CHAPTER – I

INTRODUCTION

‘Health is wealth’ is a proverb that more suits the human society in the present scenario. Cardiac diseases are more common among this generation. In earlier days these diseases struck people of age group around 60-70. But nowadays even younger generations are mostly affected with cardiac diseases. Some researchers have made a study on the early causes of this disease. Those studies concluded a number of reasons and some of the major reasons are listed below.

- Food habits
- Advancement in the living style of the people
- Working atmosphere and nature of work
- Lack of physical activities

A recent statistics reveal that almost 60 percent of the total world population are affected by cardiac diseases. This disease is also more common among men than women. Also, it is shocking to hear that one of the hundred fetuses is affected by heart disorders. A number of medications are being developed in the medicinal field to control and cure these diseases to the core. These life supporting medicinal procedures make the people feel comfortable, and it aids in maintaining their daily routine without any interruption. It is always advisable to have a proper and accurate diagnosis of the disease before following any medications.

A number of diagnostic tools and algorithms are being developed by the researchers for various diseases. But developing a diagnosing tool for cardiac diseases is quite challenging. This is because these tools need more accuracy and response as compared to the diagnostic tool of other diseases. On the other hand, research is also focused on to simplify and support the conventional diagnosis procedures. Due to the adequate availability of data, these development methods have low risk factors and are easy when compared to the earlier methods.

Certain works are focused on the development of simplistic diagnostic tool and algorithms to diagnose heart disorders at pediatrics and fetal stages. The diagnosis and medications at this stage can support with the lower risk of fetal disease with the growth of pediatric. This work focuses on the development of one
such algorithm for analysis and classification of cardiac disorders with the signals obtained using fetal electrocardiography.

ECG is the preliminary tool used to diagnose cardiac disorders. This device records the electric pulses reflected during the contraction and expansion of the heart. In order to know the generation of electric pulses by the heart, the basic study related to the structure of heart is necessary. Section 1.1 explains the basic structure of the heart.

1.1 PHYSIOLOGY OF THE FETAL HEART
The physiology of the fetal heart mainly deals with the fetal heart development and fetomaternal compartments.

1.1.1 Fetal Heart Development
The first organ developed in the fetus is the heart. It grows gradually with every stage of fetus development. The picture of the fetal heart at its early stage is shown in the Fig.1.1

![Early Stages of Development of Fetus Heart](image)

The critical period of development of heart is between the 3 to 7 weeks of fertilization in which the development of the basic structure of heart develops as a simple heart tube and develops into a four-chambered structure. Each stage of development of heart is shown in Fig.1.2.
The heartbeat begins from the third week of fetus life. During this stage, it begins to pump the blood through the closed circulatory system. The development of eye, ear and the respiratory system begins after this process. The fetal heart can be analyzed with the aid of ultrasound imaging technique during the 7th to the 9th week of pregnancy. The heartbeat rate cannot be obtained during this period of imaging. Therefore, the imaging analysis done at this stage does not provide any information related to fetal heart heard at the 20th week of pregnancy. The heartbeat can be heard as such without any amplification devices during this stage. The rate of fetal heart beat at this stage will be 120-160 beats per minute. A certain amount of diagnostic information can be obtained at this stage of analysis.

The ECG signal acquired at this stage contains fetal components and maternal components. The morphology-based signal analysis done at this stage will furnish a variety of information related to fetal heart. Therefore, to acquire details regarding the fetal heart activity, analyzing morphological features of the mother ECG have received much interest. The analysis can be made with the signal acquired from the abdomen from the 18th to the 20th week of conception. The brain waves can be recorded after the 6th week of fertilization. During this period, the development of skeleton will be complete, and most of the reflexes will be present for analysis.
The developed embryo at this stage is about 0.5cm in length. The head, mouth, liver, and intestines will begin to take shape at this stage. The muscles begin to develop at 12-14 weeks. Generally the weight of fetus at this stage will be 30g and is about 7cm long. The spontaneous movements can be observed at this stage. At the 26th week, the fetus begins to inhale and exhale. During this stage, neither the air nor the oxygenating blood is supplied to the heart. It just provides an exercise to the respiratory system before birth. The fetus will be able to survive outside the womb after 23 -24 weeks. But the probability of survival outside the womb at this stage is only 15%. The probability of survival outside the womb is 56% and 79% from the 24th and 25th week of pregnancy respectively.

1.1.2 Fetomaternal Compartments
The schematic diagram for simplified anatomy of the fetomaternal compartments is shown in the Fig.1.3. The fetus is surrounded by different anatomical layers and each layer has different electrical conductivity. The amniotic fluid is having the highest electrical conductivity, and vernixcaseosa is having the lowest electrical conductivity. These two layers surround the fetus completely.

Fig.1.3 Anatomy of Fetomaternal Compartments
The subcutaneous fat and the skin in the maternal abdomen are much thin, and it is about ten times smaller than the muscle tissue. This compartment also has poor conductivity. These two layers have a considerable influence on the recorded fetal
ECG. The different tissues and layers of the heart are called as volume conductor. The fetal cardiac signals propagate up to the maternal body surface through the volume conductor. The electric conductivity and geometric shape of the volume conductor constantly changes throughout gestation.

The volume of amniotic fluid, the placenta are begin to increase during the second half of gestation in fetus itself. The vernixcaseosa layer is formed between the 28th and the 32nd weeks of gestation. This layer is having low electrical conductivity and it electrically shields the fetus. This makes the process of acquiring the fetal surface ECG very difficult. However, this layer begins to dissolve slowly from the 37th to the 38th weeks of pregnancy.

Different interpretations have been presented in the earlier studies for recording the fetal ECG signals during the third trimester of gestation. These studies were based on the preferred current pathways such as the umbilical cord, ornasalcavity, or even random holes in the vernixcaseosa. This preferred current path way hypothesis, explains some of the differences between adult and fetal ECG and vector cardiogram shapes.

1.2 ANATOMY OF THE FETAL HEART
A healthy heart makes the art of life more beautiful. The heart plays a major role in the purification and pumping of blood to various organs of the body. The anatomy of a fully developed fetal heart is given in Fig.1.4.

![Fig.1.4 The anatomy of the fetal heart](image-url)
There are some functional differences between the fetal and the adult heart. After birth, the left ventricle pumps blood to the body and the right ventricle pumps the blood to the lungs for acquiring oxygen. This cycle is not followed for the fetus. For fetus, the oxygen is supplied by the placenta. Therefore the blood is no longer pumped to the lungs for this purpose. Instead, both the ventricles pump the blood throughout the body (including the lungs).

There are two shunts, namely the foramen ovale and the ductus arteriosus for pumping the blood into the ventricles. These shunts form the link in the outgoing vessels of both the ventricles. By this process, the blood enters the right atrium and to bypass the pulmonary circulation.

A similar kind of adaptation in the fetus is the ductus venosus. This ductus venosus is a vessel which makes the blood to bypass the liver. This vessel carries the blood with oxygen and nutrients from the umbilical cord, straight to the right side of the fetal heart. After birth, the foramen ovale begins to close with the first breaths. The ductus arteriosus begins to close partially in 10 to 15 hours after birth. It takes up to three weeks for complete closure. The ductus venosus also begins to close shortly after birth. This closure begins when the umbilical cord is cut and blood flow between the mother and the fetus stops. There are also few other minor changes in the physiology of the baby's heart and its circulatory system that take place within the first year after birth.

The heart is a muscular organ. This takes deoxygenated blood from various organs of the body through the veins. This deoxygenated blood is pumped through the arteries into the lungs for purification. The various parts of the heart and its functions are described below.

1.2.1 Heart wall
The position of the heart is maintained during its various activities by a layer called Pericardium. Pericardium is a fluid filled cavity which supports the heart. The pericardium segregates a serous fluid. This fluid aids in avoiding the friction between the heart and its surrounding organs. The layer of pericardium that covers the outside of the heart is known as visceral layer or Epicardium. This layer protects the outside wall of the heart.

A thick middle layer of the heart is known as Myocardium, and it plays a vital role in the pumping of blood. A thin lining inside the heart is known as
Endocardium. This lining prevents sticking of blood inside the heart. The layer of heart which forms a sac around the pericardial cavity is known as parietal layer. All these layers together protect the heart from various physical external shocks.

1.2.2 Chambers of Heart

There are four chambers in the heart. They are

- Right atrium
- Left atrium
- Right Ventricle
- Left Ventricle

The atrium sucks the impure blood from various organs of the body and it makes it to flow through the veins into heart. The walls of atria are thin and less muscular compared to the ventricles. These ventricles are connected to the arteries for pumping out the pure blood from the heart. There are two major valves present in the heart. These valves are called as atrioventricular (AV) valves and semilunar valves. These valves aid in avoiding the reversal flow of blood. The valve placed on the right side of the heart is known as tricuspid valve, and the one which is placed at the left is called bicuspid valve. One more valve known as chordate tendineae is attached to the ventricle side. This valve avoids the backward folding of AV valves.

Another valve which is smaller than the AV valve called semilunar valve. The semilunar valve is used to carry out the blood from the heart to various organs of the body. The semilunar valve which is placed on the right side of the valve is called pulmonary valve, and the one which is placed on the left is known as the aortic valve.

The sinoatrial (SA) node of the heart acts as the pacemaker of the heart. The generated signal is transferred through the atrioventricular (AV) node. The AV node passes into the interatrial septum and the interventricular septum. The node then splits in the interventricular septum as right and left branches as many purkinje fibers. These fibers stimulate the muscle cells and supports in the pumping of blood out from the heart.
1.3 ELECTRICAL ACTIVITY OF THE FETAL HEART

Though the mechanical function of the fetal heart differs from an adult heart, its beat-to-beat electrical activity is rather similar. The wave-like pumping action of the heart is controlled by a network of neural fibers that are distributed throughout the myocardium. These neural fibers coordinate with the regular contraction and relaxation of the heart. The myocardial stimulation starts from the SA-node. This SA node acts as the natural pacemaker for the heart.

The SA-node is a cluster of cells. These cells are located in the upper-right posterior wall of the right atrium. The function of these cells is to send the electrical impulse that triggers each heartbeat. This impulse further stimulates the second cluster of cells, namely the AV-node. This AV node is situated in the lower posterior wall of the right atrium. After the AV-node, the depolarization front enters the bundle of HIS, the left and the right bundles, and ends in the Purkinje fibers, depolarizing the ventricular muscles in their way.

The process of contraction of myocardium is known as the depolarization cycle or systole. It is then followed by the repolarization cycle of diastole. During this, the myocardium relaxes and becomes ready for the next activation. A complete cardiac cycle is depicted in Fig.1.5.

![Fig.1.5. The activation cycle of the fetal heart](image)

The functions of heart chambers can be categorized as systole and diastole. The contraction of the muscles is known as systole. During this cycle, the blood is pushed out of the chamber. Similarly, the relaxation of the muscles is known as diastole. During diastole, blood fills the chambers of the heart.
1.4 CARDIAC CYCLES
The cardiac cycle can be categorized into three phases. They are
- Atrial systole
- Ventricular systole
- Relaxation

During the atrial systole, the AV valves get opened, and the semilunar valves get closed. The contraction of the atria occurs for pushing blood into ventricles. The ventricles are in diastole during this phase. Following the atrial systole, ventricular systole occurs. The AV valves get closed and the semilunar vale gets opened. Contraction of ventricle occurs to push the blood aorta and the pulmonary trunk. The next phase to the atrial systole is the relaxation phase. During this phase, the semilunar valves get closed, and the blood pours into the heart from the veins. Repolarization of cardiac muscles occurs and makes the heart preparatory for the next cycle of repolarization and contraction.

1.5 ECG WAVE DESCRIPTION
The ECG waveform consists of waves, intervals and segments. The waves are labeled by the letters P, Q, R, S and T. The duration of time between the different waves is called segments. For example, the duration between S and T waves is known as S-T segment. The entire ventricular depolarization is indicated by these segments. The waves and the segments on a time interval represent the time for ventricular depolarization and repolarization. This is described in Fig.1.6.

Fig.1.6 ECG waveform Description
All the parameters from the ECG waves, intervals and segments are needed for the diagnosis of CVD’s. In an ECG, P wave indicates the depolarization of atrial myocardium. It denotes the start of atrial contractions that pump the blood to the ventricle. The time duration of electrical impulse to travel between sinus node to the AV node is called PR-interval. During the ventricular depolarization, the blood is pumped to the lungs and to the other parts of the body. The ventricular depolarization is indicated by the QRS wave.

The S-T segment when it is similar to the QRS wave indicates the early part of ventricular depolarization. This segment aids in the diagnosis of ventricular ischemia. This segment can be either prolonged or compressed. The repolarization of the ventricular myocardium is represented by the T wave. The time duration of this wave is longer than depolarization time and is also slightly asymmetrical. The time interval from the beginning of QRS complex to the end of T wave is called Q-T interval. The time duration of this wave is 0.2 to 0.4 seconds which represents the time for both ventricular depolarization and repolarization. This interval depends on gender of the patient and heart rate.

1.6 VARIOUS FETAL HEART DISORDERS
The various fetal heart disorders are explained in the following sections

1.6.1 Atrial Fibrillation
One kind of irregular heartbeat is known as Atrial Fibrillation. This type of disorder can lead to blood clots, stroke, heart failure and other heart related disorders. Generally, the heart contracts and relaxes at some regular intervals. During atrial fibrillation, the upper chambers of the heartbeat at irregular intervals than beating effectively to move the blood into the ventricles.

1.6.2 First Degree AV Block
The prolongation of PR-interval on an ECG for more than 200msec is called first degree atra ventricular block. Generally, the PR-interval is measured from the starting of P wave to the beginning of QRS complex. This interval should be between 180 to 200msec for adult subjects. When this interval has crossed more than 300msec, it is considered as first degree AV block. In this block, every atrial pulse is transmitted to the ventricles resulting in regular ventricular rate.
1.6.3 Wolff-Parkinson-White Syndrome
It is the condition of additional pathway in the heart. Generally, the electric pulses in the heart flow through certain paths. For the subjects with Wolff-Parkinson-White Syndrome, the heart walls will have an additional pathway for the flow of electric pulses. This will result in faster heartbeat rate than normal. So, these subjects will have extra heartbeats than the normal subjects in the given time period.

1.6.4 Idioventricular Rhythm
Generally, the pacemaker of the heart triggers each heartbeat in the SA node. These signals will then pass into the AV node. If the ventricle does not receive any signals from the SA node or AV node, the ventricular myocardium itself becomes the pacemaker rhythm. These ventricular signals are transmitted cell-to-cell between cardiomyocytes and not by the conduction system, creating wide QRS complex (>0.12 sec). The rate is usually 20-40 bpm. If the rate is greater than 40 bpm, it is called accelerated idioventricular rhythm. The rate of 20-40 is the "intrinsic automaticity" of the ventricular myocardium.

1.6.5 Ventricular Tachycardia
Ventricular Tachycardia is a rapid heartbeat rate that starts from the lower chambers of the heart. A person with this disorder will have more than 100 beats per minute with a minimum of 3 irregular beats in a row. This condition generally develops as an early or late complication of a heart attack. This is also caused due to

- Anti-arrhythmic drugs (used to treat an abnormal heart rhythm)
- Changes in blood chemistry (such as a low potassium level)
- Changes in pH (acid-base)
- Lack of enough oxygen

1.7 THESIS OUTLINE
The introduction about development of and structure of heart in fetus, the description of ECG waveforms and the various kinds of disorders that are associated with the fetal heart will be the core of the discussions carried out in the chapters of this thesis. The structure of the thesis is organized as follows.
Chapter 1 discusses the introduction of fetal heart development and the deviations in the fetal Electrocardiogram. It also discusses various fetal heart disorders.

Chapter 2 discusses the literature survey made on the topics relevant to the development of this algorithm. The survey is carried out under the noise removal from ECG signals, separation of fetal ECG signal from the maternal components and on the various methodologies proposed by the researchers for diagnosing the fetal heart disorders.

Chapter 3 discusses the various noise removal and fetal ECG separation methods followed in this work. This phase of work is carried out using the conventional technique, and a few innovative techniques are also adopted for noise removal and fetal ECG separation.

Chapter 4 discusses the feature extraction and classification algorithms used in this work for diagnosis of various fetal heart disorders. Morphological feature extraction technique is employed in this phase of work. The classification algorithms such as Feed Forward Neural Network (FFNN), Multi-class Support Vector Machine, Naive Bayes Classification with normal distribution, Naive Bayes classification with Multivariate distribution, Naive Bayes classification with Multinomial distribution and Hybrid Distribution-based Naive Bayes (HDNB) Classification algorithms are used for classification of the extracted features.

The results and discussions are carried out in Chapter 5. A comparative study is made with the results obtained in each phase of the work with those of the existing works. The various advantages and disadvantages of this proposed algorithm are analyzed in this chapter.

The conclusion of this research work is presented in Chapter 6, and the future enhancements that can be made with this algorithm are discussed in Chapter 7.