5.2.1 ARMED FORCES INSTITUTE OF CARDIOLOGY

As publically there is no dataset available, of CT angiographic images of heart so the data was collected personally from hospitals. Some images were collected from Armed Forces institute of Cardiology (AFIC) that includes images of only three patients. These images were divided into 2-D frames by their embedded softwares. These 2 –D images were then converted to .png and .jpeg formats for further processing.

5.2.2 AL RAZI HOSPITAL

As above mentioned dataset was not enough for processing hence the second bunch of data were collected from Al Razi hospital Lahore. This dataset includes the CT angiographic images of four patients.

5.3. EXPERIMENTAL RESULTS

The Proposed algorithm was extensively tested on CT Angiographic Images. The evaluation is done for all images using the values of accuracy, visual inspection and also computational cost.

5.3.1 VISUAL INSPECTION

Human visual inspection is the always thought to be the most reliable fast and best way to judge the results of an algorithm. It is very clear, needs lots of expertise and it is also very interest or area specific. Hence by using it we cannot always get the minute and very fine details of results.

5.3.2 PREPROCESSING

Preprocessing is used to make an image more and more useful and informative for our own sake, in this step we used to remove background noise, the area which is not of interest and also noise which can be easily removed by visual inspection in cardiac CT angiographic images.

A user who is familiar with all the procedures and methodologies of image acquisition and final CT images can easily differentiate between good preprocessed images and bad preprocessed images as Figure 5.1. We can also see the Figure 5.2 resultant images after preprocessing has been done.

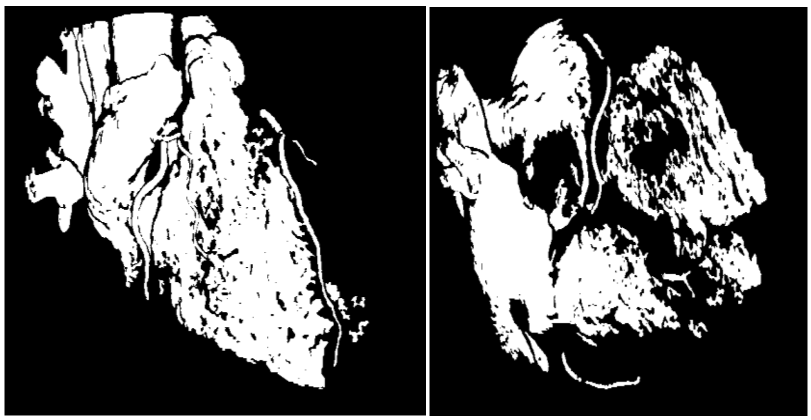

Figure 5.1 *Preprocessed Images.*

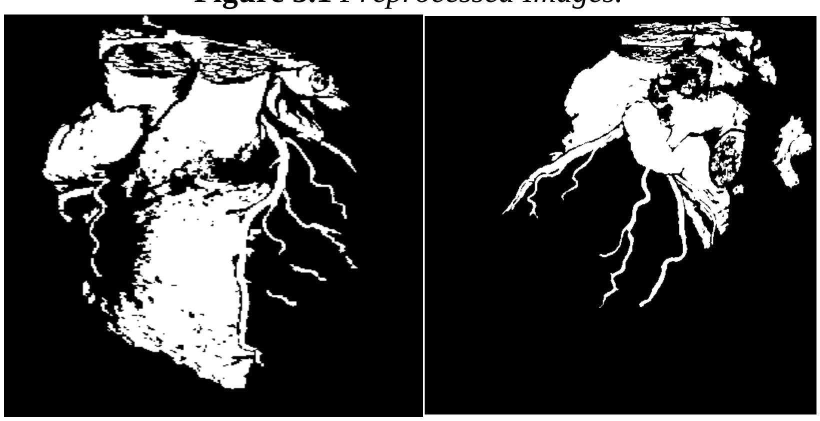

Figure 5.2 *Resultant images.*

5.4 FEATURE EXTRACTION

After Converting the RGB image to grayscale, next step is to extract the features. which we can detect the arterial tree and the sudden changes in arterial tree which show that plaque or fats has affected the coronary artery area which is the major cause of blood flow blockage.

The grayscale image is converted into binary image. To make this algorithm easier to implement MATLAB GUI (Graphical User Interface) is used with which we can point our region of interest with a single mouse click and then we can compare the arterial area of three different points.

5.4.1 Binary Threshold Technique

The binary threshold technique is applied on images and threshold was set to be 0.4. This technique converts the grayscale image to a binary image. As an output image replaces all pixels in the input image with brightness greater than level with the value 1 and replaces all other pixels with the value 0. Binary image can be depicted in Figure 5.3 shows the grayscale images and binary image.

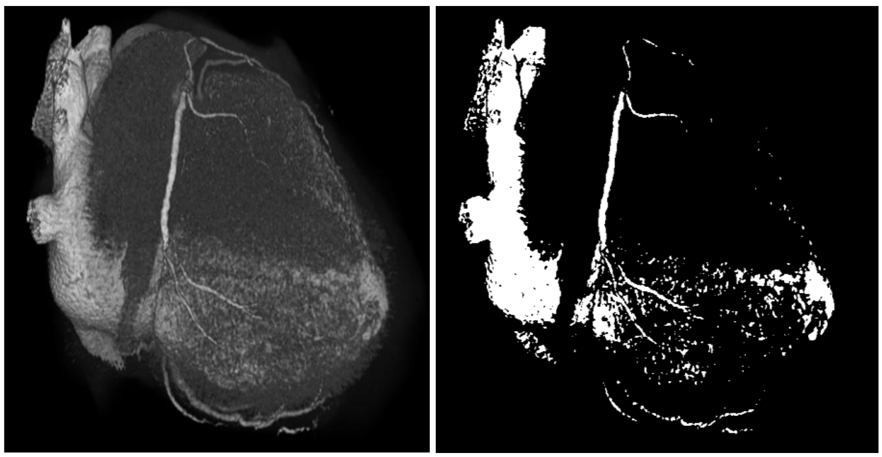

Figure 5.3 *The grayscale image and binary image.*

5.4.2 Noise Removal

Noise removal is one of the very important and cumbersome problems while extracting our important information from an image. In these algorithm morphological open operations is used for the removal of noise on the basis of size. By using this technique all the small objects were removed which were making the image noisy. The opening operators are also used for enhancement of images

The noise removal can be seen in Figure 5.4. Threshold for removing the small object was an object having less than 70 pixels.

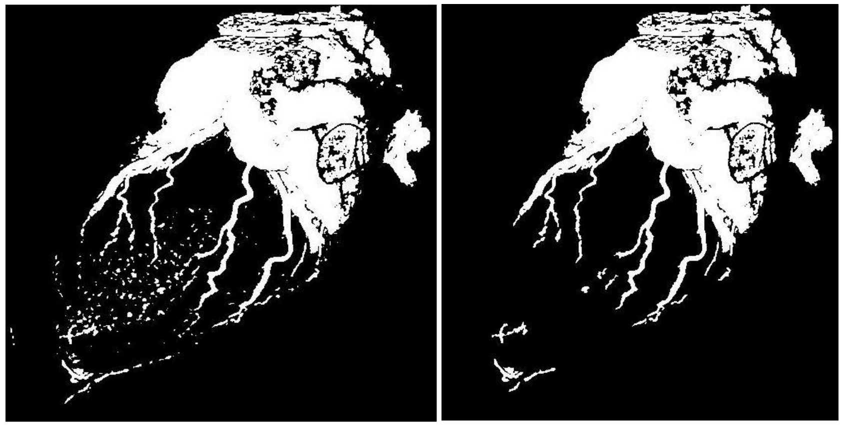

Figure 5.4 *Binary image and noise removal using opening operator.*

5.4.3 Using Morphological Reconstruction Algorithm to remove lighter objects from boundary of an image

After removing the noise from image using morphological reconstruction algorithm, the lighter borders of an image is removed so that additional area cannot be added into the real area of arteries. It can be observed in Figure 5.5.

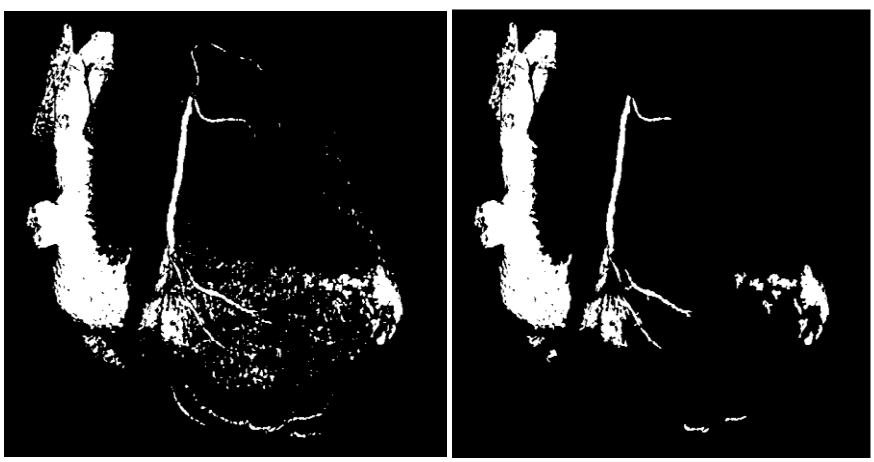

Figure 5.5 *Morphological reconstruction.*

5.4.4 Defining Region of Interest (ROI)

GUI is defined so that arterial area can point out with single click of mouse and it compares the areas of the points which were selected. ROI is selected on the basis of ‘x’ and ‘y’ coordinates and also how much number of pixels it has to count to calculate the area. The points of arterial area are labeled which is supposed to be comparing with each other. It can be shown in Figure 5.6

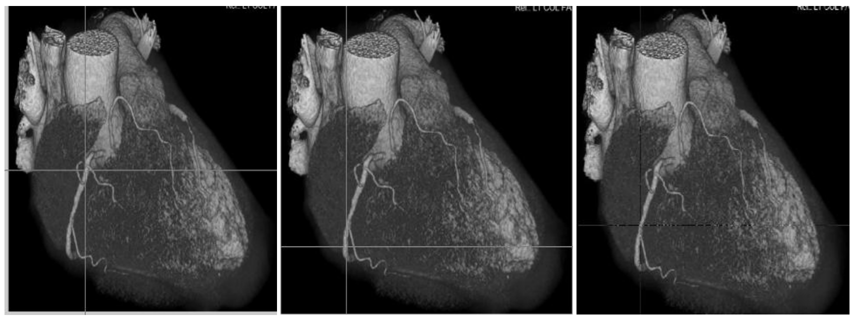

Figure 5.6 *Region of interests (roi1, roi2, roi3).*

5.4.5 Defining size of Basic ROI

The size of ROI is defined [50×50] as 50 pixels in horizontal direction and 50 pixels in vertical direction. It may also be varied but if we make it more and more pixels to account for area calculation and area comparison then computational cost is so much increased which make the algorithm slower.

5.4.6 Making ROI for specific labeled regions

The three points as ROI's as roi1, roi2, roi3 are labeled. With 50 iterations of each labeled ROI, the area are calculated and specified the points on the basis of which arteries has to be tracked and results has to be made either the image used is of a normal person or a patient with narrow and shrunk arteries. Total 32 images were used and Results are depicted in following Table 5.1 which shows the comparison of provisional diagnosis and the results that are evaluated with the proposed algorithm and Resultant images of the abnormal arteries can be shown in Figure 5.7.

Image #	Provisional Results	Algorithm Results
Im1	Normal	Normal
Im2	Normal	Normal
Im3	Normal	Abnormal
Im4	Normal	Normal

Im5	Normal	Normal
Im6	Abnormal	Abnormal
Im7	Abnormal	Abnormal
Im8	Normal	Normal
Im9	Abnormal	Abnormal
Im10	Abnormal	Abnormal
Im11	Abnormal	Abnormal
Im12	Abnormal	Normal
Im13	Normal	Normal
Im14	Abnormal	Normal
Im15	Abnormal	Abnormal
Im16	Abnormal	Abnormal
Im17	Abnormal	Abnormal
Im18	Normal	Normal
Im19	Normal	Normal
Im20	Abnormal	Abnormal
Im21	Abnormal	Normal
Im22	Abnormal	Normal
Im23	Abnormal	Abnormal
Im24	Abnormal	Abnormal
Im25	Normal	Normal
Im26	Normal	Normal
Im27	Normal	Normal
Im28	Abnormal	Abnormal
Im29	Abnormal	Normal
Im30	Normal	Normal
Im31	Abnormal	Abnormal

Table 5.1 *Results of images.*

Figure 5.7 *Resultant Image*

5.5 Accuracy

Total 31 images were used in which 13 images were of normal and healthy arteries and 18 were considered to be abnormal or blockage arteries. 26 were correctly classified and 5 images were wrongly classified. This makes the accuracy 83.8 percent. Table 5.2 shows the confusion matrix.

	Normal	**Abnormal**
Normal	12	1
Abnormal	4	14

Table 5.2 *Confusion Matrix.*

5.6 Computational Cost

The algorithm is implemented by using Matrix laboratory (MATLAB) software having image processing tool box and computer vision tool box. While system specifications used are Core i5 2.30 GHz with 4GB RAM memory. Time duration taken by each step is calculated one by one. The algorithm for each image has run 5 times and its mean computational time is computed. Computational cost of the proposed algorithm is 7.1 seconds.

5.7 Precision

I achieved the following precision using my algorithm

$$\boldsymbol{Precision} = \frac{\boldsymbol{True\ Positive}}{\boldsymbol{True\ Positive + False\ Positive}} \qquad \textbf{Eq. (5.1)}$$

Precision is about 75%.

5.8 Recall

I achieved following recall value

$$\boldsymbol{Recall} = \frac{\boldsymbol{True\ Positive}}{\boldsymbol{True\ Positive + False\ Negative}} \qquad \textbf{Eq. (5.2)}$$

Recall is about 92% as normal image classified as abnormal has very low ratio.

5.9 Specificity

$$\boldsymbol{Specificity} = \frac{\boldsymbol{True\ Negative}}{\boldsymbol{True\ Negative + False\ positive}} \qquad \textbf{Eq.}\ (\mathbf{5.3})$$

Specificity achieved is 80%.

5.10 Summary

Proposed algorithm is extensively tested on available dataset. The major aspects are three which are used to check the validity of proposed algorithms and these are accuracy, computational cost and visual inspection. First, I arterial tree on the basis of their area feature is extracted and then they are classified into healthy or abnormal arteries. The algorithm takes 7.1 seconds to evaluate the results. Secondly achieved accuracy is 83.8 percent.

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

Advances in medical imaging technology and computer science have significantly enhanced interpretation of medical images, and contributed to early diagnosis. The typical architecture of a Computer Aided Diagnosis (CAD) system includes image pre-processing, region of interest (ROI), feature extraction, and classification. Coronary Artery disease has been recognized as a major cause of death and also most abundant among heart diseases. In this disease artery supplying blood to heart muscle called Coronary artery in medical terms is blocked partially or sometimes fully which cause heart attack, as no supply of blood to heart causes heart function failure To detect this disease by using CT angiographic image was the major goal of this research.

In this thesis, a system for the detection of Coronary Artery disease is designed and implemented. First step of proposed system is acquitting the CT angiographic images of heart patients. From two hospitals datasets were collected that includes Armed Forces Institute of Cardiology (AFIC), Rawalpindi and Al Razi hospital, Lahore. Second step is the preprocessing of images to remove noisy area to lower the processing time. After preprocessing, next step is to extract the features. As a sudden or abrupt change in arterial tree area shows that there is some blockage fat or some plaque in artery hence arterial area calculation is key feature of this research. As anatomy and physiology of heart tells us that arteries always grew in a continuous manner and their area slowly decrease from growing main artery to branch arteries downwards. Hence while tracking an artery if an abrupt or sudden change occur in arterial area, patient must have some disease.

The developed method is tested on 50 images taken from two hospitals. The major aspects are computational time, accuracy and visual inspection on the basis of which validity of algorithm is checked. the proposed algorithm has achieved an average accuracy of 83.8%. The mean computational time calculated for the proposed method is 7.1 seconds.

6.2 FUTURE WORK

The proposed system for the detection of coronary artery diseases is implemented on CT Angiography. Another way to detect disease can be implemented using CT angiography images and using pattern recognition techniques if image acquisition is properly known to us, if we do not know angles with which the imaging system has acquired the images we cannot fix the dimensions and also cannot compare the results. Next step will be the automatic detection of blockage in arteries using 2D and 3D CT angiography images.

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DECLARATION

I hereby declare that the thesis report titled as "Coronary Artery Disease Using CT Angiography" my own work. To the best of my knowledge, it contains no materials previously written by another person, nor material which to a substantial extent has been accepted for the award of any degree or any other education institute, except where due acknowledgment is made in the thesis. Any contribution made to the research by others, with whom I have worked at E&ME or elsewhere, is explicitly acknowledged in the thesis. I also verified the originality of contents in thesis through plagiarism software.

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