HEURISTIC DETECTION OF BLOCKAGE IN CORONARY ARTERIES FROM CARDIAC MAGNETIC RESONANCE IMAGING IMAGES AND PREDICTING HEART FAILURE RISK USING DIGITAL IMAGE PROCESSING

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Abstract— Cardiac diseases are the leading cause of death of human being in present era. Cardiovascular diseases include illnesses that involve the blood vessels (veins, arteries and capillaries) or the heart, or both. Diagnosis and follow up of these pathologies can rely on numerous cardiac imaging modalities which include echocardiography, CT(Computed Tomography), coronary angiography and Cardiac MRI(Magnetic Resonance Imaging). Imaging of these organs help in tracking the diagnosis and treatment of diseases. Among the existing medical imaging modalities, cardiac magnetic resonance imaging (CMRI) has attracted significant interest in the research and clinical communities. It is a noninvasive technique that is capable of acquiring most of the cardiac physiological measures: cardiac structure, function, perfusion and myocardial viability. It can provide clearer and more diagnostically useful images of the heart and blood vessels than other modalities which help physicians evaluate both the structure and functioning of the organ. It enables the discovery of abnormalities that might be obscured with other imaging methods. CMRI can produce images of cardiovascular structures without interference from adjacent bone or air. The segmentation of CMRI images can be performed manually by experts, but it is a time consuming process, and prone to error. The manually performed segmentation is also subjective in nature. Hence, efforts have been made to make this segmentation procedure completely automatic. There are automated/semi-automated segmentation methods available for detection of heart blockage but the quest is to look for a more better blockage detection approach. Therefore, there is a need of robust and heuristic algorithms which requires minimum or no user interaction and provides the accurate segmentation. Furthermore, the accurate segmentation can provide much useful information which can be helpful for determining the cardiac health for diagnosis and treatment.

Keywords – Cardiac blockage, Cardiovascular, Coronary artery, CMRI, DIP, Edge Detection, Heart failure.

I. INTRODUCTION

Coronary artery disease, in short, CAD is one of the main and important cause of human death in various countries all around the world. Every year millions of dollars is invested for the treatment of coronary artery disease too, yet it possess a serious potential threat to millions of lives. However, due to the existence of several heart imaging modalities the detection of cardiac blockage was made easy. Over the last few years, several bold steps were taken in the area of cardiac imaging techniques. As a result rapid improvement and development were made in this area [1]. Presence of plaque in the walls of coronary arteries are the chief indicators of Coronary Artery Disease. The five main coronary arteries, which are the main areas of plaque deposition are the Right Coronary artery (RCA), Posterior Descending (PDA), the Left Main (LM), Left Circumflex (LCX) and Left Anterior Descending (LAD) [1].

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It can be observed from medical reports that doctors will be able to diagnose properly and hence can provide better and reliable treatments to the affected people if the cardiac disorders get detected as early as possible. However, due to the presence of various improved and advanced noninvasive medical imaging methods, it has become very easy for doctors and cardiologists to detect, diagnose, perform surgeries and operations[2]. But still cardiac blockage is a severe problem among all other heart disorders. Accurate detection and diagnosis of blockage is required for proper cardiac treatment. Proper medication could be provided to the affected patients before its too late.

A. Motivation behind the Study

Maximum number of deaths around the world occur due to cardiac diseases. There are several heart disorders out of which cardiac blockage is the focus of discussion; as it is the chief cause of deaths due to cardiac arrest, which in medical term is also called Myocardial Infarction (MI) [1,3]. Efforts have also been made towards diagnosing Cardiovascular Diseases to provide efficient treatments and, hence, significantly decrease its mortality rate [4,5]. Cardiovascular diseases (CHD) has also gained a lot of attention because of its epidemic developmental increase after the Second World War, especially in the developed and industrialized countries but, however, presently CHD has made the whole world its victim and target. Though the death rates for CHD are slowly declining in most of the developed countries but are increasing simultaneously in developing and under developed countries mainly due to changes in lifestyle and demography and rapid urbanization. Presently, according to statistics, approximately 3.4 million women and 3.8 million men, die because of heart disease every year around the world[7,8]. Given below is the figure 1.1 which shows that the death rate in men is more compared to that of women due to heart diseases. According to one statistics, in 2003, it was seen that the total expenditure on medical health care is around 169 billion euros, approximately, which is an average of 3724 euros per capita per year, in the European Union (EU). Of this amount, 62 % contributes to the direct cost while 21% contribute to loss in productivity [9,12].

A Study of Global Burden of Disease, showed that, in 1990, the death rate due to heart disease were 3.5 million out of 6.2 million total deaths all around the world. It was also estimated that this death toll will increase by 2020. The figures roughly predicted were 7.8 million out of 11.1 million total deaths [8,10]. In 1990, 47% of the overall deaths related to heart disease in the developing countries has occurred before 70 years of age, as compared to the high-income industrialized countries, where it is only 23% [8,10,12]. Both in India and China the death rates will increase enormously. On the other hand, for developed and high economic nations, there will be a gradual fall in the DALYs rate from 20 million to 15 million during the same time period. This difference in DALYs rate due to heart disease between the developed and developing nations will become more in the coming 20 years [11,12].

B. Objective

To detect blockage in coronary arteries as clear and as accurate as possible from Cardiac Magnetic Resonance
Imaging (CMRI) images of coronary arteries and vessels and also to heuristically predict the possibility of heart attack in near future. Basically, a medical procedure is followed for detecting heart blockage. At first, to detect any kind of cardiac disease at first electrocardiogram test (ECG) is used or prescribed. Based on the result of the electrocardiogram test obtained it can be determined whether there is any abnormality present in the functioning of heart or not. Cardiac Magnetic Resonance imaging, in short CMRI is a non invasive method or technique which provides higher resolution and almost excellent quality of images if compared to other existing techniques. These two features of CMRI are very much crucial for accurate detection of coronary artery blockages. Hence, CMRI images are used. The focus is to detect the edges as accurately as possible by using available image processing techniques, so that, medical analysis becomes more accurate and easy. By doing so the Region of Interest (ROI) can be explored for better diagnosis. To calculate the heart failure risk expectancy time, some sort of heuristic algorithm is needed. Able to predict the possibility, as accurate as possible, will contribute a lot in the medical research field. Not only that, the death rate due to cardiac arrest can also be minimized to some reasonable extent. Thus, this mathematical model will be useful for calculating the amount of blockage and its current status as well as predict the life expectancy of a patient suffering from blockage via an early warning and a near approximate heart failure time.

II. Diagnostic Aspects

Heart pumps blood to the whole body. It is almost the size of a human fist, placed inside the chest with a cone shape and a pointed end faces to the left. It weighs between 280 to 340 grams in men and 230 to 280 grams in women, according to Henry Gray's "Anatomy of the Human Body."[13] In a normal adult, on an average the heart beats nearly 60-80 times per minute. In a newborn or infant, on an average the heart beats nearly 70-190 beats per minute. Heart beats faster in a newborn baby as compared to an adult heart. Heart pumps about 5-6 liters of blood in the body on an average [13]. The heart has its own system of blood vessels. Arteries deliver oxygen-enrich blood from the heart to the rest of the body. Aorta is the biggest artery, which leaves the heart and branches into smaller vessels. Veins deliver deoxygenated blood back to the heart from rest of the body with the help of inferior and superior vena cava, which drain into the right atrium. Capillaries connect arteries to veins [13]. The heart has the five main coronary arteries, the Right Coronary artery (RCA), Posterior Descending (PDA), Left Main (LM), Left Anterior Descending (LAD), Left Circumflex (LCX). Several other small vessels branches from these five main coronary arteries. Below given is an image of a normal heart showing coronary arteries, major arteries and veins.

A. Heart Blockage

Heart block is a disease or inherited condition, that causes a problem within the normal functionality due to some sort of obstruction or "block"[6]. Arrhythmia could be a symptom of heart blockage. Arrhythmia is defined as a condition where the rate of heart beat gets irregular i.e., the heart may beat very faster (tachycardia) or very slower (bradycardia) compared to normal heart beat. In some serious cases, reduced flow of blood may also cause damage to the heart [6,14]. Heart blocks may be either congenital (present from birth) or acquired (developed after birth).
Electrocardiogram or EKG, is a test which is used to detect as well as record the electrical activities of the heart. Data is mapped on a graph for clinical review by cardiologists [6,14].

Problems responsible for heart attack due to artery blockage:

1. Calcium or fat deposition of plaque inside the artery walls (atherosclerosis).
2. A blood clot inside an artery which was already narrowed due to calcification,
3. A spasm of the artery’s muscular wall.

![Figure 2.2: (1) Deposition of Plaque in the Artery Walls preventing Proper Blood Flow [28] and (2) A Blood Clot in an Artery already Narrowed by Atherosclerosis [29]](image)

![Figure 2.3: (a) A Spasm occurs in a Normal Coronary Artery and (b) A Spasm occurs in a Plaque Buildup Coronary Artery [30]](image)

**B. Types of Heart Blockage**

There are three types of heart block. They are **first degree heart block** (least severe), **second degree heart block**, and **third degree heart block** (most severe). These three types could occur in case of both congenital heart block as well as acquired heart block [15]. The figure below shows the types of heart blockage.

![Figure 2.4: Types of Heart Blockages [31]](image)
Causes Of Heart Block\[16\]

- It can occur if there is any other heart disorder.
- Other diseases also may raise the risk of heart block, such as sarcoidosis and the degenerative muscle disorders Lev's disease and Lenegre's disease.
- Exposure to any kind of toxic or harmful substances. Taking medicines which can cause heart problems as a side-effect, like calcium channel blockers. In such cases, the symptoms may last as long as the patient is on medication. However, if the doses are regulated the problem might be tackled with.
- It can also develop over time (acquired) and affects people of any age.
- Sometimes due to some surgical reasons the patient may acquire cardiac problems. If the signaling system of the heart gets affected then the patient may have heart blockage, however, in many cases the problems slowly disappear with time.

Signs and Symptoms Of Heart Block
If a person has a heart block, they may experience[17]:

a. Slow or irregular heartbeats,
b. Shortness of breath,
c. Light headedness and fainting,
d. Pain or discomfort in the chest,
e. Difficulty in doing exercise due to the lack of blood being pumped around the body.

Heart Block Treatment

No treatment is required for person suffering from first-degree heart block. For second-degree heart block, a pacemaker is required to keep the heart function in a particular way. Pacemaker makes use of the electrical impulses which sets the heartbeat at a normal pace. For people having third-degree heart block, a pacemaker may be needed depending upon the age of the patient. In worst case, a pacemaker is also implanted during the time of birth. In emergency cases, usually a temporary pacemaker is used[18].

C. Types of Heart Blockage –

Heart failure
A medical condition, which makes the heart unable to pump the required quantity of blood that the body needs. In certain cases, either it’s the heart which loses it’s power to pump the normal quantity of blood to the whole body or the heart do not filled with the required blood amount. A person may suffer from either or both of these problems. Heart failure grows with time, thereby weakening the heart and if not treated on time may affect either or both sides of heart. Usually, it’s both sides which gets affected. However, if only the right-side is affected then the heart becomes unable to pump sufficient amount of blood to the lungs. If only the left-side is affected then the heart becomes unable to pump sufficient amount of blood to the whole body[19,20].

Causes of Heart Failure
There are several disorders which can not only cause damage to the heart muscle but also leads to heart failure [1,2,19]. These disorders, which if do not cause a direct heart failure but still increases the possibility to a large extent. Following are some of the leading cause of death due to heart failure [1]:

- Coronary heart disease (CAD): Also known as coronary heart disease, is caused by narrowing of the arteries that supply oxygen-rich blood to the heart due to plaque buildup.
- High Blood Pressure: Also known as hypertension is the force of blood exerted against the walls of the arteries as blood flows through them. If this pressure rises and stays high over time, it can weaken the heart and lead to plaque buildup.
- Diabetes: It is a disease in which the body’s blood glucose level is too high. Over time, high blood sugar levels can damage and weaken the heart muscle and the blood vessels around the heart, leading to heart failure.
- Heart attack: A heart attack may occur when a coronary artery becomes suddenly blocked, stopping the flow of blood to the heart muscle and damaging it. All or part of the heart muscle becomes cut off from its supply of oxygen.
• Cardiomyopathy: Damage to the heart muscle. Causes include artery or blood flow problems, infections, and alcohol and drug abuse.

III. HEART IMAGING MODALITIES

Since, Cardiovascular diseases (CVD) are the major cause of death worldwide therefore, efforts were made towards diagnosing the CVD as early as possible so that efficient treatments could be provided and, hence, significantly decrease its mortality rate [5]. Various noninvasive imaging techniques are available which are being widely used over the last few years in order to provide noninvasive cardiac imaging methods that exactly describe the cardiac structures and also assess myocardial perfusion, function, and metabolism, e.g., Computed Tomography (CT) Scan, Cardiac Catheterization, Nuclear imaging, Electrocardiograph and Cardiac Magnetic Resonance Imaging (CMRI) [21]. The one which is most needed for the study is Cardiac Magnetic Resonance Imaging (CMRI).

A. Cardiac Magnetic Resonance Imaging

Cardiac Magnetic Resonance Imaging (CMRI)

Cardiac magnetic resonance imaging (CMRI) machine uses a computer, radio waves and a very strong magnetic field in order to create good quality images of heart structures and images of other body organs like bones, some soft tissues and internal organ structure. Basically, CMRI is used for the detection and also monitoring of several heart disease. It is also used for studying or examining the human heart. Functionality of heart, affected due to congenital cardiac disorders can be determined with the help of CMRI test [22,23]. When CMRI machine is used to study the blood vessels in heart, kidneys, and brain, then it is referred to as magnetic resonance angiography (MRA) [24]. Though, almost similar technology is used in both MRA and MRI, but some special settings are required for the detection and diagnosing disorders of blood vessels. Sometimes, to make the images more clear a harmless dye is used.

![CMRI Image Of Normal Coronary Arteries](image1) ![CMRI Image Of Coronary Artery Blockage](image2)

Figure 3.1: CMRI Image Of (a) Normal Coronary Arteries[32] and (b) Coronary Artery Blockage[33]

Merits of CMR are [1,25] :

i. CMRI is non-invasive and provides detailed accurate result,
ii. CMRI doesn’t exposes the patient to any kind harmful radiation,
iii. CMRI can be repeated sequentially over time, and has the ability to generate cross-sectional images in any plane,
iv. CMRI has the ability to distinguish the differences between two arbitrarily similar but not identical tissues,
v. CMRI produces cardiovascular images without any kind of interference from the adjacent bone or air that could easily affect and disturb the output,
vi. CMRI can produce images of better quality and higher resolution,
vii. Operators also do not face any kind of trouble while operating the CMRI machine.
Demerits of CMR[1,25]:

i. CMRI data acquisition is a relatively long and complex process,

ii. CMRI is unfit for persons suffering from claustrophobia.

iii. CMRI is not suitable for patients with metal implants due to its magnetic nature,

iv. CMRI suffers from sensitivity to noise and image artifacts,

v. CMRI tests are costly and hence arises the question of affordability,

vi. If the patient undergone a surgery in the previous 6 weeks, then CMRI test for such patient is not prescribed,

vii. Large sized patients can’t fit into the tube of the CMRI machine,

viii. Image quality also degrades if the patient can’t stay still inside the CMRI tube.

Cine CMR, Tagged CMR, Contrast-Enhanced CMR (CE-CMR), Late Contrast-Enhanced CMR (LCE-CMR), Dynamic Contrast-Enhanced CMR (DCE-CMR) are types of CMR.

IV. ALGORITHM & REPRESENTATION

A. Proposed Algorithm

Step 1: Input the CMRI image

Step 2: Perform pre-processing and image enhancement method

Step 3: Removal of extra information on the CMRI image, if any

Step 4: Apply the suitable filtering technique for noise removal

Step 5: Detect the edges of the input image

Step 6: Identify the Region Of Interest (ROI)

Step 7: Crop to extract the Region Of Interest

Step 8: Perform Segmentation

Step 9: Determine the cross-sectional area of the segmented arterial section

Step 10: Calculate the percentage of blockage predict the heart failure risk factor accordingly

Step 11: Obtain the result in the form of images, reports or both

B. Diagrammatic Representation of Proposed Algorithm

![Flowchart](image-url)

Figure 4.1: Flowchart of the Proposed Methodology
IV. CONCLUSION
Statistical studies show that coronary heart blockage is one of the most important and a vital factor that is responsible for large number of deaths worldwide due to heart failure as compared to other cardiac disorders. So we need to develop some inexpensive and fully automated system for accurate detection of blockage. Comparative studies show that several works related to blockage detection have been done earlier where each such work has its own benefits and drawbacks. In order to detect a blockage, it becomes essential to identify the edges of coronary arteries and their branched vessels prominently and in details. The outcome of the proposed methodology was almost satisfying but obviously cannot be termed optimal. Unless the edges of coronary arteries present in the input CMRI image is clearly identified the Region of Interest cannot be detected properly. If edges gets clearly detected then dependence on other complex procedure becomes less. Image processing techniques, available for processing and analyzing of medical images, makes diagnosing of diseases and disorders easy and therefore plays an crucial role in the field of medical science.
The mathematical calculation which was used to find the Heart Failure Risk Expectancy Time provides the desirable output, though value of parameters and the rate of plaque deposition was assumed. Other factors affecting heart failure due to blockage was not taken into consideration. However, if real life situation are considered then this algorithm will provide a near optimal result which is obviously heuristic in nature.
Thus, the problems which are faced in heart diagnosing methods can be dealt with easily and might contribute to the medical research field a lot by proper and timely diagnosing. The search for new and more improved ways is on and should be adapted to overcome the faults and make blockage detection error free as much as possible.

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