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Application of sound analysis in the diagnosis of heart and respiratory diseases

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Abstract: In this article, we will introduce the applications of sound processing in heart and respiratory diseases. Sound waves are longitudinal mechanical waves. This wave physics can propagate in solids, liquids and gases. The material particles that transmit this wave physics oscillate in the direction of the wave propagation. Longitudinal Biomechanical waves occur in a wide range of frequencies. And meanwhile, the physical frequencies of sound waves are in the range that can stimulate the human ear and brain to hear. This range is approximately 20 Hz to about 20,000 Hz and is called audible range. Longitudinal mechanical waves whose frequency is below of the audible range are called subsonic waves, and those whose frequency is above of this range are called ultrasonic waves.Whenever we hit an object, the layers of air move between our hand and the object, and if these movements are more than 16 times per second, a sound is created. In order to better study the role of speech organs in the production of Persian language phonemes, it first seems necessary to provide brief information on how to produce phoneme or sound. Phoneme or sound is produced by the vibration of air molecules. Vibration means the movement of air molecules from their place in a certain direction and their return to their original place. This physical phenomenon is called a wave.

Keyword : Sound Processing, Heart and respiratory system, Vibration, Ultrasonic Wave

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1- Introduction

Respiratory sound analysis provides researchers and physicians with a wealth of information on the physiology and pathology of the respiratory system and airways. For example, lung sound analysis can be used to diagnose pulmonary abnormalities such as pleurisy, pneumatorax, bronchial astluna, emphysema, and pneumatorax. Tracheal sound can also be used to diagnose airway obstruction and estimate respiratory flow. When recording breathing sounds from the chest, in addition to these sounds, heart sounds are also received. Because when listening to heart sounds, people can be asked not to breathe for a short time, the effect of breathing sounds on heart sounds can be greatly reduced. But the constant presence of heart sounds that are received with respiratory sounds makes it difficult to analyze respiratory sounds.

The main power of heart sounds is in frequencies below 150 HZ, which interferes with the low-frequency components of respiratory sounds and changes the properties of respiratory sounds in both time and frequency domains. Because the maximum power of lung and trachea sounds is in the frequency range below 250 Hz and below 800 Hz, respectively, and the recorded power of lung sound is less than the power of trachea sound. The effect of heart sounds is greater on the sound of the lungs. In addition, with the increase of respiratory flow, the power of respiratory sounds increases and then decreases the effect of hearts sounds on these sounds. For this reason, in most studies, attempts have been made to eliminate or reduce the effect of heart sounds from lung sounds in low (7.5 ml / s / kg) and medium (15 ml / s / kg) flows.

The use of high-pass filters with a cut-off frequency of 70-100 Hz is the simplest way to reduce heart sound, but with this method, in addition to heart sound, most of the respiratory sounds, especially lung sounds, are eliminated. For this reason, various methods have been proposed to reduce heart sounds from lung sound, including the use of adaptive filters, removal of parts with heart sounds in lung sound in the time-frequency domain, and signal reconstruction using interpolation-based filters, violet-based filters and removal of parts with heart sounds from violet signal coefficients and reconstruction of these coefficients using AR models.

The first step in most of the methods offered to reduce heart sounds is to diagnosis of parts with heart sound in lung sound. Due to the fact that heart sounds are more powerful than lung sounds, various methods based on thresholding of temporal and frequency characteristics of

lung sound have been proposed to detect parts with heart sound in lung sound. The most important methods presented that can be mentioned are lung sound threshold in the time domain, local variance of lung sound, average local power of lung sound in the frequency range of 20-40 Hz, fractal variance dimension and fractal variance and multiply the violet coefficients of the lung sound by adjacent surfaces. High differentiation error, sensitivity to parameters and semi-automaticity are the most important problems of most of the proposed methods for separating parts with heart sound in lung sound.

Analysis of the relationship between flow and respiratory sounds is another field that has attracted the attention of many researchers. Respiratory flow is usually measured directly (using nasal cannullaes or pneumalachographs attached to pressure or temperature sensors) and indirectly (measuring changes in chest volume). Many flow measurement methods are ineffective for analyzing swallowing sounds and nutrition-related research. Nor can these methods be used to measure the flow of children, patients with neurological abnormalities, and patients with physical abnormalities or patients suffering from poor posture control. For this reason, various methods have been proposed to estimate the flow from respiratory sounds, especially tracheal sounds.

The function of the respiratory system is to supply oxygen to the tissues and remove excess carbon dioxide from the blood, most of which is exchanged in the lungs. During inhalation, air is pumped into the lungs through the airways, and after pulmonary ventilation and as during exhalation, air containing carbon dioxide is directed out of the body. The airways are divided into upper and lower airways from above the larynx. The upper part consists of the nose, sinuses, throat and part of the oral canal, and the lower part consists of the larynx, trachea, bronchial tubes, and lungs. Figure 3.1 shows the structure of the respiratory system.

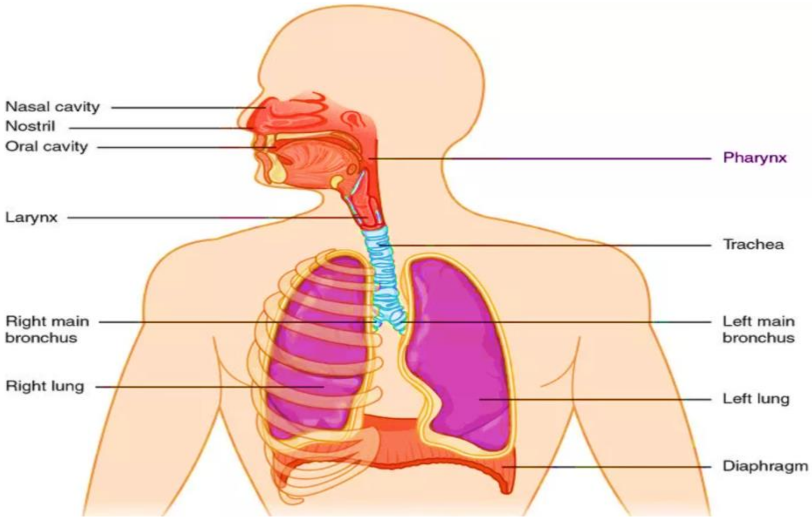

Figure 1: Respiratory system

The purpose of this chapter is to provide a brief description of the respiratory system, respiratory sounds and how they are recorded, and the temporal and frequency characteristics of respiratory sounds. In the following, section 3-2 gives a brief explanation of how to record respiratory sounds, and section 3-3 introduces lung sound. A summary of the characteristics of tracheal sounds is given in Section 3-4. Finally, sections 3-5 are devoted to heart sounds.

2- Chest breathing sound data acquisition

One of the simplest non-invasive methods of examining the respiratory system is to listen to respiratory sounds. Using a stethoscope is the most common way to receive respiratory sounds on the surface of the skin through the ear. Because the properties of stethoscopes depend on frequency, these instruments do not have an ideal function for transmitting respiratory sounds. In fact, to make them easier to use in clinical cases, they weaken and amplify sounds selectively and within the clinically optimal frequency range. Because heart sounds have a component in the frequency range below 100 HZ and are not easily heard by the ear in this frequency range, stethoscopes amplify frequencies below 112 Hz.

Two types of sensors are commonly used to record breathing sounds: an electret microphone with a coupling chamber and an accelerometer. The use of small electret microphones is a common way of recording speech and music. If these microphones are coupled to the skin surface using a chamber, they can record breathing sounds with high sensitivity [3]. Studies have shown that structures that use smaller conical chambers are more sensitive to high frequencies of lung sounds, although the sensitivity of these sensors to ambient disturbances is also high [4,5] The use of contact accelerometers is another common method of recording sounds is respiratory. These accelerometers can be calibrated using reference oscillations. Accelerometers are more expensive and more fragile than electret microphones, and may amplify at frequencies close to the desired frequencies of lung sound analysis.

In some studies, new tools have been proposed to improve the reception and display of sounds and respiratory flow [7, 6]. The performance of different sensors in [8, 9] is also compared. Various disturbances are heard when breathing sounds are recorded. These disturbances can be divided into two main groups:

1) Environmental disturbances: such as ventilation system, computer, fluorescent lamps, speech, music, ...

2) Disorders caused by body parts:

(a) Respiratory disturbances: such as chest movement, respiratory muscle noise, and respiratory flow in instruments

(b) Disorders that are unrelated to breathing: such as heart murmur, swallowing murmur, vascular murmur, intestinal murmur, etc.

When recording breathing sounds, the ambient noise level should be less than 45dB. The best way to eliminate environmental clutter is to use an audio compartment. Using this method, environmental disturbances can be reduced by a maximum of 30 dB. [10]. In some papers, methods based on wavelet pack [11], adaptive filters [12], and reduction of the perturbation power spectrum from the main signal power spectrum [10] have been proposed to eliminate environmental perturbations.

Another area of research in the field of respiratory sound, have been studied respiratory muscle sound analysis and VMG (Electroinyograph) EMG (vibromyography) of healthy people with COPD (chromic obstructive pulmonary disease) and how they change in has been compared these two groups[15, 13, 14]. The static and statistical changes of electrical and mechanical signals of the respiratory muscles have also been investigated [16].

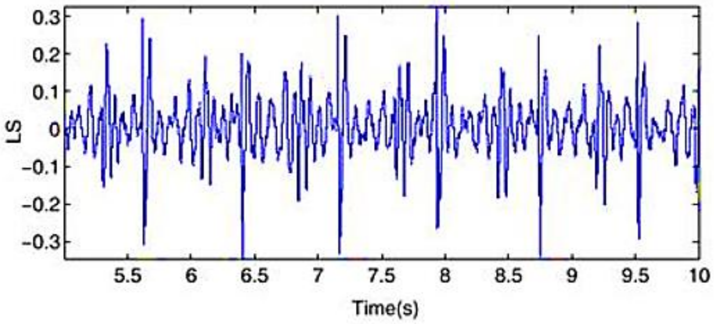

Figure 2: The lung sound of a normal person

3- Lung sound

The title lung sound did not have a clear meaning for a long time. In 1985, at the 10th meeting of the World Association of Lung Sounds[1] fine crackles, coarsc crackles, wheezing, rhonchi, and breathing sounds heard from the surface of the wall or inside the chest were considered lung sounds [3, 17].

In this project, lung sound is the sound of breathing that is recorded from the surface of a normal person's chest. Lung sound is produced by the vibration of air in parts of the lungs and bronchies. In smaller bronchies, the air velocity is less than necessary for vibration. For this reason, the airflow in the smaller airways does not produce sound.

The lungs and chest act as a low-pass filter in the path of sounds produced to the surface of the skin. For this reason, most of the energy of lung sound recorded from the skin surface is concentrated at frequencies below 250-200 Hz [19, 18] However, if more sensitive microphones are used, lung sound can be received up to frequencies around to 100 H2 [3]. In some studies, the amount of air flow changes [25, 24, 23]. Lung volume

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[1] ILSS International lung sounds socicly

change is another factor that can change the intensity of lung sound. Studies show that lung volume has less effect on lung sound compared to flow intensity [27, 26].

The intensity of the lung sound also varies in different parts of the chest. In recent decades, many researchers have researched the reasons and methods of these changes [3]. Using radioactive xenon lung scanning [28] and radionuclide ling scanning [31, 30, 29] methods, it has been shown that the intensity of lung sound is directly related to the amount of ventilation. Therefore, lung sounds are louder in places where pulmonary ventilation is better.

Figure 3.3 shows a sample of a normal person's lung sound (80s was taken at the time of sampling) along with the corresponding spectrogram and flow. In this form, the positive values of the flow represent the tail and the negative values represent the exhalation. Lung sound spectrogram shows that as the flow increases, the sound pawer of the lungs also increases. Also, according to the spectrogram shown, it can be seen that the main power of lung sound is in the frequencies below 300-250 Hz. The power density spectrum of the lung sound was calculated using the Welsh Periodogram With windows 100 Ins long and 50% overlap between adjacent windows. According to the density spectrum of lung sound, which is shown in Figure 3-4, A, it can be seen that the obtained spectrum is descending without a peak.

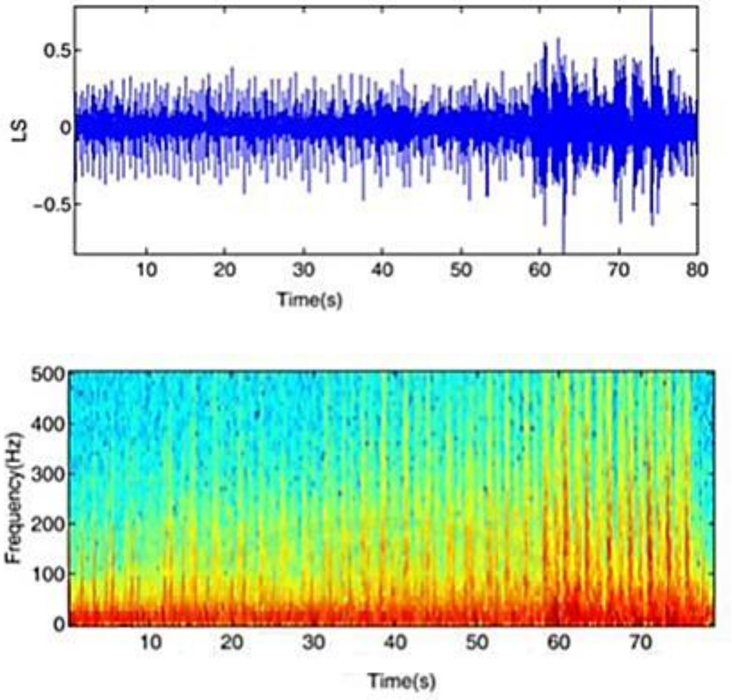


Figure 3: A: A sample of a normal person's lung sound, B: Spectrogram

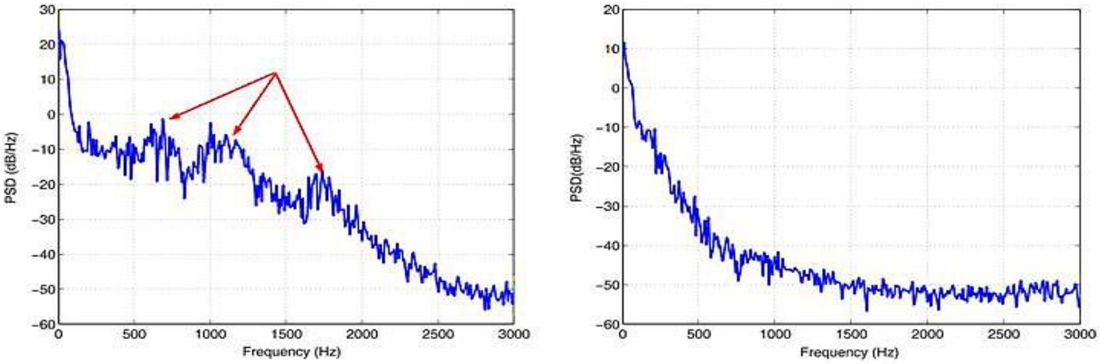


Figure 4: Density of the power spectrum of sounds A: Lung and B: Trachea.

4-Trachea sound

Tracheal sound is very important in the analysis of respiratory sounds and is the most important reference for estimating flow and diagnosing obstruction in the respiratory tract. The sound of the trachea is caused by the vibration of the air in the upper part of the airways. These vibrations can be received after reaching the surface of the skin in the suprasterual notchd or lateral neck. Because the distance between the sound source in the trachea and the location of the sensor is less than in the lungs, there is not much tissue in the path of these sounds. The sound of the trachea is less filtered and purer than the sound of the lungs. It is also easier to place the sensor on the trachea and record the signal than to record the sound of the lungs, and there are no disturbances caused by the presence of hair on the surface of the chest skin in the trachea. Figure 3-5 shows a few seconds of a normal person's trachea sound. The sound of the trachea is louder than the sound of the lungs and has a wider range of frequencies, ranging from frequencies less than 100 HZ to frequencies around 1500 HZ. Of course, most of the power of the tracheal sound is in the frequencies below 850-800 Hz [19, 18, 3]. Recent studies have shown that, unlike lung sound, which has a non-peak spectrum, the spectrum of the trachea has a peak. This indicates that intensification in the respiratory tract is the source of tracheal sound production [19, 3].

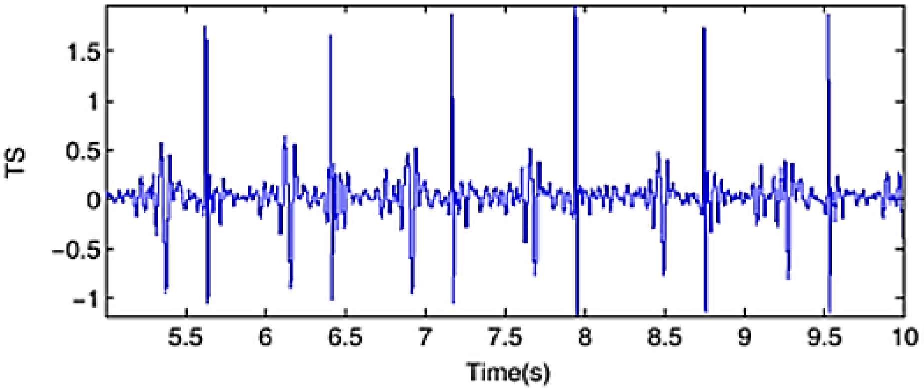


Figure 5: The sound of a normal person's trachea

Figure 6 shows the sound of the trachea (data collection time was 88s), the corresponding spectrogram and flow. It should be noted that the lung and tracheal sounds shown in Figures 2, 5, and 6 were recorded simultaneously are related to one person. The trachea sound can be seen accurately in the spectrogram. The main power of the trachea sound is in the frequencies below 1200 HZ, which is in a wider frequency range. Also, the sound of the trachea is higher than that of the lungs, and the sound of the trachea increases significantly with increasing flow.

The power spectrum density of the trachea is calculated similar to the density spectrum of the lung sound using the Welsh periodogram with windows 100 ms in length and 50% homogeneity between adjacent windows (Figure 4-b). Depending on the density of the tracheal sound spectrum, it can be seen that the obtained spectrum has three peaks in the frequencies of about 700 Hz, 1100 Hz and 1750 Hz, which indicates the presence of amplification in the tracheal sound.

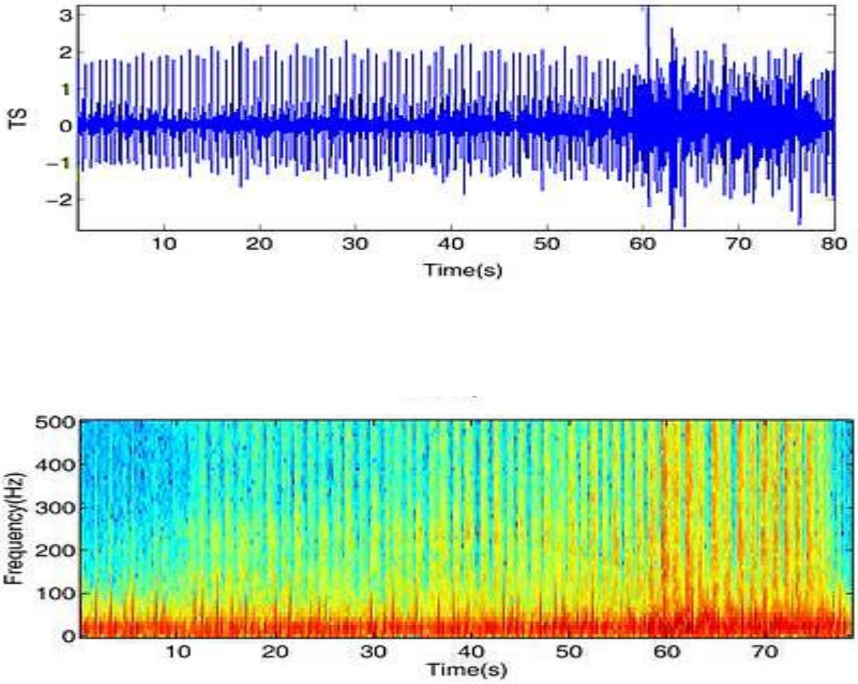


Figure 6: A: An example of a normal person's trachea sound, B: Spectrogram

5-Heart sounds

A schematic of the heart and how it relates to the lungs is shown in Figure 7. If we listen to normal heart sounds using a stethoscope, a lob-like sound is heard in each heart cycle. The sound of "lobe", is the first sound of the heart, which heard as the atrioventricular valves close at the beginning of the systole, and the "dub" sound is the second sound of the heart, which heard as the aortic and pulmonary valves close and heard at the end of the systole.

At the beginning of the systole, the contraction of the ventricles causes blood to flow to the atrioventricular valves (mitral and tricuspid) and these valves bulge toward the atria until the tendon cords are suddenly stimulated and stop. The elasticity of the valves and tendons leads the blood back into the ventricles, causing the ventricular wall, valves, and intraventricular blood to vibrate. These vibrations, which are transmitted through the tissues to the surface of the chest, produce the first sound of the heart. The first sound of the heart is about 0.14s is heard [32]

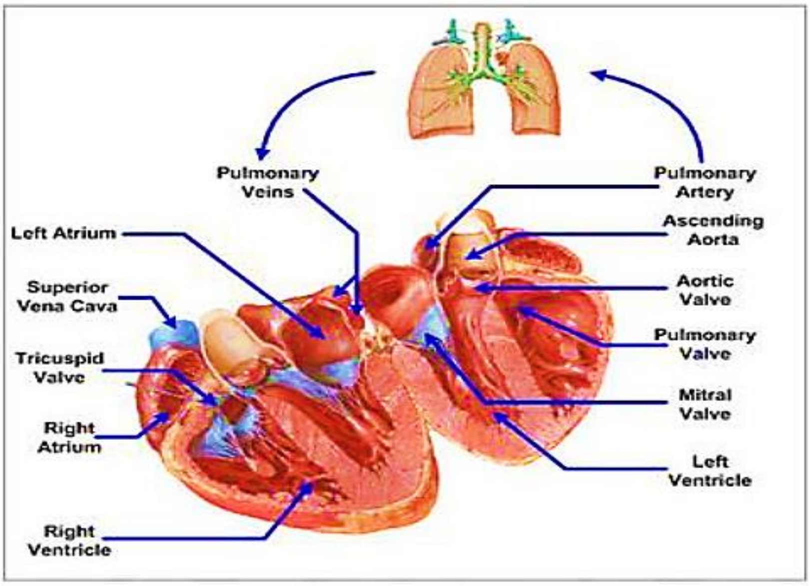


Figure 7: Schematic of the heart and how it relates to the lungs

The second sound of the heart is heard at the end of the systole, when the crescent valves between the ventricles and the aorta and lung arteries close. When these valves close, they bulge toward the ventricles, and their elasticity sends blood back into the arteries. The vibrations resulting from this reciprocating movement of blood are propagated in the wall and along the arteries, which can be heard after reaching the skin surface with the help of a stethoscope. The second sound of the heart is about 0.11 s. 0 continues [32].

In addition to the first and second heart sounds, two other sounds are produced in one heart work cycle. With the onset of the middle third of diastole and the movement of blood from the atria into the ventricles, the blood inside the ventricles vibrates. These vibrations produce a very weak sound called the third sound of the heart.

The atrial sound of the heart (the fourth sound of the heart) occurs when the atria contract and, like the third sound of the heart, is caused by the movement of blood from the atria to the ventricles. The frequencies of the third and fourth sounds of the heart are usually so low that they cannot be heard by the ear and can only be recorded with the help of a phonocardiogram.

Most of the energy of the first and second sounds of the heart is in the HZ200-150 frequency range [35, 34, 33], which interferes with the low-frequency components of respiratory sounds. Heart sounds change the characteristics of respiratory sounds (especially lung sounds) in both time and frequency domains [36], as shown in Figure 8. This figure shows an example of a lung sound signal with a spectrogram. As can be seen, in the realm of time and in the moments when there is a heartbeat, the amplitude of the heartbeat is greater than that of the lungs, and the dominant signal is the heartbeat.

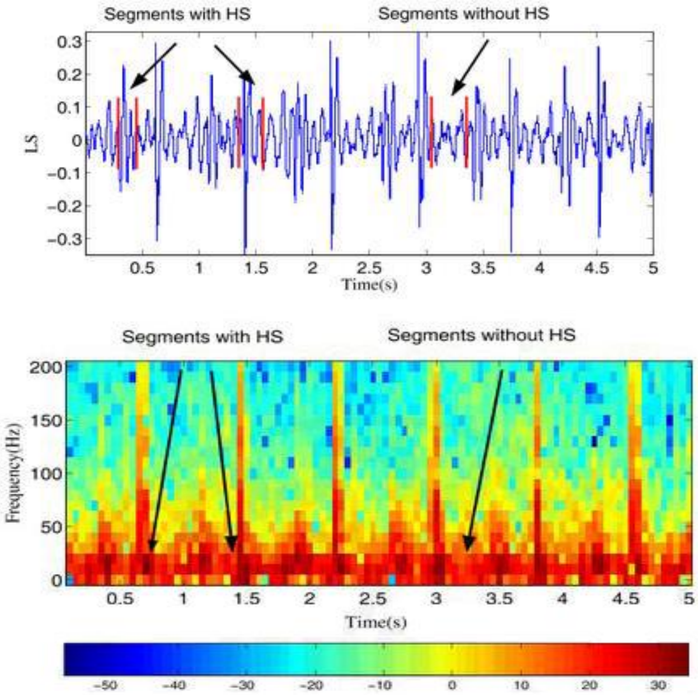


Figure 8: Effect of heart sound on lung sound in time and frequency domain, a: lung sound in time domain and b: corresponding spectrogram.

5-1-PCG signal

Electrocardiogram (ECG) signal recording, which is caused by the electrical activity of the heart, has been considered as a non-invasive and at the same time safe and fast method for diagnosing the function of the heart for many years. The phonocardiogram (PCG) signal also contains information about the function of the heart, which is due to its mechanical vibrations. Cardiac sounds are made from the vibrations of the heart valves, as well as the murmurs, so by processing the PCG signal, useful information can be obtained about the condition of the valves or possible holes in the wall between the ventricles and the atria.

Critical characteristics of the cardiovascular system can also be obtained using other recorded signals, of which pressure signals are of particular importance. Extraction of cardiac signals and their analysis has been considered by cardiologists for many years. The main problem in processing these signals is the extraction of vital components, the detection of abnormal rhythms and the improvement of the correct efficiency of diagnoses. The importance of the problem form and the type of problems in processing such signals have caused that in addition to physicians, medical engineers and signal processing specialists are also interested in solving it. The importance of diagnostic and therapeutic applications of the problem, especially for the heart signal, is such that today, after nearly a century of its design in engineering circles, this issue is still part of the research in signal processing, and with the introduction of new signal recording technologies and the introduction of new processing techniques, we see the use of these tools and methods to improve the quality of vital indicators extracted from cardiac signals.

The stethoscope is a well-known tool for the medical profession, and physicians have long relied on it to diagnose heart disease. New advances in cardiac imaging have changed this view. Echocardiography and

Magnetic Resonance Imaging (MRI) to diagnose heart problems have completely overtaken traditional methods of listening to Auscultation (heart sounds). Today, the main use of a stethoscope is as a primary test to ensure the health of heart function, not to diagnose disease. People who do not have normal heart sounds are sent to a cardiology clinic for further diagnosis and examination.

In today's world where medical technology is moving in an economical and cost-effective way to diagnose and maintain human health, adding the ability to detect abnormal sounds and providing information about how the heart works is one of the things that can increase the decision-making power to diagnose complications. In recent years, many efforts have been made to diagnose the complication and its type only by listening and recording heart sounds. Currently, most of the work done is in the field of analysis of heart signals.

The most common methods available for filtering and processing cardiac signals cover a wide range, such as domain conversion methods, especially time-frequency transformations such as violet conversion to statistical methods, methods based on parametric models and methods based on random assumption or chaotic assumption of heart signal. But in most cardiac signal processing methods, the morphological nature of the signal is underestimated and they only seek to find features that make a significant difference between different groups of cardiac signals and thus provide a vital indicator to aid the diagnosis process. In recent years, models have been proposed to describe the behavior of the heart and its output signals, which fall into two general groups: statistical models and mathematical models. Statistical models (such as the self-recursive model) look at the heart and its signals from a random perspective. While in mathematical models the behavior of the heart and its signals are described explicitly and definitively with mathematical relations. Since the heart has quasi-certainty and quasi-intermittent behavior, the appropriate model to describe it should be a combination of statistical and mathematical models.

The only model proposed to describe the behavior of the heart, the model proposed by McSherry et al [1] for the ECG signal. The proper description that this model gives of the ECG signal makes it possible to perform various processes on this signal, and many advances have been made in this field.

In fact, processing based on the ECG signal model directly began when Sameni et al. [2] used this dynamic model in a generalized Kalman filter structure, and by estimating the clean ECG signal from its noise version, the noise removal process Did well for this signal. Then, Sayadi et al., Assuming a self-recurring dynamics for the ECG signal dynamic model parameters, considered them as generalized variables of a Kalman filter, and by estimating these parameters, processes such as compression and noise removal [3], performed zoning [4], and anomaly detection [5] for the ECG signal. This chapter describes the structure of the heart and the origin of electrical signals and heart sounds.

5-2-Anatomy of the heart

The heart is made up of four chambers: the left and right Atrium, and the left and right Ventricles. The left and right sides of the heart are separated by Septum (muscle walls). Circulatory cycle includes sequence: limb blood flow, Vena Cava (the great vein), the right atrium, the right ventricle, Pulmonary Artery, the lungs, Pulmonary Veins, the left atrium, the left ventricle, the aorta, and the bloodstream of the organs, as shown in Figure 3-9. To create this flow cycle, the heart muscle expands and contracts regularly to keep the blood flowing in its proper pattern. In effect, the heart acts like a blood pump, pumping blood from the organs to the lungs, where it injects oxygen and releases carbon dioxide. The heart then pumps blood from the lungs back to the organs, and this cycle is repeated over and over again. Pump-like action of the heart consists of two stages: Systole and Diastole. The diastolic phase is sometimes called the resting phase. There are four valves in the heart that prevent blood from flowing backwards: Mitral valve, Tricuspid valve, Aortic valve, and pulmonary valve.

The mitral and tricuspid valves are located between the atria and the ventricles and prevent blood from returning to the atria during ventricular contraction. The aortic and pulmonary valves are also located at the beginning of the aortic and pulmonary arteries and prevent blood from returning to the ventricles when the ventricles are at rest. Figure 3-10 shows the position of these valves in systole and diastole. Blood from the organs enters the right atrium through the great vein, and blood from the lungs enters the left atrium through the pulmonary vein.

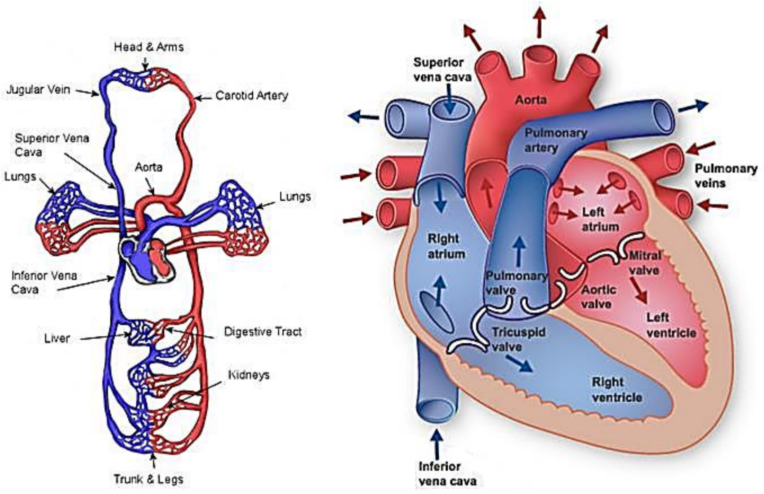


Figure 9: Anatomy of the heart and circulatory system; Red pathways: arteries, blue pathways: veins

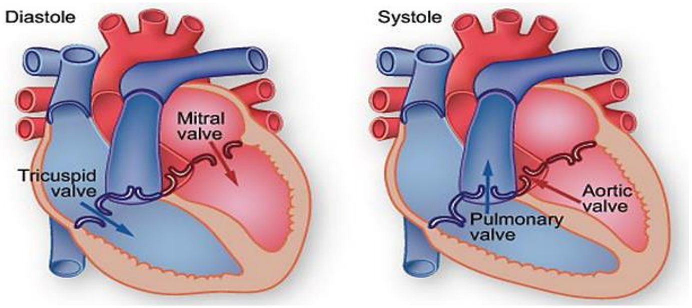


Figure 10: The position of the heart valves in the state of systole (right figure) and diastole

(left figure) [6].

In the diastolic phase, the atrioventricular valves (mitral and aortic) are open, and the blood from the atria enters the ventricles mainly (about 70%) passively and the rest (about 30%) actively and with atrial contraction. At this stage, the arterial valves are closed. In the next stage, which is ventricular contraction, the atrioventricular valves close due to the pressure difference between the ventricle and the atrium, and blood enters the aortic and pulmonary arteries through the arterial valves. At the end of the systole, the ventricles begin to expand, causing a rapid drop in pressure behind the arterial valves, at which point the valves close. This completes the circulatory cycle.

5-3- Electrical conduction system of the heart

As mentioned earlier, the heart acts like a muscle pump that pumps blood to the tissues and organs of the body. The heart, like all other pumps, needs an energy source to perform its function, which is supplied by an electrical conduction system built into the heart. In fact, this system produces electrical pulses (called action potentials) that pass through the heart muscle, stimulating them, constricting the heart and causing blood circulation. The heart's electrical conduction system consists of three main parts [8]:

1. Sinoatrial node (SA): This node is located above the right atrium and close to the upper vein and is known as the natural pacemaker. The SA node, as the fastest set of self-stimulating cells, automatically depolarizes itself and produces excitations in the form of electrical pulses at appropriate intervals of the body's activity that propagate along the atria and cause them to contract.

2. Atrial-ventricular (AV) node: This node is located in the wall between the two atria, and between the atria and the ventricles, and conducts electrical pulses from the atria to the ventricles. The AV node acts as a delay in the path of the pulses and therefore plays an important role in the electrical system of the heart. Because without this delay, the atria and ventricles will contract at the same time, and as a result, the transfer of blood from the atria to the ventricles will not be effective.

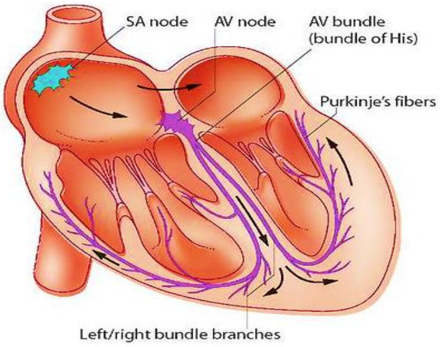
3. His-Purkinje system: This system is composed of a set of special cells of electrical conduction of the heart that transmit electrical pulses from the AV node to the ventricles and cause them to contract. The different parts of this system are:

(A) His bundle

(B) Left and right bundle branches

C) Purkinje,s fibers

Figure 11 shows the different parts of the heart's electrical conduction system.



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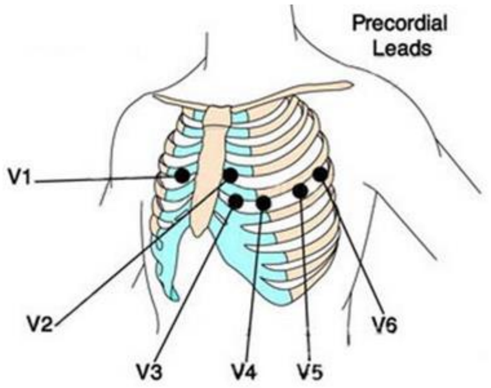

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Figure 13: Morphology and timing of action potentials in different areas of the heart

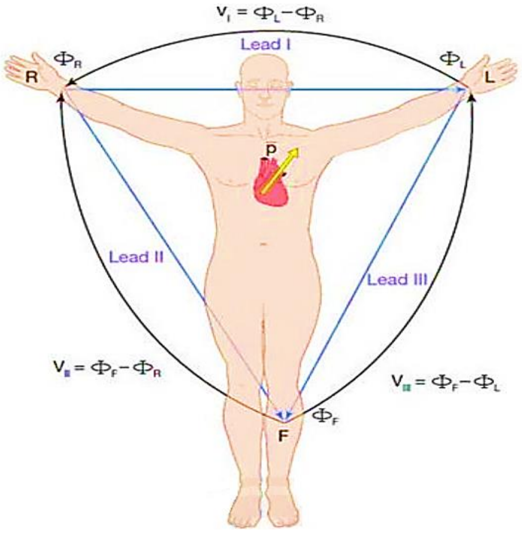

Figure 12: Location of electrocardiogram signal recording electrodes in Eindhoven method [10]

5-5 Application of sounds of hearts

Heart murmurs are mainly caused by vibrations due to pressure differences when the heart valves close. Normal opening of the heart valves is a relatively slow process and does not produce an audible sound. Heart sounds are relatively short and are determined by changes in loudness, pitch, and quality.

In the ventricular contraction phase, the left ventricle contracts slightly earlier than the right ventricle, leading to the closure of the mitral valve before the ventricular valve. In the evacuation phase, the left ventricle empties earlier than the right ventricle, causing the aortic valve to close shortly before the pulmonary valve. The first sound of the heart (SI) is due to the closure of the mitral valve (M1), followed by the Tricuspid valve (T1). In other words, S1 consists of two components, M1 and T1, the first component of which is more intense.

The second sound of the heart (S2) is caused by the closing of the aortic and pulmonary valves. The first component (A2) is due to the closure of the aortic valve, and the second component (P2) is due to the closure of the pulmonary valve shortly after the aortic valve.

The third sound (S3) occurs shortly after (A2) and is a low-frequency vibration that occurs during diastole due to the rapid filling of the ventricles. S3 is commonly heard in children, adolescents, and young adults. Hearing it after the age of 30 is considered an abnormal Ventricular gallop and a possible sign of abnormal heart function. But in some cases, the third voice is heard by the age of 40, especially in women [8].

The fourth sound (S4) is a low-frequency noise that is heard at the end of diastole, just before S1. S4 results from rapid ventricular filling during atrial contraction, which causes the left ventricular wall and mitral apparatus to vibrate. S4 is commonly heard in infants, children, and adults over the age of 50. A loud S4 sound, especially if accompanied by a jolt, is a sign of Pathology [8].

In addition, there may be another group of heart sounds, which are noise-like sounds called heart murmurs. These murmurs, which can be caused by both physiological and pathological factors, are caused by increased blood flow to the heart. High heart rate can be quite normal, especially in children, but it can also be caused by a narrowing of the bloodstream. Mormors are divided into two groups based on their location in the cardiac cycle: systolic and diastolic, the types of which are discussed below [13].

- Systolic murmurs: Systolic murmurs are divided into two categories, excretory systolic murmurs, and Pan-systolic Murmurs. Excretory systolic murmurs occur immediately after S1 and include:
- Aortic or Pulmonary Valve Stenosis: This excretory systolic murmur occurs temporarily between S1 and S2. Due to calcium deposits, these valves lose some of their softness and become weak. As a result, these valves do not open completely and block blood flow, leading to disturbed flow.) Appears. Pulmonary valve stenosis is similar to that of the aortic valve and manifests itself in the PCG signal; difference is that it is not symmetrical and its peak is closer to the end of the systole.

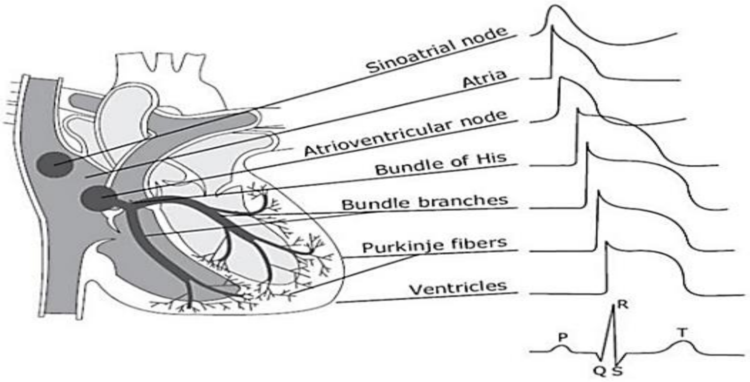

Figure 14: Morphology and timing of action potentials in different areas of the heart

5-5 Application of sounds of hearts

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- Mitral or Tricuspid Valve Insufficiency: When the ventricles contract, if these valves cannot withstand the pressure from the ventricles, an opening is made in them and blood returns to the atrium. The passage of blood through this hole creates a turbulent flow and causes the appearance of this murmur. The shape of this murmur is uniform in the PCG signal and extends from S1 to S2.

The second type of systolic murmurs that is, pancystolic murmurs occur in systole. These murmurs are as follows:

- Atrial Septal Defect: Due to the creation of a hole in the lower part of the walls separating the two chambers of the heart, a path is created between the two atria and causes murmurs.
- Ventricular Septal Defect: This complication is as acute as atrial septal defect: except that the defect is located at the bottom of the heart and between the two ventricles.

Diastolic murmurs: The types of diastolic murmurs are as follows:

- Mitral valve stenosis: As mentioned in the case of aortic valve stenosis, these valves become stiff and do not allow blood to flow completely and smoothly, and the flow becomes disturbed. As a result, it causes vibrations that are heard as diastolic murmurs. Mitral valve stenosis is much more common than tricuspid valve. This murmur occurs at the end of diastole and has a descending-ascending shape. In more severe cramps and hardships, its shape will be smooth and from S2 to S1.

- Aortic or Pulmonary Valve Insufficiency: These murmurs occur at the beginning of diastole, start at a high amplitude and gradually decrease, and have a downward pattern in PCG.
- Coronary Arterial Stenosis: Arterial duct stenosis causes turbulent flow that may produce audible vibrations at the beginning of diastole. However, most of this turbulence is not enough to make an audible sound.

The characteristics of different heart sounds as well as murmurs are given in Table 1.2.

Heart sounds, which are actually caused by different valves in the heart, are better heard in certain areas of the heart. These areas are called auditory areas, and the name of each area is affected by the heart valve, which produces sound corresponding to that area. These areas are shown in Figure 3-15 and are [8]:

- Aortic: Located in the area between the second ribs on the right side of the sternum
- Pulmonary: Located in the area between the second ribs on the left side of the sternum
- Mitral: Located near the coccyx and in the area between the fifth ribs on the left side of the sternum
- Tricuspid Valve: Located at the bottom of the chest and on the left side

It should be noted that these auditory areas, as shown in Figure 7.2, do not correspond to the actual location of the heart valves.

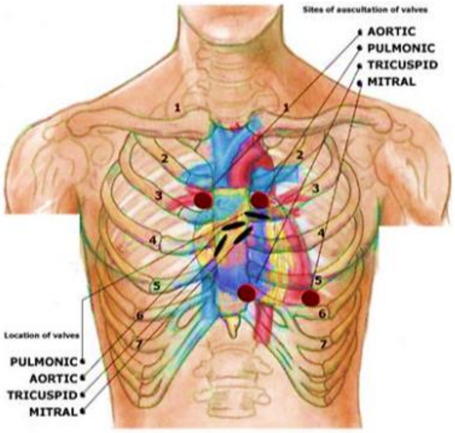

Figure 15: Different auditory regions of the heart sound (actual location of heart valves different from these locations)

As mentioned earlier, visual representations of the waveform associated with cardiac sounds are called phonocardiograms (PCGs), and the technique used to record these sound signals is called photocardiography. This technique provides a visual representation of cardiac sounds and thus allows the study of momentary dependencies between the mechanical activity of the heart and the sounds produced. Figure 3-16 shows an example of a simultaneous ECG and PCG signal. Figure 3-17 also shows the flow and blood pressure diagram of the left side of the heart along with its electromechanical activity.

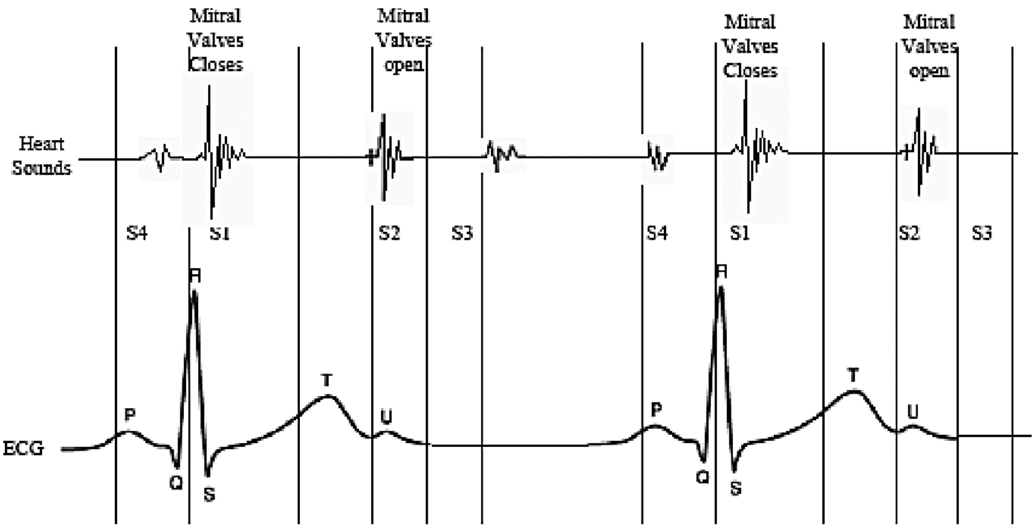

Figure 16: A sample of ECG and PCG signals recorded from a healthy person without murmurs

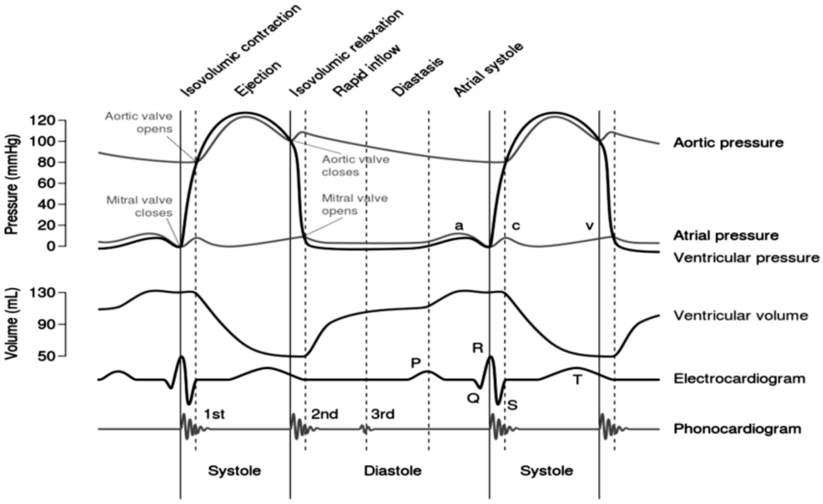

Figure 17: Diagram of pressure and flow in the left ventricle of the heart and how they relate to electronic (ECG) and mechanical (PCG) activity of the heart

The heart sound recording process involves a sequence of exchanged on signals: a sensor to convert vibrating sound into an electrical signal, a preamplifier to amplify the signal, a filter to prevent interference, and an analog-to-digital converter to convert the signal to Digital form [12].

Microphones and accelerometers are common choices for recording sound as a sensor. These sensors have a high frequency response that is suitable for the body's audio signals. A microphone is a sensor in contact with air that measures the pressure waves generated by the movement of the chest wall. Accelerometers, on the other hand, are contact sensors that directly measure the movement of the chest wall. Both sensors can be used to record body sounds. Also, due to the frequency content of the PCG signal, which is less than 1000 Hz (see Table 3-1), the appropriate sampling frequency for this signal is at least 2000 Hz. Today, new electron stethoscopes have made PCG signal recording much easier. These stethoscopes use sensors specifically designed for heart sounds.

Table 1: Characteristics of heart sounds and murmurs

Relative position	Sound	Tims	Frequency range
10 to 50 milliseconds after the R peak in the ECG signal	S1	100 to 160 milliseconds	10 to 140 Hz
280 to 360 milliseconds after the R peak in the ECG signal	S2	80 to 140 milliseconds	10 to 400 Hz
440 to 460 milliseconds after R peak on ECG signal or 120 to 180 milliseconds after aortic and pulmonary valve closure	S3	40 to 80 milliseconds	15 to 60 Hz
40 to 120 milliseconds after the start of the P wave in the ECG signal	S4	30 to 60 milliseconds	15to 45 Hz
Systolic murmurs	Between S1 and S2	Variable	60 to 150 Hz
Diastolic murmurs	Between S2 and S1	Variable	10 to 60 Hz
Aortic or pulmonary valve insufficiency	Between S2 and S1	Variable	150 to 1000 Hz

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