ANALYSIS OF TRACHEAL SOUNDS ACQUIRED FROM PATIENTS WITH LUNG CANCER

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ABSTRACT

In this study an attempt has been made to determine the quantitative characteristics of the sounds which are caused by the presence of a tumor in the bronchial tree. For this purpose, a special instrumentation system consisting of a PC equipped with an A/D converter, a water-sealed spirometer and amplifiers for tracheal sounds, environmental sounds and a flow potentiometer have been used. Using this system the tracheal sounds of the subject, environmental noise and the flow rate of the breathing of the subject were recorded simultaneously.

Although vocal cords and oral cavity produce interfering sound signals, trachea was selected as the precise location to acquire the diagnostic lung sounds. This is because

- the malign tumors of the lung are mostly found in the large bronchi,
- respiratory sounds measured at the trachea undergo very little filtering, and
- characteristics of the tracheal lung sounds do not depend on subject's morphology to a great extend.

The sound signals were filtered using high pass and low pass filters having cut-off frequencies at 100 Hz and 2500 Hz, respectively. A sampling frequency of 5 kHz was selected. 1024 data points were extracted from the proper inspiration and expiration phases of each subject. Using a Hanning window and DFFT, the Welch periodogram was estimated.

Because patients with lung cancer and chronic obstructive pulmonary disease (COPD) are usually heavy smokers, they have similar symptoms. Therefore, COPD patients were also included to this study.

Regions of diagnostic significance in the frequency spectra of subjects studied have been identified and confirmed using the statistical t-test. The area of such a region in the frequency spectra above 633.8 Hz in the inspiration phase of patients with lung cancer and COPD was determined as a distinctive feature with a possibility of less than 18 % error.

ÖZET

Bu çalışmada, bronş ağacındaki tümörün neden olduğu seslerin nicelik özellikleri saptanmaya çalışıldı. Bu amaçla bir örnekselden sayısala çevirici, bir sulu spirometre, trakea ve çevre sesleri için yükselticiler, akış reostası ve kişisel bilgisayardan oluşan özel bir sistem kullanıldı. Bu sistemle, trakea sesleri, çevre gürültüsü ve nefes alma hızı eş zamanlı olarak kaydedildi.

Ses telleri ve ağız boşluğunun, trakea seslerine ek sesler yaratabilme olasılığına rağmen, trakea akciğer seslerinin ölçüleceği yer olarak seçildi. Bunun nedeni

- habis akciğer tümörlerinin çoğunun büyük bronşlarda bulunması,
- akciğer seslerinin trakeadan ölçüldüğünde çok az filtre olması,
- trakeal akciğer seslerinin karakterinin kişinin yapısal özelliklerine fazla bağımlı olmamasıdır.

Ses işaretleri alt kesim frekansı 100 Hz, üst kesim frekansı 2500 Hz olan yüksek geçiren ve alçak geçiren iki süzgeçten geçirildi. Örnekleme frekansı olarak 5 kHz seçildi. Her denek için uygun inspirasyon ve ekspirasyon fazından çıkarılan 1024 veri noktası ve bir Hanning pencere fonksiyonu kullanılarak Welch Periodogramının kestirimi yapıldı.

Akciğer kanserli ve Kronik Obstruktif Akciğer Hastalığı (KOAH) olanlar genellikle uzun yıllar sigara içen kişiler oldukları için benzer semptomlar verirler. Bu nedenle, KOAH'lı hastalar da bu çalışmaya alındı.

Deneklerden elde edilen frekans spektrumlarında tanı önemi olan bölgeler ayırt edildi ve bu bölgelerin tanıdaki önemi t-testi ile doğrulandı. Akciğer kanserli ve KOAH'lı hastaların inspirasyon evrelerinin frekans spektrumları 633.8 Hz üzerindeki bölgede 18% den daha az hata payı ile ayırt edici olarak saptandı.

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LIST OF ABBREVIATIONS

COPD	Chronic Obstructive Pulmonary Disease
R1	Region 1
R2	Region 2
R3	Region 3
TA	Total Area
NR1	Ratio Of Region 1 To Total Area
NR2	Ratio Of Region 2 To Total Area
NR3	Ratio Of Region 3 To Total Area
NNR1	Averaged Value Of Region 1 Of A Group
NNR2	Averaged Value Of Region 2 Of A Group
NNR3	Averaged Value Of Region 3 Of A Group
CA	Cancer

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1. INTRODUCTION

1.1. Motivation and Objectives

Auscultation to breath sounds is a common diagnostic tool used by the practicing physician. The evaluation of the lung sounds usually includes the following parameters; quality of sounds, the presence of additional sounds, their timing within the respiratory cycle, and their amplitude. The information about the quality is related by such descriptive terms as vesicular, bronchial, or Bronchovesicular sounds. The presence or absence of additional sounds, namely, wheezes, crackles, and pleural rib, is noted. The timing of the events is given with reference to the phase of respiratory cycle, e. g., early inspiratory crepitations. The relative amplitude of the sounds, both normal and additional, is subjectively evaluated by the examiner and usually described in three categories such as normal, reduced or increased [1].

Although auscultation is simple, non-invasive and cheap, it is a subjective technique. Conventional stethoscopes have a suitable coupling with the skin, but their frequency responses are uneven, some frequencies being amplified and others attenuated. Stethoscope bells have a strong attenuation above 300 Hz, and diagrams amplify frequencies around their frequency resonance; thus conventional stethoscopes are not appropriate for quantitative data [2].

Because of these reasons, objective systems should be used to detect the lung sounds. The aim of this study is to determine the lung cancer by using an electronic system. Most of the malign tumors of the lung raise in the main bronchus or one of its main branches. Although trachea is near the vocal cords and oral cavity which produces noises, trachea was preferred as a area to collect the lung sounds, because respiratory sounds measured at trachea undergo very little filtering [2], trachea is a precise area to collect the lung sounds and tracheal lung sound is not greatly depended on subject's morphology [3].

Because cigarette smoking is a major etiologic factor of lung cancer and COPD, and patients with COPD and lung cancer have similar symptoms such as cough, sputum, etc., it was studied also on patients with COPD.

1.2. Measurement System and Measurement Method

The system contains tracheal sound channel, environmental sound channel and flow -meter apparatus. When the subject breaths, the tracheal sounds of the subject, the environmental sounds and flow rate of the breathing of the subject are recorded simultaneously.

When the subject breaths through the spirometer, first probe is attached to the trachea to collect the tracheal sounds, second probe simultaneously collects the environmental noise and at the same time flow rate apparatus produces some signals when the subject breaths through the spirometer. These three signals coming from the first probe, second probe and flow rate apparatus simultaneously are filtered with cut -off frequencies at 100 Hz and at 2500 Hz . These signals are then applied to an IBM compatible PC equipped with a 12-bit PCL A/D converter card for quantization and storage.

The sampling frequency used for the data acquisition was 5 kHz. 1024 samples were extracted from inspiration and expiration phases. If, at the same time interval, environmental noise is less than ∓ 5 V and flow rate is above 750 ml/second. 1024 points FFT was applied on using a Hanning data window in Welch periodogram.

1. 3 Historical Background

Since antiquity, physicians have listened to the sounds within the chest. The ancient Greeks recognized at least two characteristic sounds: (1)pleural friction rub, and (2)the splashing sound made by fluid within the chest cavity when the patient was shaken. Until the nineteenth century, the examiner detected these sounds by listening with the ear placed directly against the chest wall [4].

In 1816, a young French doctor, Renee Theophile Laennec, faced with examining the chest of a very obese woman, rolled a sheaf of paper into a cylinder; he placed one end on the patient's chest and put his ear to the other end. Laennec named his invention the

stethoscope, from the Greek stethos, "breast", and skopein, to view". He employed subsequently a wooden cylinder, and in 1819, he published a treatise on what he had learned with his instrument[4]. He explained the first accurate descriptions of normal and abnormal breath sounds, correlating them with pathologic autopsy findings [4].

In recent years, phonopneumograms, which are visual displays of breath sounds, have been used to analyze a breath sound more detail than using a conventional stethoscope [4].

In 1924, Bass reported a clever method using a condenser microphone and oscilloscope that displayed normal and abnormal breath sounds. Cebot and Dodge were able to show in 1925 that coarse and fine rales were associated with conspicuous low and high frequency components respectively [5].

In 1955, McKusick used a special device called a sound spectrograph and made the first detailed frequency analysis of the sounds. He showed, for example, that the normal inspiratory vesicular sounds were of maximal intensity at a frequency of about 200 Hz and decreased rapidly thereafter. He found no sound energy at more than 500 Hz, because the ear is relatively insensitive to sounds in this frequency range [5].

In addition to this, McKusick et al demonstrated that the spectrograms of moist and dry crackling rales were different, the dry rales containing more high frequencies. Calibrated amplitude plots reported by WEISS and CARLSON in 1970 allowed visual presentation of the overall amplitude of sounds, including pauses and duration differences as well as a study of the relation of the amplitudes in inspiration and expiration. Adventitious sounds were not clearly distinguished from one another by these methods nor by the integrating envelope detector described by WOOTEN and WARING [5].

Banaszak et al , in 1973, used a system for simultaneous recording of breath sounds and breathing velocity. This double display was accomplished by adding a device called a pneumotachometer to create phase chart and display the velocity of breathing [4].

In 1970's, the terminology was still confusing and Fraser and Pare said that "it almost seems that every physician has his own classification [6].

In 1976, The International Lung Sounds Association began to hold annual meetings to discuss the lung sounds. The association consists of physicians, engineers and physiologists from different countries. Their common interest is in thoracic acoustics.

Their aim is to bring an objective and quantitative approach to this area instead of the existing confusing terminology. The American Thoracic Society published the results of the first meeting in 1977 [6].

In 1978, the British physician Paul Forgacs published his famous book "Lung Sounds". This study was important and the most serious one since Laennec's work. He observed and explained the mechanisms of respiratory sounds in this book. This study provided some objective fundamentals for respiratory sounds instead of known anatomy and physiology of the respiration system [6].

Speculations on the difficulty of visually differentiating lung sounds were presented by Forgacs in 1967. He pointed out that the study of crackling was difficult because the sounds follow one another so rapidly that neither the individual crackles, nor the rhythmical pattern made by their sequence can be identified with the unaided ear. He noted that the oscilloscope showed the regular waveforms of a wheeze but only at time base speeds at which one saw such a small section of sound that it was very difficult to judge the timing of the wheezes in relation to the respiratory cycle [5].

Forgacs, and Nath and Capel described the repetitive nature of rales in some patients but their published tracings had time scales below 100 mm/s and did not reveal clearly the waveform characteristics of the adventitious. The amplitude deflections produced by rales, for example, are similar to deflections found in tracings in which no rales are described since the specific waveforms of the rales are obscured at this speed [5].

Space-age technology has provided more sophisticated computer-based methods, such as time expanded waveform analysis [5]. Time-expanded waveform analysis was used by Murphy et al., in 1973. After storing the recorded sounds in the memory of a computer, he replayed the signal at a much slower rate. These time-expanded wave forms of typical sounds showed patterns that allowed the various categories of sound to be visually distinguished from one another [4].

Innovate use of phonopneumography has been made by Dr. Steve S. Kraman has employed a technique, subtraction phonopneumography, to determine the site of production of respiratory sounds. By using this technique, he explained that the source of the main component of the normal inspiratory sound is more peripheral than the mainstem bronchi. On the other hand, expiratory sounds were found by Dr. Kraman to come from a more central location than inspiratory sounds [4].

Dr. Kraman also showed that during quiet breathing in healthy subjects, no detectable laryngeal noise can be heard in the vesicular breath sounds [4].

Dr. Kraman, in 1983, explained that musculoskeletal noise seriously contaminates what is usually considered to be lung sound [7].

2. STRUCTURE OF THE RESPIRATORY SYSTEM

2.1. Anatomy of The Lungs

The lungs are cone shaped organs that completely fill the pleural spaces. The right lung is divided by the fissures into an upper, a middle and a lower lobe. The left lung is divided into an upper and lower lobe. The upper lobes lie more anteriorly and the lower lobes extend posteriorly . There are 10 broncopulmonary segments in the right lung and left lung . Bronchopulmonary segments are seen in Figure 2.1.

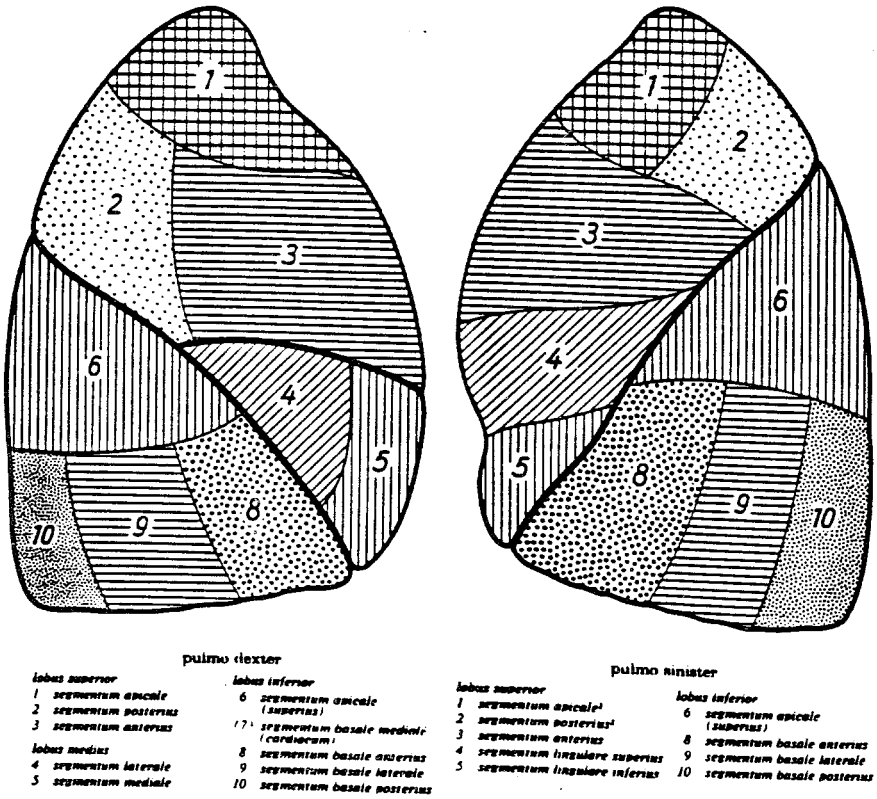


Figure 2.1. Bronchopulmonary segments of the lungs. [9]

Air moves into and out of the lungs through the airways, which are subdivided into two components from a functional point of view: (1) the conducting airways, often called the tracheobronchial tree, and (2) the terminal respiratory units(acini). The conducting

airways function chiefly to conduct gas into and out of the terminal respiratory units, where the actual gas exchange takes place.

2.1.1. The bronchial tree

Tracheobronchial tree consists of the trachea, the bronchi and the bronchioles. Tracheobronchial tree is seen in Figure 2. 2.

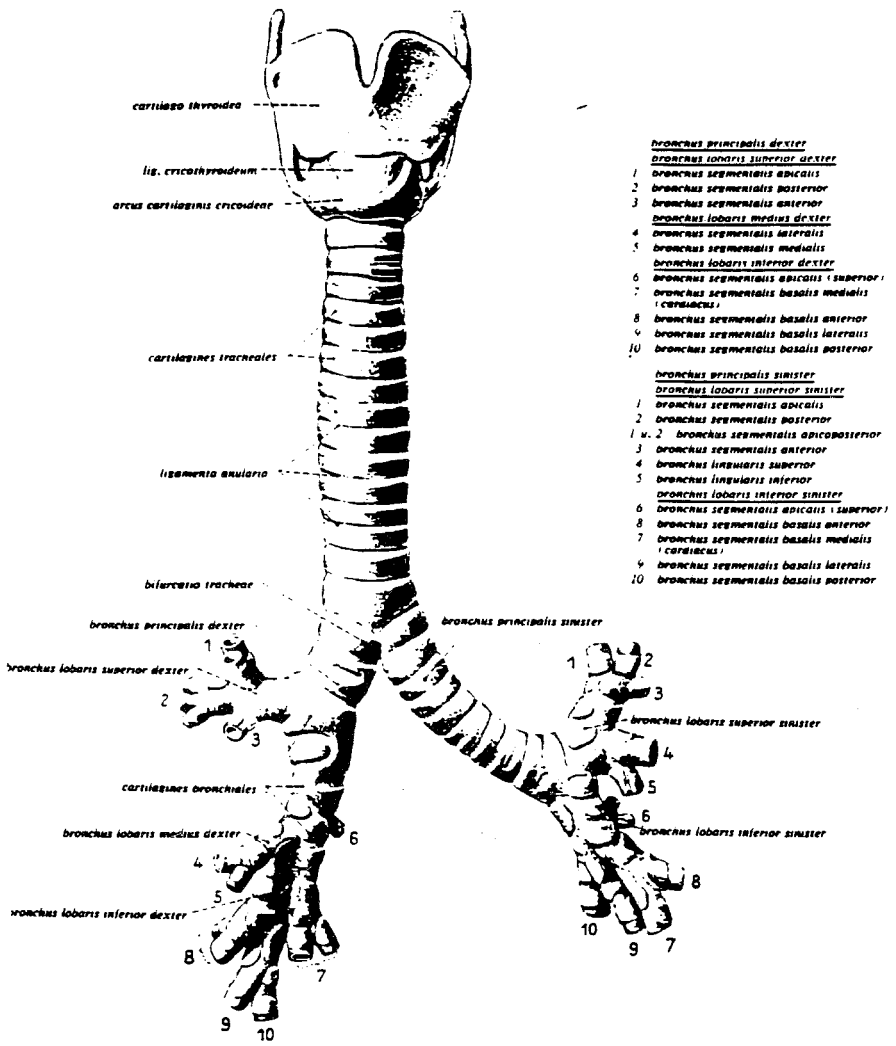


Figure 2.2. Tracheobronchial tree [9].

2.1.2. The trachea

Trachea is located in the superior mediastinum and is approximately 12 cm long and 2 cm wide. It is reinforced and kept patent by c- shaped rings(cartilage), which allow momentary expansion of the esophagus into the trachea during swallowing. Trachea bifurcates into main stem bronchi at the carina(septum) behind the sternal angle at level T5

2.1.3. The main stem bronchi (primary bronchi)

The primary bronchus are divided into 2 groups:

2.1.3.1. The right main stem bronchus

It is wider, shorter, and more vertical than the left main stem bronchus and divides external to the lung parenchyma into three lobar bronchi.

2.1.3.2. The left main stem bronchus

It is narrower(because of smaller left lung volume), longer, and more horizontal than the right because the hearth is toward the left and divides external to the lung parenchyma into two lobar bronchi.

2.1.4. The lobar(secondary) bronchi

Each bronchus supplies one lobe. There are three lobar bronchi in the right lung and two in the left lung. The right lower lobar bronchus is most vertical, most nearly continues the direction of the trachea, and is larger in diameter than the left, it is therefore the most common resting place for small aspirated objects. The lobar bronchi are divided into segmental bronchi.

2.1.5. The segmental(tertiary) bronchi

Each segmental bronchus supplies a Bronchopulmonary segment. It enters the center of the segment accompanied by a segmental branch of the pulmonary artery. A segmental bronchus may branch 6 to 18 times to produce 50 to 70 respiratory bronchioles which merge with alveolar sacs and terminate in the alveoli constituting the lung parenchyma [8].

3. RESPIRATORY FUNCTION

Respiration is usually separated into four functional subdivisions .

1. *Ventilation*- the movement of air from outside to inside to the body and the distribution of air within the tracheobronchial system to the gas exchange units of the lungs.
2. *Diffusion*-the movement of O_2 and CO_2 across the alveolar-capillary membrane between the gas in alveolar spaces and the blood in pulmonary capillaries.
3. *Perfusion*-the flow of mixed venous blood through the pulmonary arterial circulation, distribution of the blood to the capillaries of gas exchange units, and removal of the blood from the lungs through pulmonary veins.
4. *Control of breathing*-the regulation of ventilation, usually in accordance with changing metabolic demands.

3.1. Ventilation

Air moves from outside the body into the gas exchange units of the lungs because contraction of the muscles of respiration normally generates sufficient force to expand the lungs and chest wall and to overcome the resistance and inertia in the system. Accordingly, the volume gas that reaches the individual gas exchange units is determined by the mechanical properties of the lung parenchyma, airways, and chest wall, and by the force provided by the muscles of the respiration.

The amount of air that enters the lung with each breath is called the *tidal volume*. When the lungs are fully expanded, the amount of gas they contain is called the total lung capacity. The maximal volume of gas that a person can exhale from total lung capacity is called the *vital capacity*, and the amount of gas remaining in the lungs at the end of maximal expiration is called the *residual volume*. Another important static lung volume is the functional residual capacity, which is the volume of gas in the lungs at the end of a normal breath.

To cause air to flow from outside they body into the gas exchange units, a muscular (or other mechanical) force must be exerted to overcome not only the elastic recoil of properties of the lungs and chest wall but also their resistive and inertial properties. In contract to distansibility, which is not affected by the rate of movement the forces required to offset resistance and inertia are markedly influenced by the velocity of airflow. Except in a few patients (e. g. , those with severe obesity), inertial forces are ordinarily, small and usually ignored, thus only those factor, affecting airways resistance are important.

Resistance to airflow is affected chiefly by the caliber of the air passages. Although the diameter of each successive generation of airways decreases. The combined total cross-sectional area at any level increases steadily throughout the tracheobronchial tree from the main bronchi to the peripheral airways. This means hat airways resistance progressively decreases and that most of the resistance of the human tracheobronchial tree resides in large airways. direct measurements reveal that between 50 and 80 per cent of total resistance to airflow originates in airways greater than 2 mm in diameter.

Changes in the cross-sectional area of airways can also result from changes in lung volume and diseases of the lung parenchyma or the airways themselves. During inflation of the lungs from functional residual capacity, airways are pulled open so that resistance to airflow decreases during deflation, charges during inflation and deflation because of the combined effects of the tethering action of the attachments between the lung parenchyma and small bronchioles and the distending effects of pleural pressure on larger airways.

Elastic recoil of the lung, which governs the pull of the attachments and the magnitude of pleural pressure, affects the size of all airways. It follows that when elastic recoil is decreased, as in the patients with emphysema, airways are narrowed and resistance is increased.

Airway narrowing can also result from bronchospasm, edema and secretions within the lumen [10]. Maximum expiratory flow -volume curves are often recorded in the pulmonary function laboratory to determine ventilatory abnormalities. In the presence of airway obstruction, expiration is usually much more difficult than inspiration because the expiratory closing tendency of the airways is greatly increased, whereas the negative intrapleural pressure of inspiration actually"pulls" the airway open. Consequently, air tends to enter the lung easily, where it becomes trapped. Moreover because of partial obstruction of many airways and because they collapse more easily than normal airways, maximum expiratory flow is markedly diminished.

A simple, useful test of airway obstruction is the forced expiratory vital capacity(FVC). To obtain the recording, the examiner asks the subjects to inspire maximally to total lung capacity, then to exhale into the spirometer with maximum expiratory effort as rapidly and completely as possible. The total excursion of the record represents the forced vital capacity which is illustrated for a health subject in Figure 3. 1. A.

In normal lungs and lungs with obstructed airways, the forced vital capacities may be equal, but often they are not, owing in part to air trapping. In addition, there is a marked difference in the flow rate at which the subjects can expire, especially within the first second. This forced expiratory volume during the first second(FEV1) is recorded and used for comparison between healthy subjects and patients. In a healthy subject, the forced vital capacity expired in the first second(FEV1/FVC%) is about 80 percent. However, in the subject with airway obstruction shown in Figure 3.1.B. This has decreased to only 47 percent [4].

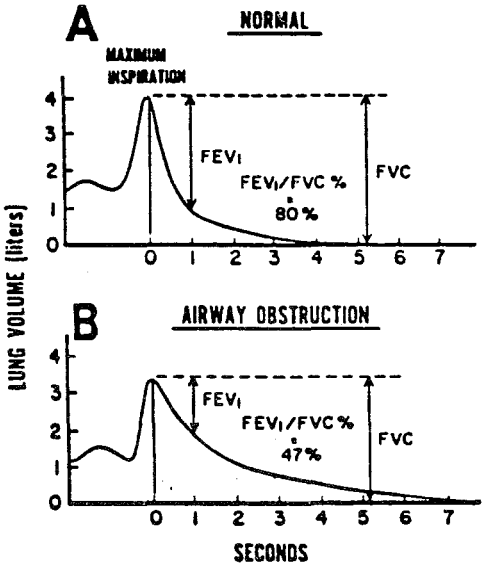


Figure 3.1. Forced vital capacity for a healthy subject and for a subject with airway obstruction.

4. LUNG SOUNDS

4.1. Types of Normal Breath Sounds

Four types of breath sounds are heard over the normal chest.

4 1.1. Normal vesicular lung sounds

Vesicular lung sound is a relatively soft, low-pitched sound, sometimes described as a sighing or gentle rustling; it is heard over most of the peripheral parts of the lung. The inspiratory phase is markedly longer than the expiratory phase, the I:E ratio being about 3:1. Expiration is much quieter than inspiration, usually being almost inaudible. There is no pause between inspiration and expiration.

4 1. 2. Bronchial lung sounds

Bronchial lung sounds are characteristically loud, high pitched sounds and resemble the sound of air blowing through a hallow pipe. Their expiratory phase is louder and longer than their inspiratory phase. They are normally present only over the manibrium, and a distinct pause can be heard between the inspiratory and expiratory phases.

4. 1. 3. Bronchovesicular lung sounds

These sounds are a mixture of bronchial and vesicular sounds. Their inspiratory and expiratory phases are about equal in length. They are normally heard in two places:(1) anteriorly, near the mainstem bronchi in the first and second intercostal spaces, and (2) posteriorly, between the scapulae.

4. 1. 4. Tracheal lung sounds

These sounds, not usually auscultated, are present over the extrathoracic portion of the trachea. They are very loud, are very high-pitched , and have a hollow or harsh quality. The expiratory phase is slightly longer than the inspiratory phase [4].

Audible places over the normal chest of four types of breath sounds are shown in Figure 4.1.

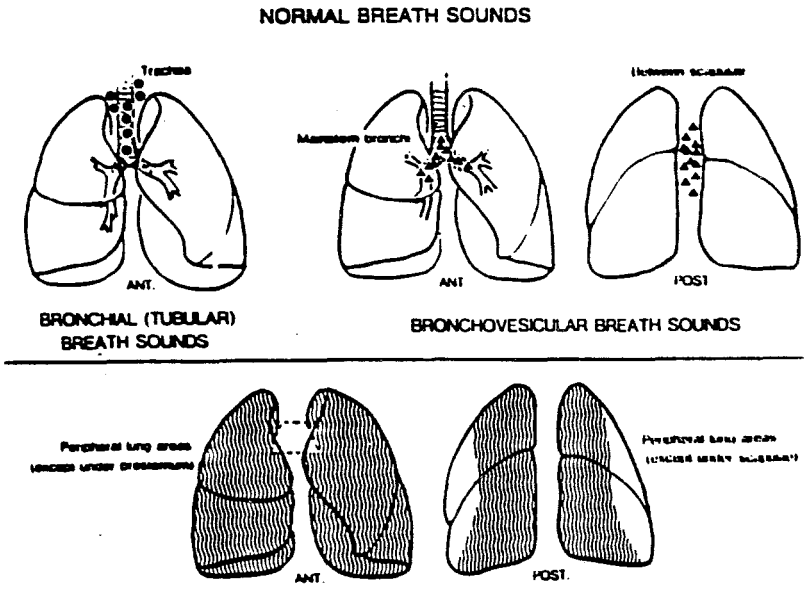


Figure 4. 1. Audible places over the normal chest of breath sounds.

4.2. Some Physical Characteristics of Lung Sounds

Although there is the lack of complete understanding of the mechanisms and sources from which respiratory sounds are generated, it is known that turbulent flow in bronchial tree is important to produce the lung sounds. If the flow rate is slow, the pattern of flow is laminar. Turbulence begins at a critical velocity. In the lung during turbulent flow, energy is transferred between colliding packets of gas, and transient pressure variations occur, generating sound. Air flow in the bronchial tree is turbulent in the trachea and the first few generations of bronchi. There is laminar flow in the peripheral bronchi because of the increasing of the total area. The diameter of individual airways decreases at each division from the lobar bronchi towards the periphery of the lung, but the number of airways in each generation increases exponentially. The result is a considerable expansion of the total cross-section of the airways with a corresponding fall in the flow velocity of gas from the central bronchi towards the periphery of the lung [11] [12].

There are different ideas concerning lung sound intensity. When there is an obstruction in one of the segments of the lung, intensity recorded over this segment is not similar to the homologous segment of the other lung. On the other hand, lung sound intensity is also dissimilar in homologous segments of the lung for the healthy person according to R. Dosani et al [13].

Transmitted lung sounds are louder on the right side than on the left [14]. Moreover, the relationship between the flowrate and lung sound amplitude is linear in healthy subjects [15].

To obtain power spectra of the lung sounds, several filtering techniques are used, however these filtering techniques change the power spectrum of the lung sound [16].

The relationship between the spectra of the lung sounds when they are collected from the chest wall and the trachea varies according to the authors; when the lung sounds are recorded from the chest wall, the maximal frequencies of expiratory and inspiratory breath sounds are in 446∓ 46 Hz ∓ SD and 286∓ 53 Hz ∓ SD and when the lung sounds are recorded from the trachea the power spectra of the tracheal sounds have a broad spectrum with a sharp decrease at a cut-off frequency that varies between 850 and 1600 Hz according to Noam Gavriely, et al [1].

It is important to monitor while tracheal sounds are being recorded, because the power spectrum does not change if the flow rate is above 0. 75 L/second. [17] [18]].

There is a negative correlation between cut-off frequency and individual height when the lung sounds are recorded from the trachea [19].

5. CHRONIC OBSTRUCTIVE PULMONARY DISEASE AND LUNG CANCER

5.1. Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease(COPD) is a common disorder usually characterized by progressive obstruction to airflow and a history of inhalation of such irritans as tobacco smoke. COPD also is referred to as chronic obstructive lung disease(COLD), chronic airways obstruction(CAO), and, either individually or together, chronic bronchitis and emphysema.

a. Chronic bronchitis can be defined in terms of clinical symptoms (i. e, excessive mucus secretion in the bronchial tree leading to productive cough for at least 3 months during each of 2 successive years.
b. Emphysema can be described in terms of morbid anatomy(autopsy) showing destruction of alveolar walls and abnormal enlargement of airspaces distal to the terminal non respiratory bronchiole.
c. It has become apparent that many patients develop, to varying degrees, a combination of these two entities.

Etiology:

On a precise scientific level, the etiology of COPD is unknown. However, on an environmental basis, the single most important etiologic agent is chronic inhalation of tobacco smoke.

Pathology and Pathophysiology:

1-The bronchitic component:

A- Early in the disease, the small airways demonstrate mucous plugging, inflammation, peribronchiolar fibrosis, narrowing, and obliteration.
B- In established disease, the bronchitic component includes varying degrees of mucous gland hyperplasia, mucosal inflammation and edema, bronchospasm, and impacted secretions. These elements contribute to airway narrowing and increased airway resistance.
2- The emphysematous component includes the destruction of alveolar walls and the supporting structure of the airways, which produces widely dilated airspaces [20].

5.2. Lung Cancer

Cigarette smoking is the major etiologic factor in 80%-85% of all broncogenic cancers[20]. More than 60 per cent arise in the right bronchus or one of its main branches. Figure 5.1. shows the stages of growing of a malign tumor (cancer) in the right bronchus [21]. There are 4 histologic types of bronchogenic carcinoma

1. Squamous cell carcinoma
2. Small cell anaplastic carcinoma
3. Large cell anaplastic carcinoma
4. Adenocarcinoma

Endobronchial obstruction may result in a localized wheeze detected during physical examination of the chest [10]. Obstruction, due to tumor, may cause some complications; local emphysema, atalectasis and infection . Because of this reason, auscultation findings of emphysema, atelectasis or infection may be found in patients with lung cancer.

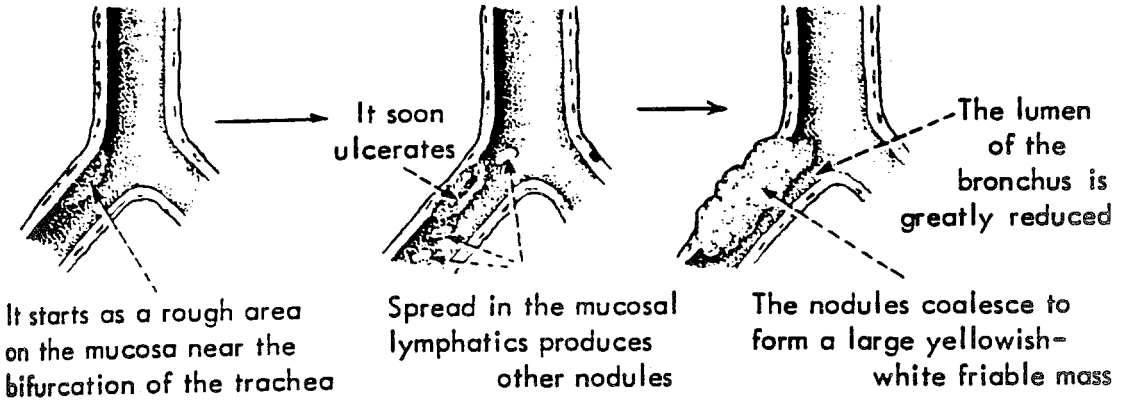


Figure 5.1. Growth of a malign tumor in right bronchus.

6. ADVENTITIOUS LUNG SOUNDS

6.1. Classification of Adventitious Lung Sounds

Adventitious sounds are heard only in pathological cases, they appear superimposed on breath sounds. Adventitious sounds are divided into major classes of continuos and discontinuous sounds.

6.1. 2. Continuos adventitious sounds

Continuos adventitious lung sounds, known as " wheezes" are relatively loud sounds of more than 250 msec duration. Wheezing is characterized by a sharp peak in the power spectral density function in the range of 400 Hz. Lower frequency continuos sounds, in the range of 200 Hz or lower are termed "rhonchi". The cause of the continuous adventitious sounds is a narrowing of an airway cross-section due to variety of reasons following,

1-secretion
2-bronchospasm
3-mucosal thickening
4-edema
5-presence of tumor or foreign body [22].

6.1.3. Discontinuous adventitious lung sounds

Crackles are usually evaluated as early crackles, or late crackles in the clinical studies.

Late inspiratory crackles: The crackling heard towards the end of inspiration in diffuse pulmonary fibrosis and other diseases characterized by pulmonary deflation is generated by this mechanism. In deflated territories of the lung, the peripheral airways of the lung, the peripheral airways remain closed until a late stage of inspiration. By then the gas contained in the alveoli supplied by these airways is considerably below atmospheric pressure. When the airway eventually reopens, the sudden equalization of pressure is accomplished by an explosive sound.

Early inspiratory crackling: Crackling at the beginning of inspiration is a common sign of chronic obstructive pulmonary diseases, particularly chronic bronchitis. In contrast to late inspiratory crackles, these sounds are low pitched, audible at the mouth, as well as over the lobes, and can not be extinguished by changes of posture [23].

The frequency, waveform and timing of crackles change according to the lung disease [24].

The analysis of the crackles in several lung diseases has been developed using some automatic detection techniques and classification methods [25] [26].

7. CLINICAL DATA ACQUISITION

7.1. Clinical Situation of Healthy Subjects and Patients

The recording of the tracheal sounds have been performed on five healthy men (age 58∓6. 3 yr.) and six male patients with lung cancer (age 64. 3∓7. 1 yr.) and 8 male patients with chronic obstructive pulmonary disease (age 55. 5∓12. 5) in a relatively low noise spirometry laboratory.

Healthy subjects in this study are non-smokers in life time and do not have any respiratory symptoms such as cough, dispnea etc.

Healthy subjects underwent following processes:

1. Respiratory sounds of these subjects were listened from their chest walls using a conventional stethoscope.
2. Respiratory functional tests were performed.
3. Tracheal sounds were recorded using the electronic system.

Age, height, classical auscultation findings from the their chest walls is represented in Table 7. 1.

Table 7. 1. Profile for Healthy Subjects.

Subject no	Age,yr	Heigth,cm	Auscultation findings
1	60	161	Normal vesicular breath sounds
2	48	164	Normal vesicular breath sounds
3	65	161	Normal vesicular breath sounds
4	52	180	Normal vesicular breath sounds
5	65	170	Normal vesicular breath sounds

Spirometry results for healthy subjects is shown in Table 7.2.

Table 7. 2. Spirometry Results for Healthy Subjects.

Subject no	FVC % Pred.	FVC1 % Pred.	MMFR % Pred.
1	117	88	100
2	105	87	100
3	94	85	100
4	81	90	100
5	112	80	90

Patients with COPD and Lung cancer underwent following processes respectively;

1-Respiratory sounds of patients were listened to their chest walls

2-Respiratory function tests were applied on all patients

3-Direct x-ray films and CT of the patients ' chest were applied.

4-Bronchoscopic examination was applied only the patients with lung cancer except patient with lung cancer (Subject No, 3) because of his coronary disease.

Age, heigth and classical auscultation findings for patients with COPD is summarized in Table 7. 3.

Table 7. 3. Profile for Patients with COPD.

Subject no	Age yr	Heigth cm	Auscultation findings	cigarettes/day	years
1	50	154	ins.wheeze..exp.wheeze	40 cigarettes	30 years
2	40	170	ins.wheeze..exp.wheeze	20 cigarettes	15 years
3	73	179	early ins.crk..exp.rhonc.	50 cigarettes	60 years
4	62	158	early ins. crk	30 cigarettes	35 years
5	74	172	late ins. crk	30 cigarettes	35 years
6	56	160	decreased lung sounds	60 cigarettes	15 years
7	50	180	late ins.crk..ins.whz..exp.whz.	40 cigarettes	30 years
8	39	186	exp.wheeze	20 cigarettes	16 years

Spirometry results for patients with COPD is presented in Table 7. 4.

Table 7. 4. Spirometry Results for Patients with COPD.

Subject no	FVC% Pred.	FVC 1% Pred.	MMFR % Pred.
1	44	50	26
2	47	27	26
3	34	80	92
4	53	50	24
5	48	50	37
6	57	50	31
7	27	43	27
8	42	58	39

Age, height, and classical auscultation findings for patients with lung cancer is given in Table 7. 5.

Table 7. 5. Profile of Patients with Lung Cancer.

subject no	Age, yr	Heigth, cm	Auscultation findings	cigarettes/day	years
1	64	167	late ins.crk.,loc.whz.on r. lung	40 cigarettes	35 years
2	63	172	ins. crk.	30 cigarettes	35 years
3	50	166	late ins. crk.	20 cigarettes	30 years
4	70	150	normal vesicular breath sound	0	0
5	67	165	ins. crk.	20 cigarettes	40 years
6	72	158	exp. whz., exp. crk.	20 cigarettes	60 years

Spirometry findings for patients with lung cancer is shown in Table 7. 6.

Table 7. 6. Spirometry Results for Patients with Lung Cancer.

Subject no	FVC % Pred.	FVC1 % Pred.	MMFR % Prd.
1	71	70	64
2	80	70	60
3	81	65	43
4	80	91	100
5	85	65	46
6	49	66	50

Results of bronchoscopic examination of patients with lung cancer is presented in Table 7. 7.

Table 7. 7. Results of Bronchoscopic Examination of Patients With Lung Cancer.

Subject no	Obstruction level of tumours of patients with lung cancer
1	Right main brronchus, onset of the sup. seg.bronc. and ant. seg.bronc. of the right lower lobe, compression of trachea due to enlargment of thyroid gland
2	Proximal part of the right lobar bronchus
3	Left primary bronchus
4	Left upper lober bronchus
5	Proximal part of the left upper lobar bronchus
6	Onset of the left basal segmental bronchi

7.2. Acquisition of The Tracheal Sounds and Signal Conditioning

7.2.1. Signal level and design of the acquisition probe

The tracheal sound is detected by an electret microphone. Its frequency response is flat between 20 Hz and 20 kHz and its gain is -62 dB. The microphone was placed in a two-part probe made of *delrin*. Part 1 of the probe is screwed to Part 2 after placing the electret microphone into Part 2. To minimize microphone twisting movements in the probe a nylon screw is used. The probe design allows generous manipulations of the microphone by hand. Because the microphone is not in contact with the skin, there is no possibility of friction noise. The probe is illustrated in Figure 7. 1.

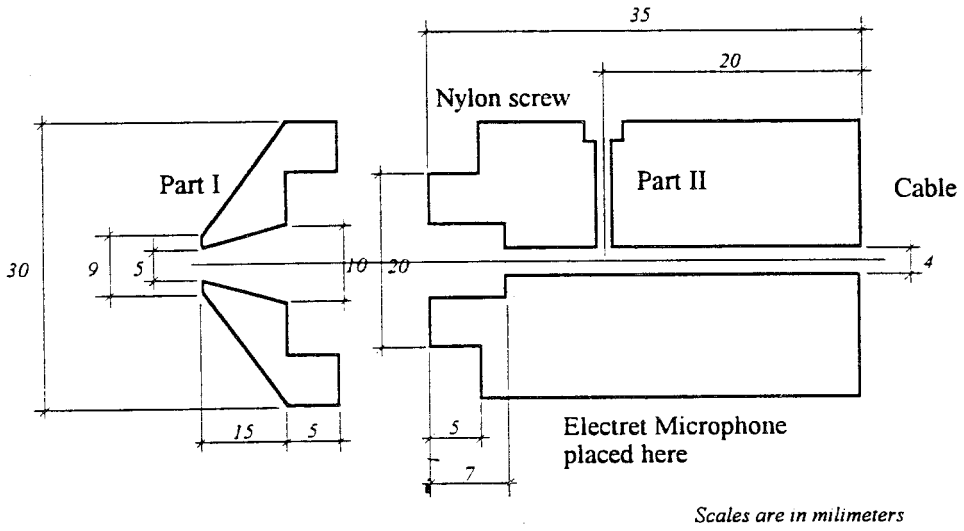


Figure 7. 1. Tracheal probe [2].

Part 1 of probe has a cavity as illustrated in Figure 7. 1. To determine the effect of the cavity in Part 1, sound waves from a loudspeaker, from a distance of 30 cm were applied to the probe. Frequency was changed from 0 Hz to 5 kHz to obtain and the frequency response cavity of probe. Figure. 7.2. shows the resulting frequency response. As can be observed from this figure, the cavity in Part 1 of the probe has an effective

frequency bandwidth between 0 Hz and 2 kHz, and a resonance frequency around 2500 Hz. Since breath sounds components above 2 kHz are irrelevant, the effect can be omitted.

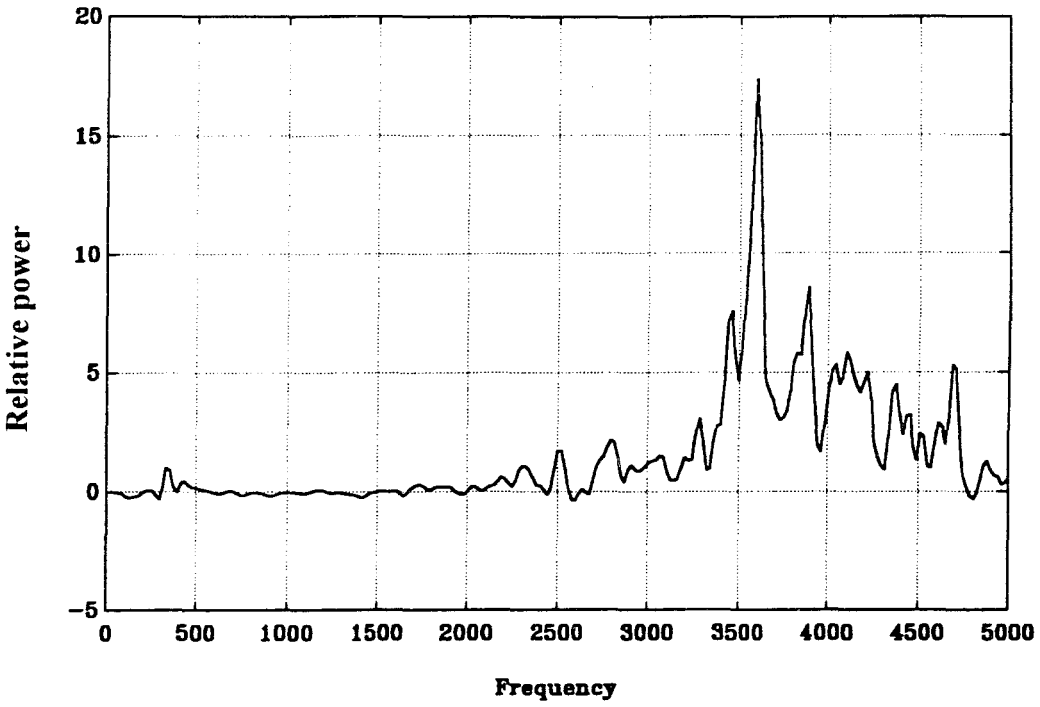


Figure 7.2. Effect of cavity of the head of the probe.

7.3. Calibration of Flow Meter Apparatus

To measure the flow rate of breathing of subjects, a water sealed spirometer was used. When the subject breaths through the spirometer, the bell of the spirometer moves up and down. A potentiometer was coupled to the spirometer for monitoring the air flow rate in volts.

A constant 9 volts was applied to the potentiometer and gas volume changes were recorded between the wiper arm and lower arm of the potentiometer. In this arrangement 1mV corresponds to 4.504 ml of gas volume change.

7.4. Analog Filtering

The lung sound signals were recorded from the anterior face of the trachea, by placing the *tracheal probe* just above the suprasternal notch on the trachea. To detect ambient noise from these measurements a second probe, the *environmental probe*, was placed near the instrumentation system and the ambient sound were also recorded. These signals were filtered through a high-pass and low-pass analog filters which are of the 6th order Bessel type. The high-pass and low-pass filters had cut off frequencies at 100 Hz and 2500 Hz, respectively. Since the signals from the flow-meter apparatus had a good signal-to-noise ratio, they were acquired directly, without filtering.

The instrumentation system including the microphone, the highpass and lowpass filters is called the sound channel. Frequency response of tracheal sound channel is presented in Figure 7. 3.

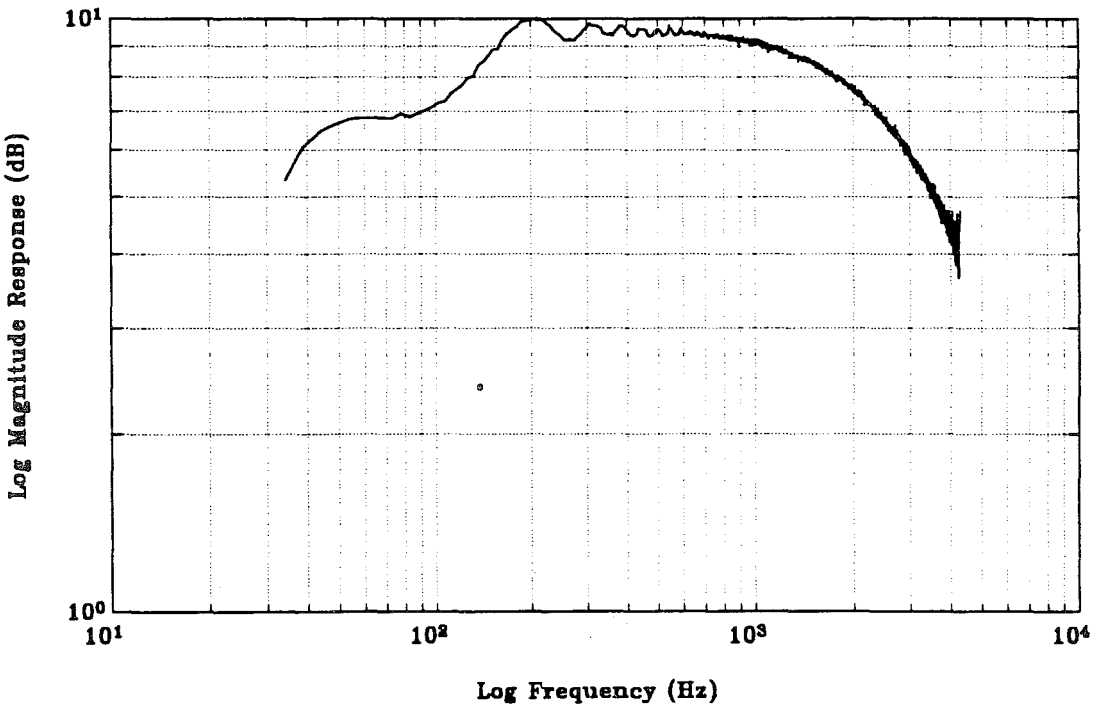


Figure 7. 3. Frequency response of tracheal sound channel.

7.5. Clinical Data Acquisition

The recording system used in this study is shown in Figure 7. 4. In this system, the three output signals coming from the recording system are converted into digital form using an analog to digital converter board (*LabBoard , PCL 718*) and *Labtech Notebook Acquisition software*. The digitized data was then stored in the hard disk of the personal computer. The data acquisition was performed at a sampling frequency of 5 kHz per channel. The measurements have been taken from 5 healthy subjects, 8 patients with COPD and 6 patients with lung cancer in a relatively low noise spirometry laboratory.

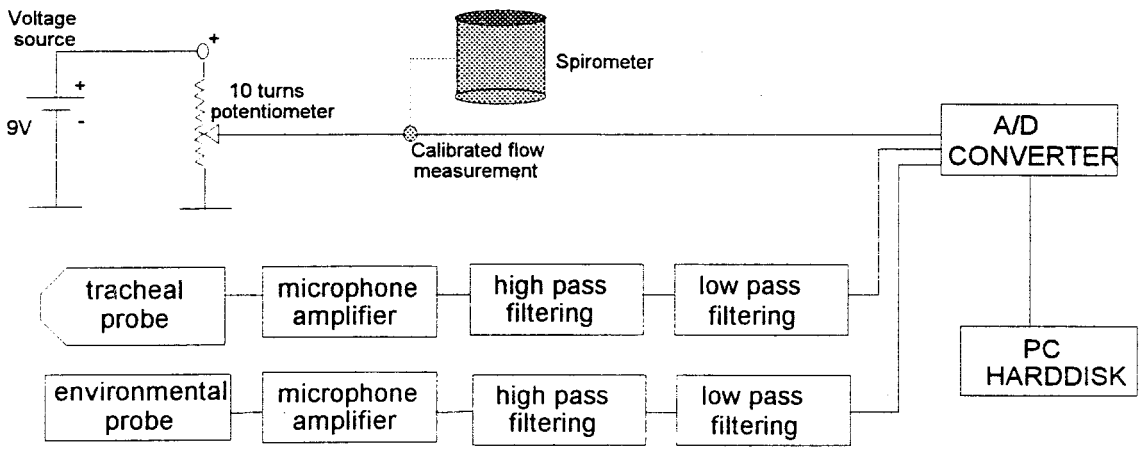


Fig. 7. 4. Recording system.

7.6. Experimental Procedure

The subject is placed in front of the spirometer. A transparent paper is placed in front of the recording part of the spirometer with special traces for helping subjects visually adjust their breathing rates to around 1000 ml/second. When he breaths through the spirometer, she/he is asked to look at the traces on the transparent paper and adjust her/his

breathing rate to about 1000 ml/second. When the paper recording system is switched on, the subject tries to parallel her/his own recording traces on the recording paper to the traces on the transparent paper. A photograph of the experimental setup is shown in Figure 7. 5.

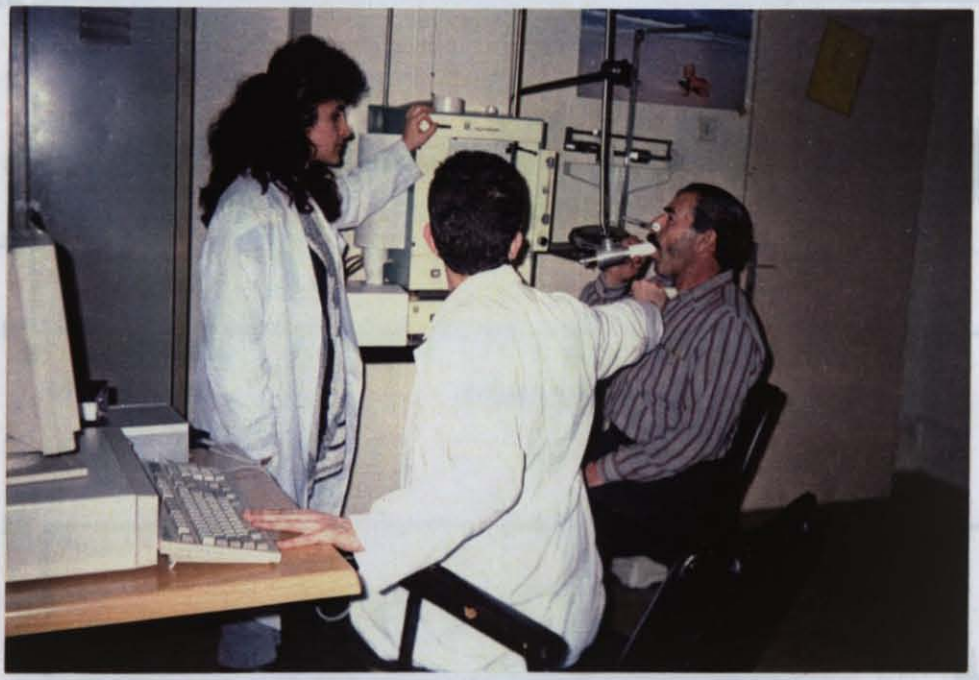
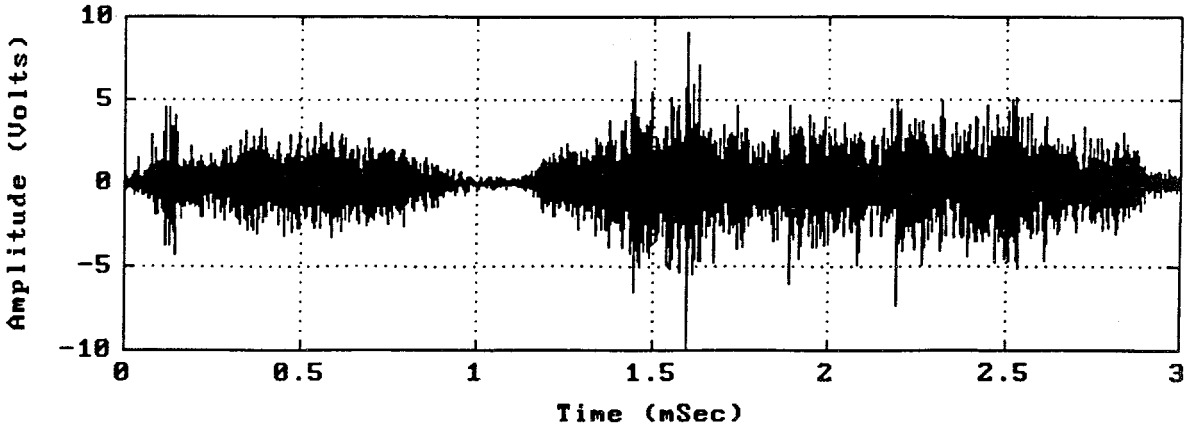


Figure 7. 5 Photograph showing the Experimental Setup.

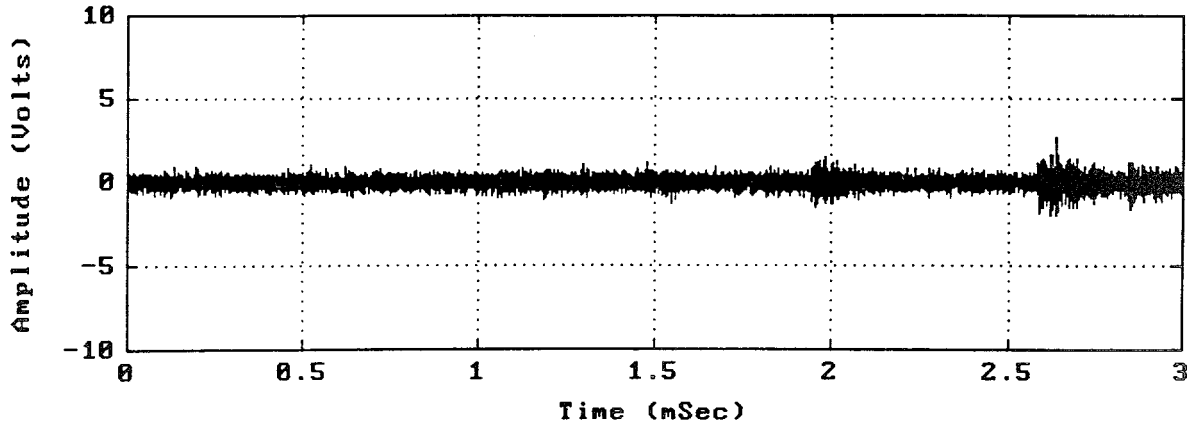
7.7. Segmentation

To process the tracheal sounds of the healthy subjects and patients, their data in the hard disk of the PC were changed from binary format to ASCII. Later, this the data was imported to DADISP software which is a signal processing software. Using DADISP, tracheal sound signals, environmental noise signals and flow rate of the tracheal sound could be seen at the same time on the video screen, (see figure 7. 6.). The inspiratory and expiratory phases of the tracheal sounds were selected if the amplitude of the ambient sound was less than $\mp$ 0. 5 V. Then, using the MATLAB software the flow signals were filtered

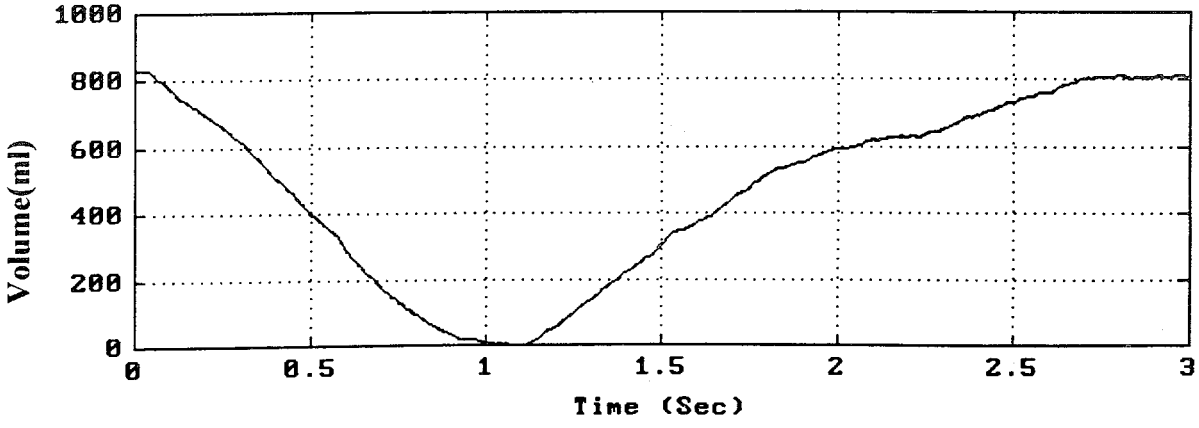
and were down sampled. The diagram of the flow rate was printed out and flow rate was measured manually in the region of the amplitude of the ambient sound is less than ∓ 0.5V. Inspiratory and expiratory phases of the tracheal sounds were selected again if the flow rate of the tracheal sound is above the 750 ml/second, because the frequency spectrum does not change if the flow rate is above 750 ml/second.



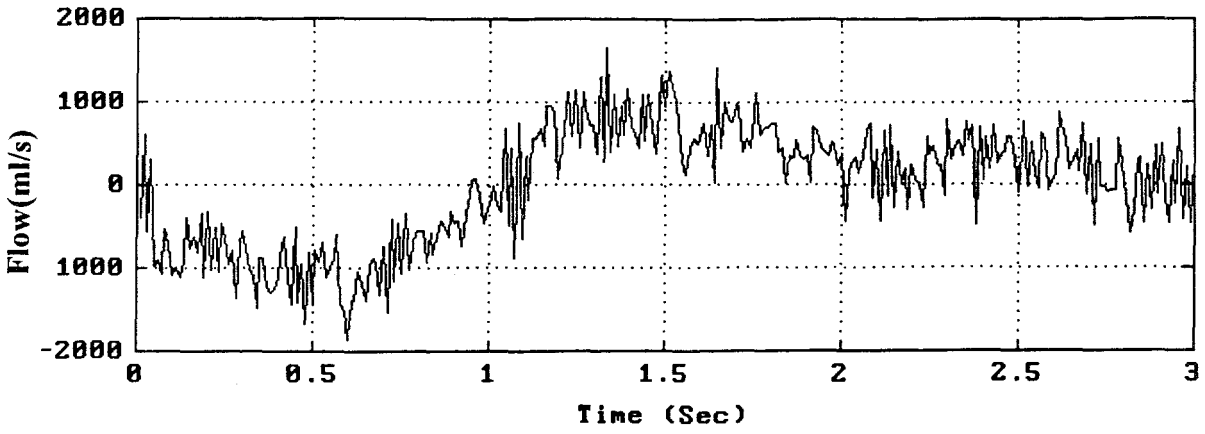
(a)



(b)



(c)



(d)

Figure 7. 6. Three channels of the patient with COPD (Subject No, 1).

(a) The inspiratory and expiratory phase of tracheal sound.

(b) Ambient sound

(c) Volume (ml).

(d) Flow (ml/s)

7.8. Digital Filtering of The Lung Sounds

After segmentation signals were passed through a Chebychev digital filter with cutoff frequency 100 Hz and 2500 Hz. The ambient sounds and tracheal sounds were digitally filtered by using a FIR filter.

Finite Impulse Response(FIR) filter is inherently stable and it can be designed so as to have an exactly linear phase characteristic in the pass band. The possible disadvantages are that high order is usually required to meet sharp cutoff specifications and that the choice of this order is usually determined by trial and error.

The windowing and tracation of FIR filter design exploits the fact that the frequency response function satisfies the Dirichlet conditions, so that the Fourier series expansion may be obtained. Truncation is achieved by a technique known as windowing, and the design of windows is critical for satisfactorily approximating the desired filter characteristics. Dolph-

Chebyshev window has the property of smallest main lobe width for a given side-lobe level in its Fourier transform. Also, the side lobes levels are equal heigth [27]. In the realization of the filter of the used in the mathematical software tool named MATLAB in the PC.

The approximation process was realized using the function:
FIR 1[Order of the filter, Normalized corner frequencies, window type(order of filter +1 ,ripple in dB)]

The order of the filter used is p=64 and the ripple level was -60 dB. The function returns p sample values of h(n) as the coefficients of a transversal filter. The tracheal sounds were then filtered using the finite convolution sum given as

$$y(n) = \sum_{k=0}^{p} b_k x(n-k)$$

where y(n) is the output of the filter at time n , x(.) is the tracheal sound sequence and b_k, k=0, 1, 2, ... , p are the filter coefficients.

In this study, Chebychev type window function was chosen due to its flat response in the pass region and the small ripples in the stop band region of the resulting filter. Corner frequencies of the filter are 100 Hz and 2500 Hz.

7.9. Second Segmentation

Examining the flow curve the beginning of the inspiration and expiration phases was determined. Data were extracted starting from the first 25 % of the breathing cycle (inspiration or expiration) on the time domain. 1024 data points were then extracted at a sampling rate of 5 kHz. For normalization purposes, the RMS values of the data were equalized to 1.

7.10. The Short-Time Fourier Transform

Although the FT (spectrum) does not explicitly show the time localization of frequency components, such a time localization can be obtained by suitably pre-windowing the signal x(t) as shown figure 7.6. Accordingly, the short-time Fourier transform (STFT), or short-time spectrum, of a signal x(t) is defined as

$$STFT(t,f) = \int_{t'} \left[x(t')\gamma(t'-t) \right] e^{-j2\pi ft'} dt'$$

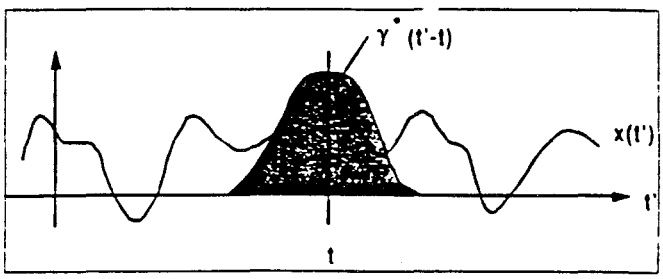


Figure 7. 7. Interpretation of the STFT as a local spectrum .

At time t, the STFT is the Fourier transform of the signal x(t) multiplied by a running analysis window $\gamma(t'-t)$. Since the window suppresses all signal features outside a local neighborhood around time t, the STFT is simply a local spectrum [28]

Short time FFT was applied on inspiratory and expiratory segments of all healthy subjects and all patients. The reason why it was applied on the STFT was that we did not have any experience about the tracheal lung sounds. We wanted to see the frequency distribution of the healthy subjects and all patients. It was determined that the frequency distribution of inspiration and expiration phases were around 500 Hz. However frequency \distribution of patients with COPD and lung cancer it is usually cumulated above 500 Hz or below 500 Hz.

STFT of inspiration and expiration phases of the healthy subject no,1 and patient with COPD (Subject No, 1) is shown in Figure 7. 8. , Figure 7. 9. ,Figure 7.10. and Figure 7.11.

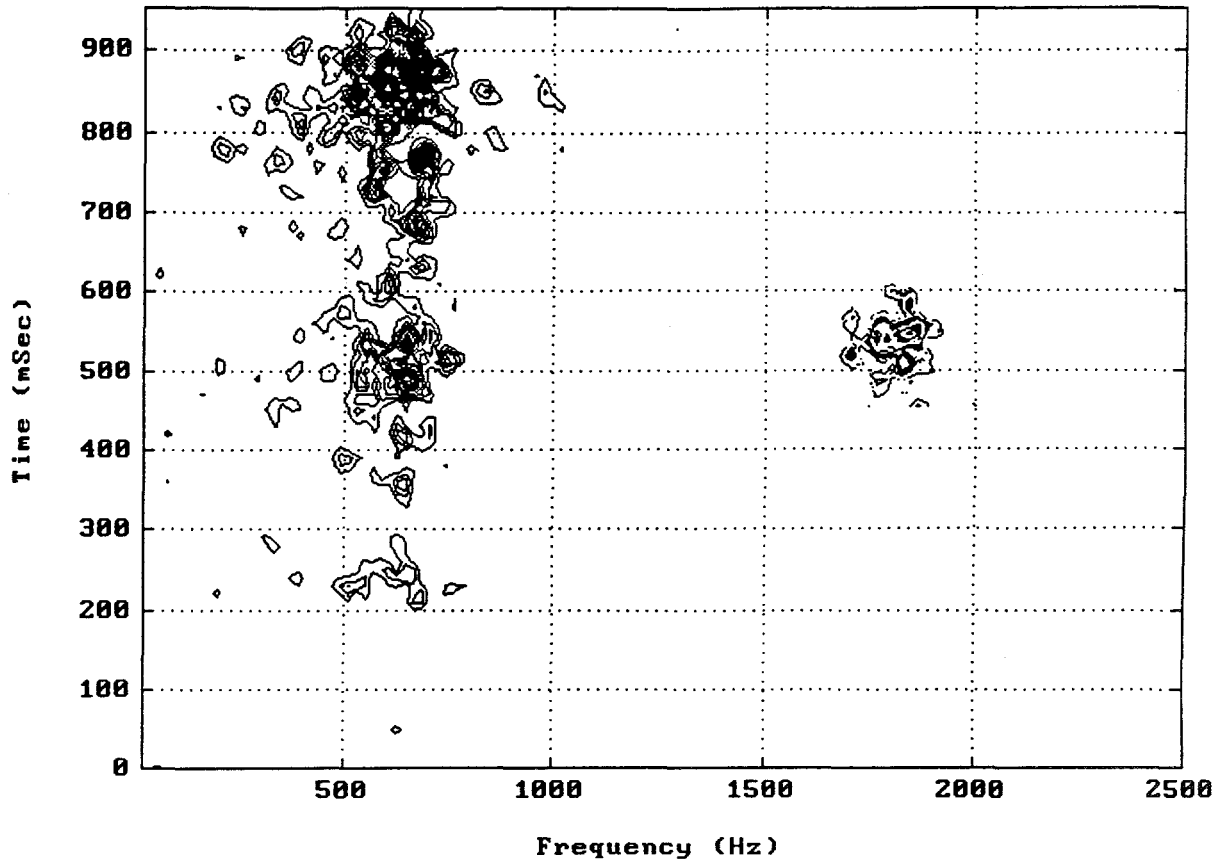


Figure 7. 8. STFT of inspiration phase of a healthy subject no. 1.

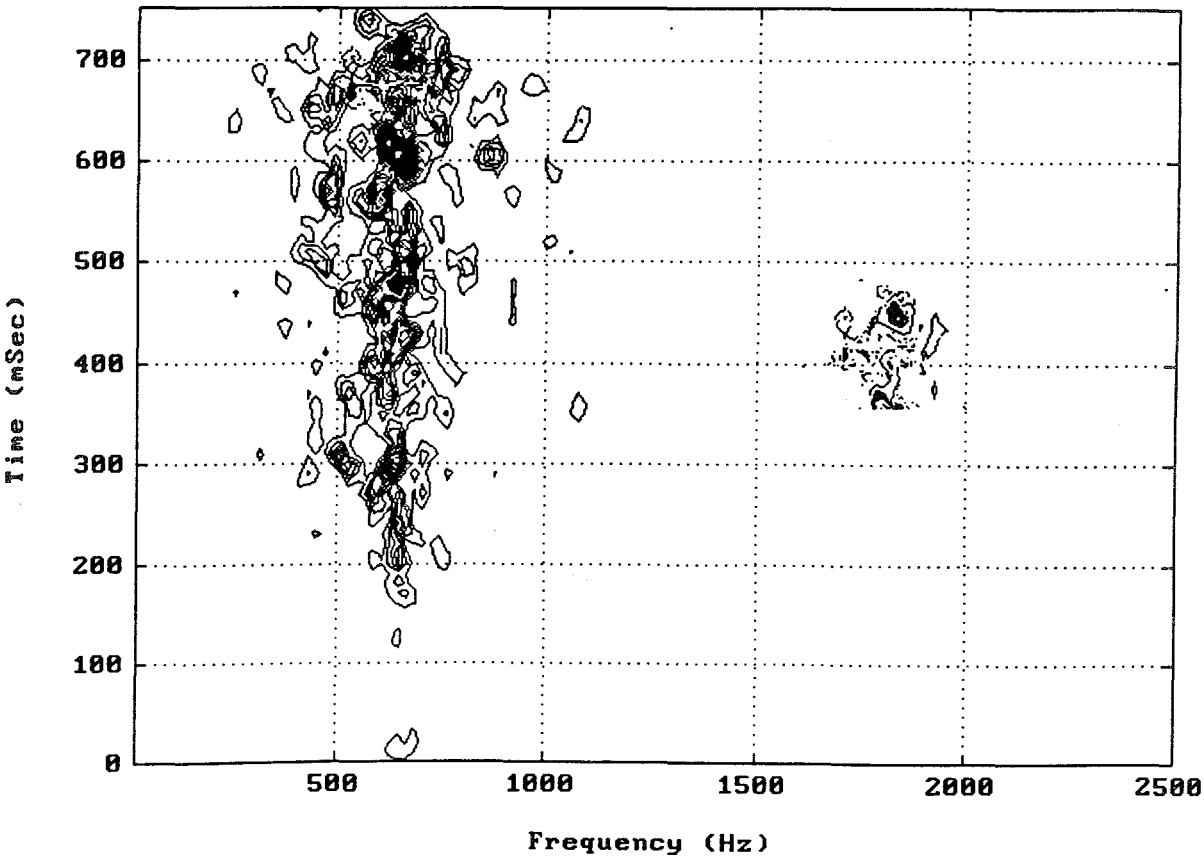


Figure 7.9. STFT of expiration phase of a healthy subject no. 1.

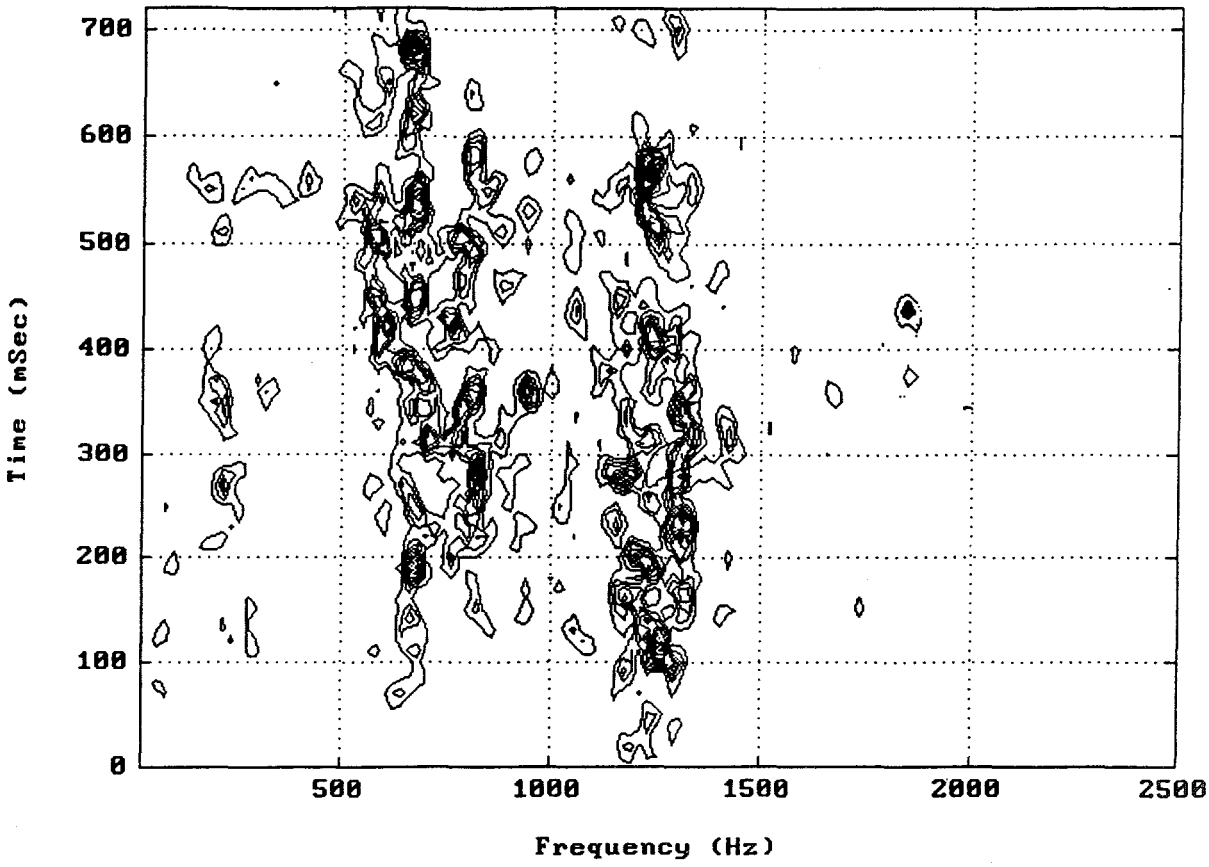


Figure 7.10. STFT of inspiration phase of a patient with COPD (subject No.1).

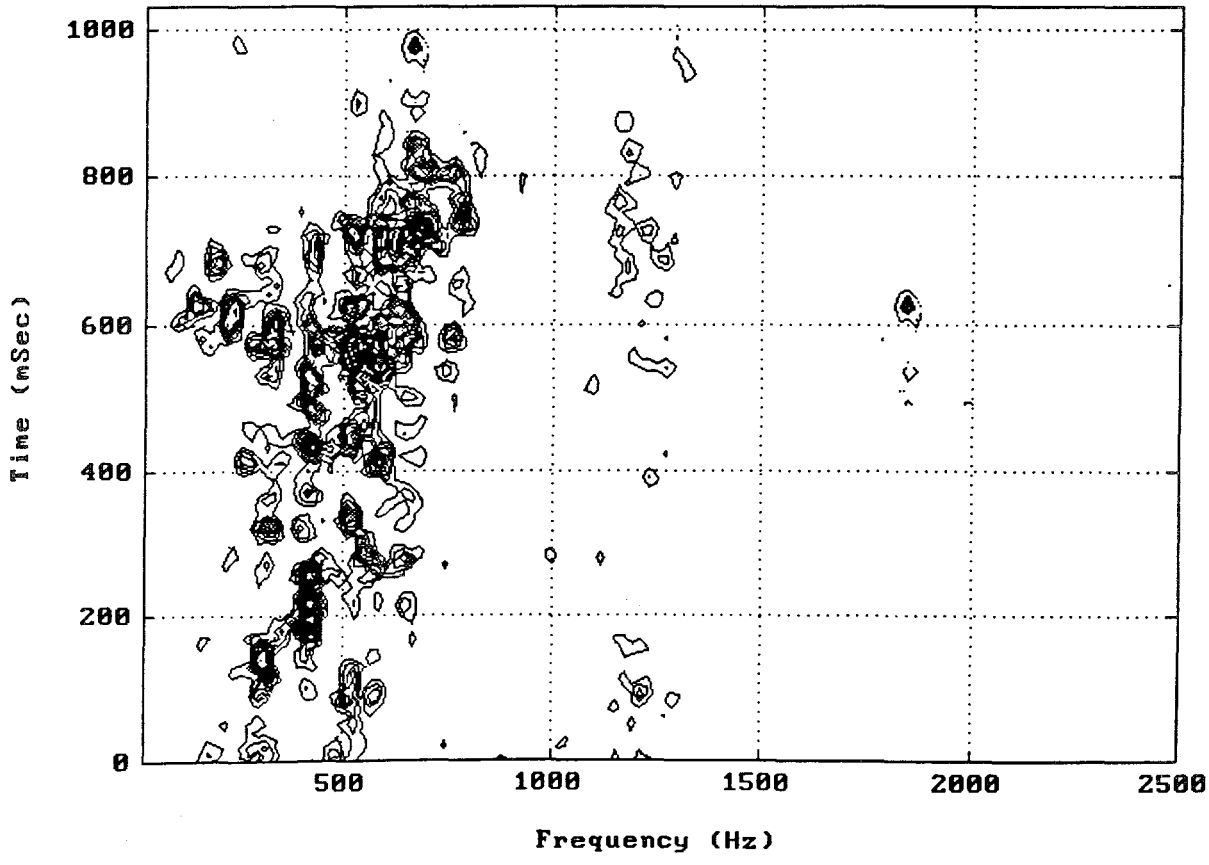


Figure 7.11. STFT of expiration phase of a patient with COPD (Subject No. 1).

7.11. Spectral Estimation

The periodogram estimator of Power Spectral Density(PSD) is defined as

$$P_{per}(F) = \frac{1}{N}\left|\sum_{n=0}^{N-1} x(n)\exp(-j2\pi Fn)\right|^2$$

where x(n) represents the available N-point data record from the process for which the PSD is to be estimated. The Welch method is based on breaking up the N-point data record x(n) into M-point segments x_n that overlap with each other by L samples

After the data record is broken into overlapping M-point segments, a data window is applied to each segment. Then, a periodogram is computed for each windowed segment using the definition given in formula. Finally, these periodograms are averaged, and the result is scaled to obtain the Welch estimate [29].

The purpose of the window is to reduce the effect of side lobes and to decrease the estimation bias, at the price of a sligth decrease in resolution. The purpose of overlapping segments is to decrease the number of segments that are averaged for a given data record length and, therefore, to decrease the PSD estimate variance.

Hanning window is a squared cosine window function.

Characteristics of Hanning window:
Highest side lobe level:-31. 5 dB
Asymptotic side lobe decay rate:-18 dB/octave
Equiv. BW(DTFS bins): 1. 50
1/2-Power BW(DTFS bins): 1. 44 [30].

In our study, we used Hanning window with segment length of 512, and an overlap of 256 (50 %).

7.12. t-Test

Frequency spectrum of each healthy subjects and patients was evaluated using t-test. . It is used to determine the statistically difference of two groups which have less than 30 cases . In t-test, firstly mean value and then variance of two groups are computed by this formula [31].

$$s = \frac{\sum(x - \bar{x})^2}{N}$$

s=variance

x is each score

$\bar{x}$ is the mean value

N is number of cases

after computing variance, standard error of the difference is calculated by this formula

$$s_{diff} = \sqrt{\frac{\sum(x_1 - \bar{x}_1)^2 + \sum(x_2 - \bar{x}_2)^2}{N_1 + N_2 - 2}\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}$$

where N_1 and N_2 are number of samples 1 and 2 , respectively

The computation of t- test is done by the following formula :

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_{diff}}$$

8. EXPERIMENTAL RESULTS

The frequency spectrum of each healthy subject and patients with COPD and Lung cancer are seen in Figure 8. 1. , Figure 8.2. and Figure 8.3. As it is shown in Figure 8.1., Figure 8.2. and Figure 8.3., the frequency spectra of all healthy subjects and patients were divided into three equal regions. These regions were determined as follows: The power of peak frequency for inspiration and expiration phases of each healthy subjects were determined, after that 50 percent of magnitude of power of peak frequency for inspiration and expiration phases were measured manually. From this point, 50% of power of peak frequency, was drawn a horizontal line for each healthy subjects. This horizontal line cuts the frequency spectrum of inspiration and expiration phases at first and the last points. These two points for inspiration and expiration phases have two frequencies. After these two frequencies were determined for inspiration and expiration phases for healthy subjects, averaged values were calculated for inspiration and expiration phases. 458.6 Hz and 633.8 Hz are averaged values of frequencies for inspiration, 570.2 Hz and 701.9 Hz are averaged values of frequencies for expiration phase.

Therefore , frequency spectrum of all healthy subjects and all patients can be divided into three equal regions. Region1 (R1) for inspiration is between 0 Hz and 458.6 Hz, Region2 (R2) for inspiration is between 458.6 Hz, Region3 (R3) for inspiration is between 633.8 Hz and 2500 Hz. These three regions for expiration phase are respectively; 0 Hz-570.2 Hz, 570.2 Hz -701.9 Hz , 701.9 Hz-2500 Hz.

Area of R1, R2 and R3 were calculated for inspiration and expiration phases for healthy subjects and patients. After that total area (TA) was calculated for each phase and subject. The results are given in Table 8. 1.

After the calculation of the total area of each healthy subject and patient, area of R1, R2 and R3 were divided to the total area. The normalized values (NR1), (NR2), (NR3) are presented in Table . 8. 1.

After measuring normalized values of R1, R2 and R3 of all healthy subjects and all patients, normalized values of R1, R2 and R3 was calculated for group of healthy subjects, group of patients with COPD and group of patients with lung cancer (NNR1), (NNR2), (NNR3). This is shown in Table 8. 2.

The t-test was applied on these normalized values of R1, R2 and R3 of groups of healthy subjects and patients. Results of t-test is seen in the Table 8. 3. .

Table 8. 1. Total And Averaged Areas of Each Healthy Subject

	INSPIRATION							EXPIRATION						
	R1	R2	R3	TA	NR1	NR2	NR3	R1	R2	R3	TA	NR1	NR2	NR3
HEALTHY														
1	35.2	84.3	105.8	225.3	15.62%	37.42%	46.96%	47.9	93.6	64	205.5	23.31%	45.55%	31.14%
2	54.8	95	40.1	189.9	28.86%	50.03%	21.12%	65.3	100.2	25.2	190.7	34.24%	52.54%	13.21%
3	41	100.6	116.5	258.1	15.89%	38.98%	45.14%	100.9	77.6	30.8	209.3	48.21%	37.08%	14.72%
4	126.9	53	70.2	250.1	50.74%	21.19%	28.07%	49.4	69.6	122.3	241.3	20.47%	28.84%	50.68%
5	120.3	50.9	57.1	228.3	52.69%	22.30%	25.01%	154	51.7	18.4	224.1	68.72%	23.07%	8.21%
COPD														
1	23.8	28.1	195.5	247.4	9.62%	11.36%	79.02%	152.1	86.6	39.7	278.4	54.63%	31.11%	14.26%
2	9	22.9	77.1	109	8.26%	21.01%	70.73%	59.4	163.5	90.2	313.1	18.97%	52.22%	28.81%
3	97.8	50.8	93.8	242.4	40.35%	20.96%	38.70%	174	23.1	22.9	220	79.09%	10.50%	10.41%
4	110.5	59.8	64.6	234.9	47.04%	25.46%	27.50%	120.2	13.4	102.2	235.8	50.98%	5.68%	43.34%
5	91.1	58.2	79.7	229	39.78%	25.41%	34.80%	97.3	88.7	56.7	242.7	40.09%	36.55%	23.36%
6	27.4	52.2	174.4	254	10.79%	20.55%	68.66%	16.8	74.5	102.7	194	8.66%	38.40%	52.94%
7	229.3	12.7	103.8	345.8	66.31%	3.67%	30.02%	12.8	40.7	222.7	276.2	4.63%	14.74%	80.63%
8	44	23.7	119.3	187	23.53%	12.67%	63.80%	171.3	22	40.3	233.6	73.33%	9.42%	17.25%
LUNG CA.														
1	96.4	22.9	126.5	245.8	39.22%	9.32%	51.46%	72.1	24.6	130.4	227.1	31.75%	10.83%	57.42%
2	32	54.2	114.8	201	15.92%	26.97%	57.11%	46.7	103.9	43.4	194	24.07%	53.56%	22.37%
3	197.9	26.2	10.2	234.3	84.46%	11.18%	4.35%	226	6.1	1.7	233.8	96.66%	2.61%	0.73%
4	40.8	66.8	146.6	254.2	16.05%	26.28%	57.67%	93.7	70.2	59.5	223.4	41.94%	31.42%	26.63%
5	104	50	76.3	230.3	45.16%	21.71%	33.13%	53.4	44.3	141.4	239.1	22.33%	18.53%	59.14%
6	126.1	76.9	19.9	222.9	56.57%	34.50%	8.93%	181.2	14.4	6.1	201.7	89.84%	7.14%	3.02%

Table 8. 2. Averaged Areas of Healthy Group and Patients Group

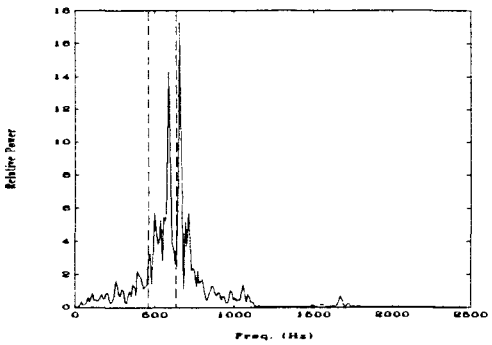
	INSPIRATION			EXPIRATION		
	NNR1	NNR2	NNR3	NNR1	NNR2	NNR3
Average Areas						
HEALTHY	32.76%	33.98%	33.26%	38.99%	37.42%	23.59%
COPD	30.71%	17.64%	51.65%	41.30%	24.83%	33.88%
CA	42.90%	21.66%	35.44%	51.10%	20.68%	28.22%

Table 8. 3. t -Test Results of Averaged Areas of Healthy Group and Patients Group

	INSPIRATION			EXPIRATION		
	NNR1	NNR2	NNR3	NNR1	NNR2	NNR3
t-test						
Normal - Abnormal	64.86%	0.05%	10.83%	39.97%	2.48%	19.91%
Normal - COPD	82.28%	0.58%	6.47%	83.11%	13.60%	24.53%
Normal - CA	47.36%	7.31%	84.14%	44.62%	11.08%	71.92%
COPD - CA	29.82%	33.81%	18.00%	51.68%	66.07%	60.86%

HEALTHY

Inspiration



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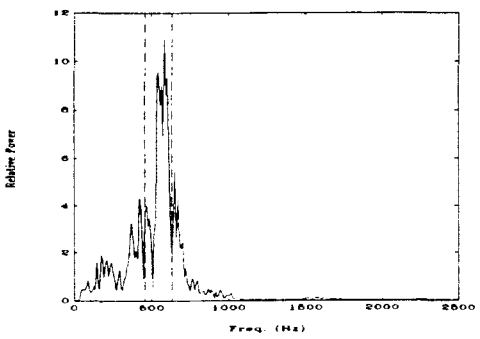

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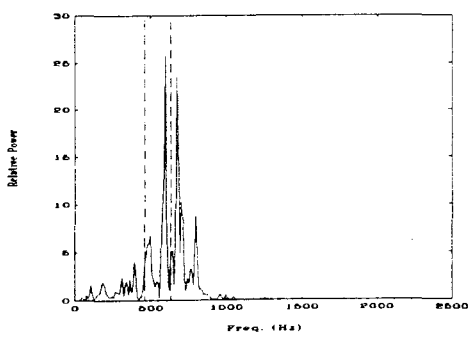

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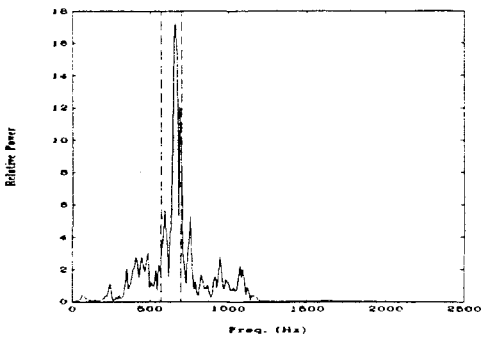

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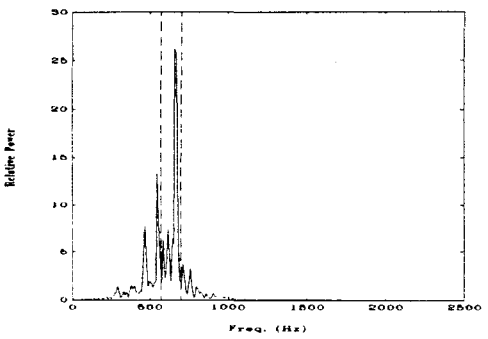

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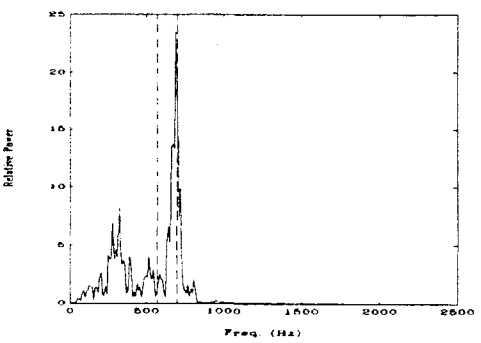

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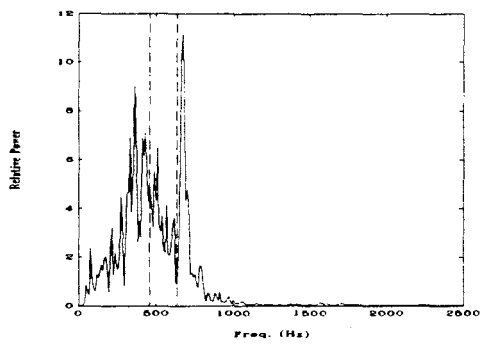
HEALTHY

Inspiration

Expiration



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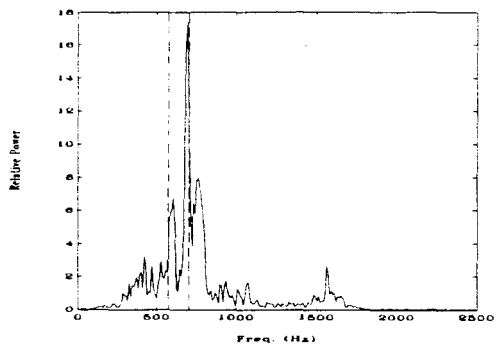

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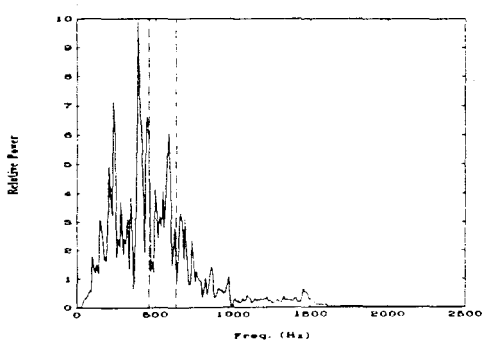

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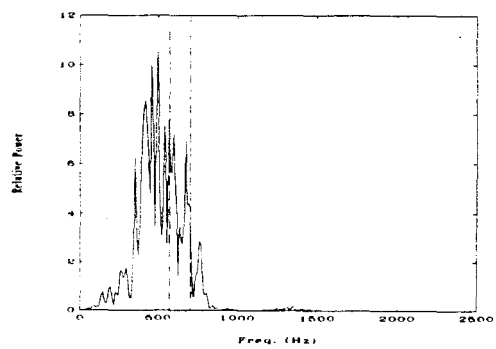

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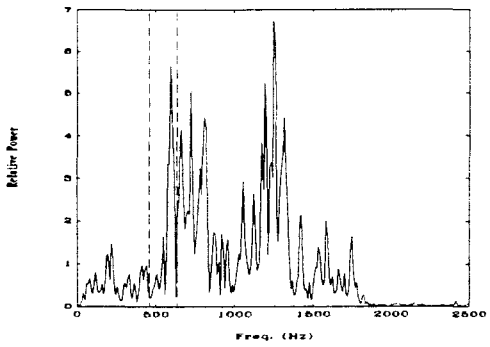
Figure 8.1. Frequency Spectra of Healthy Subjects.

COPD

Inspiration



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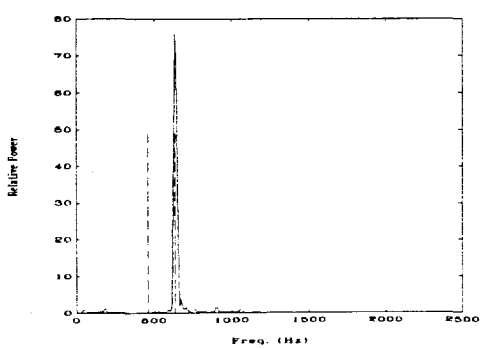

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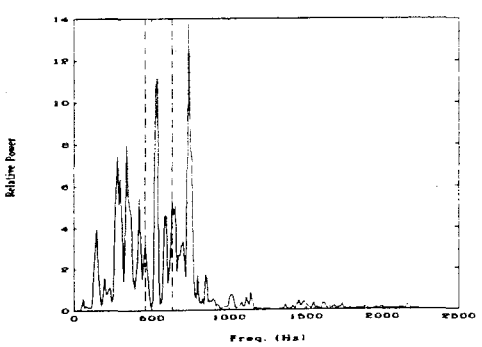

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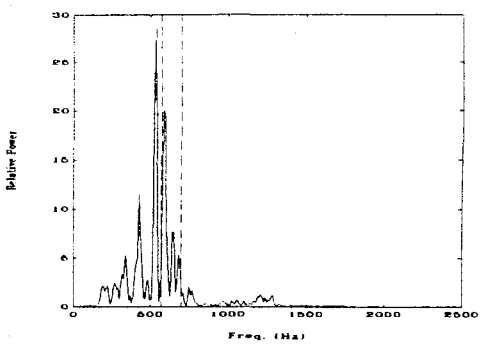

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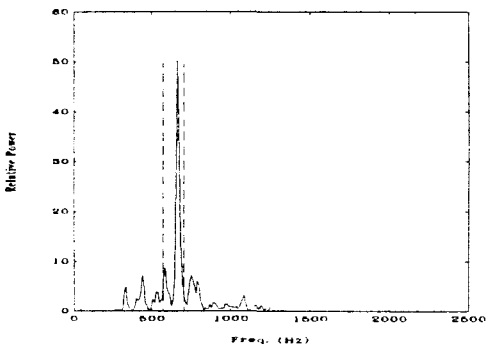

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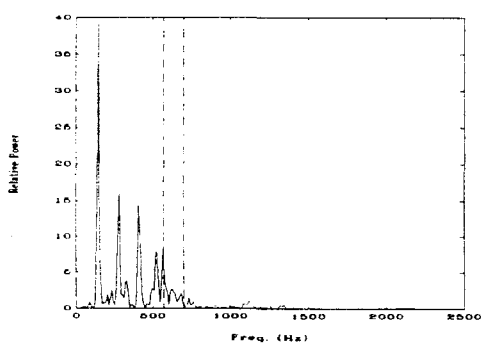

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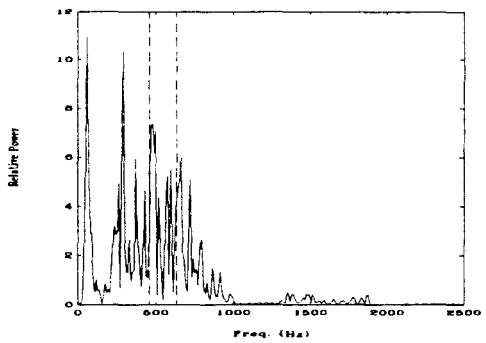

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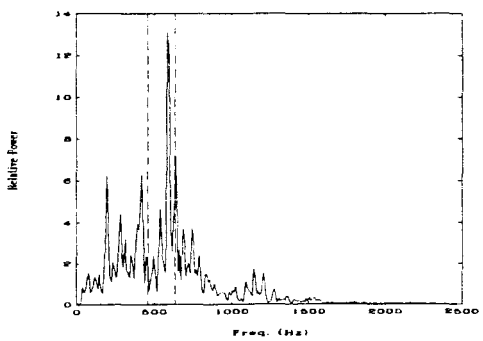

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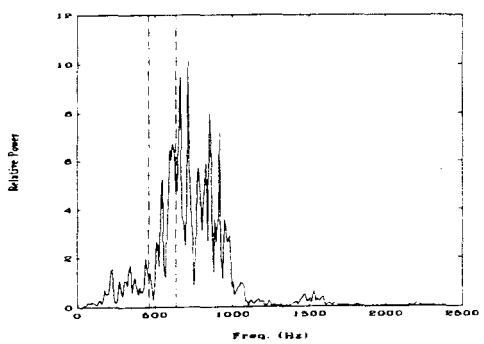

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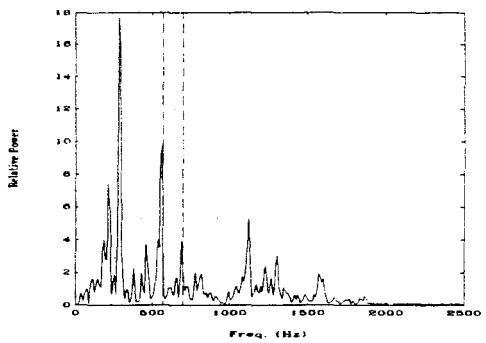

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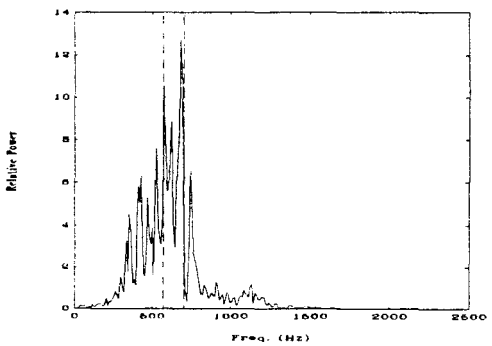

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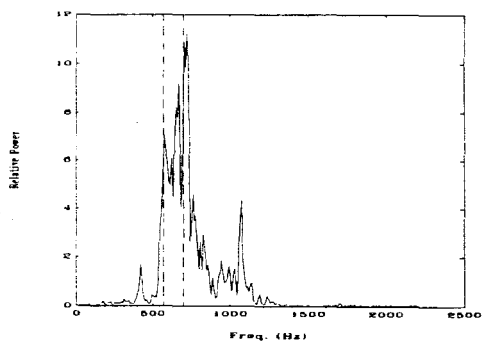

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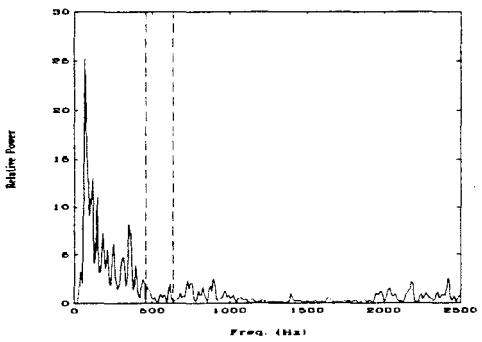

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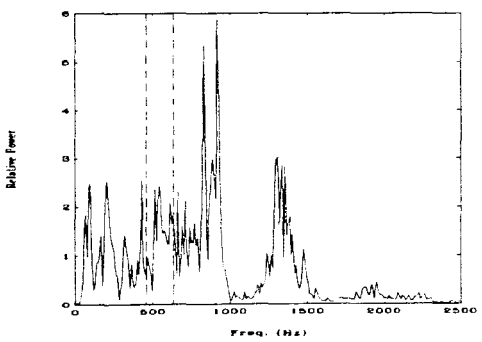

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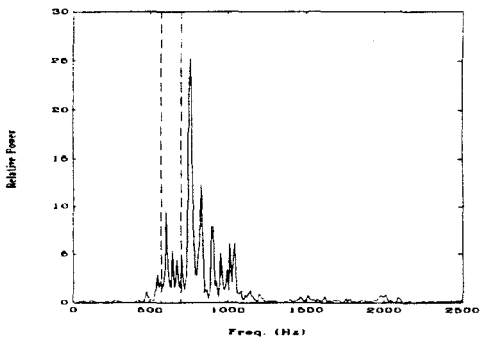

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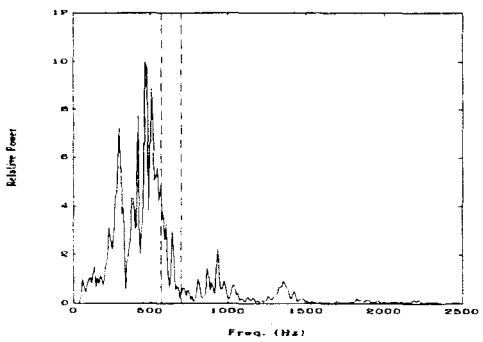

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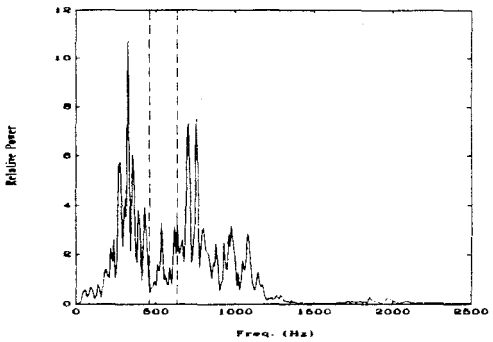
Figure 8.2. Frequency Spectra of Patients With COPD.

LUNG CANCER

Inspiration



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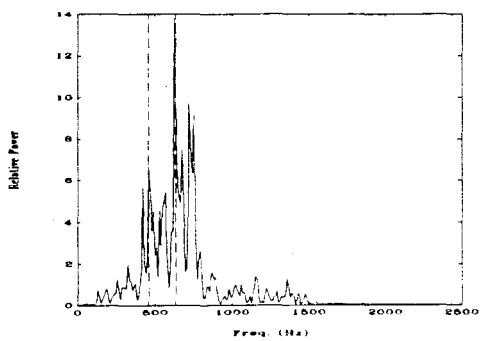

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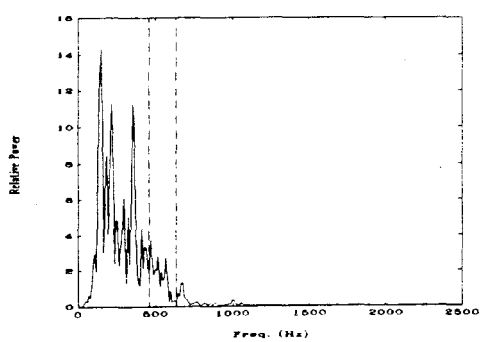

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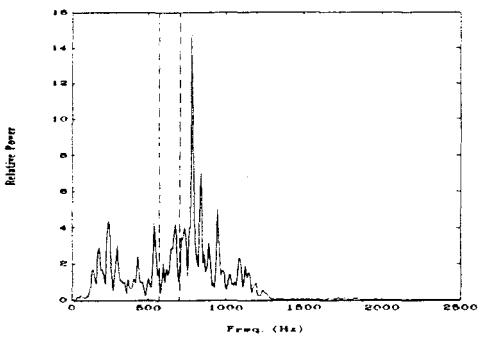

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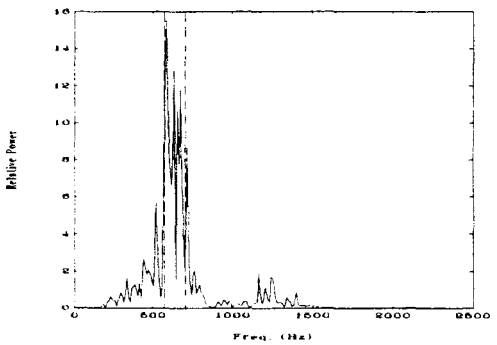

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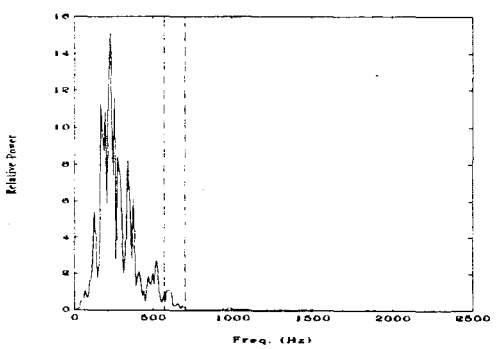

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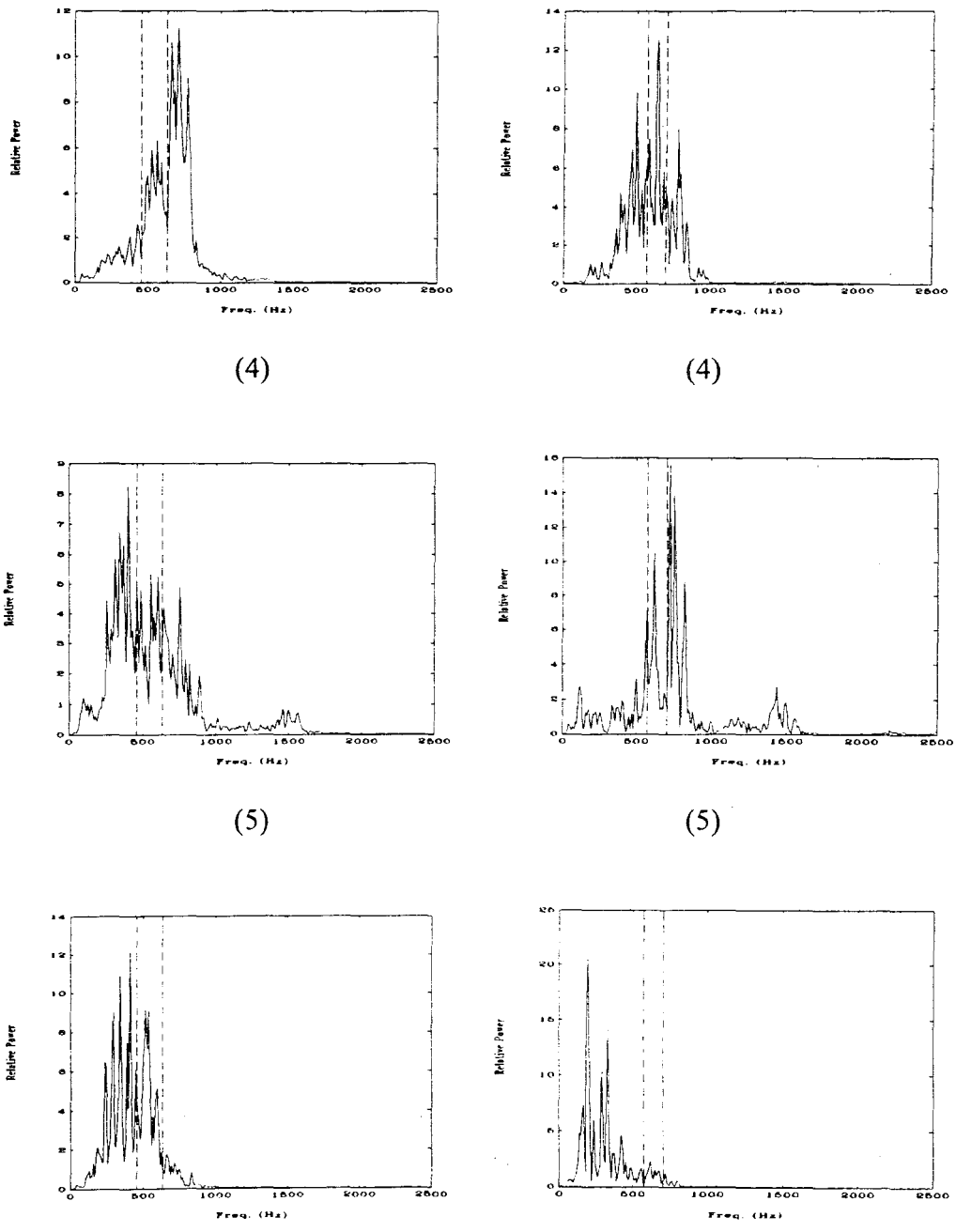
LUNG CANCER

Inspiration Expiration



(4) (4)

(5) (5)

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Figure 8.3. Frequency Spectra of Patients With Lung Cancer.

9. CONCLUSIONS

Averaged area of the regions, R1, R2 and R3 of the inspiration phase of healthy subjects are almost equal (32. 76 % , 33. 98% and 33. 26 %, respectively).

However, the averaged area of the region R3 in the inspiration phase of patients with COPD is seen to be larger (51. 65 %). This region is related to wheezing since it is rich in high frequency components.

It can be seen that the averaged area of R1 of the inspiration and expiration phases of the patients with lung cancer increases to 42. 90 % and 51. 10 %, respectively. Because this region has low frequency components, it can be related to adventitious lung sounds as called rhonchus. Rhonchus is characterized by low frequency components and is usually related to large bronchus. The cause of this increase in the area of this region in patients with lung cancer might be attributed to the fact that tumors of lung arise usually in large airways.

Application of the statistical t-test between the normal (healthy) and abnormal subjects (patients), shows that the possibility of common percentage area of mean distribution of region R2 of normal and abnormal subjects in the inspiration phase is 0. 05 % . This shows that this region is very important to distinguish the tracheal lung sounds between healthy subjects and patients.

The t-test results shows that R2 is again important for differentiation between healthy subjects and patients with COPD, and , between healthy subjects and lung cancer.

The aim of this study was to diagnose the lung cancer. Unfortunately patients with COPD and lung cancer have similar symptoms because they are usually heavy smokers. Therefore, it is important to determine the distinctive spectral characteristics between the patients with COPD and patients with lung cancer. Comparison of R3 in the inspiration phase of patients with COPD and lung cancer by using t-test results in 18 %. This shows that area of distribution of mean values of patients with COPD and lung cancer have common area as 18 percentage. Therefore, the possibility of distinguising the patients with COPD and lung cancer by using values of R3 is 82 %.

The cause of this fact can be that the lumen of the bronchi is usually obstructed in high level in lung cancer, however since the lumen of bronchi increases in inspiration phase, the air can pass through the obstructed area, that can produce high frequency sounds which are in R3.

Most of the patients suffering from lung cancer are treated with chemotherapy and radiotherapy. Successful therapy results in a decrease in the diameter of the tracheal tumor. This study shows that the technique developed in this thesis has some potential as a noninvasive tool for the evaluation of the success of these treatment methods.

Because the number of patients studied in the present thesis is rather small, it is not possible to make any predictions on whether the same technique could be used for estimating also the location of the tumors.

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