Chapter 2
2.1 Introduction

Respiration is the process of exchange of gases between the body tissues and external environment. In order to sustain life, the human body must take in oxygen, which combines with carbon, hydrogen, and various nutrients to produce heat and energy for the performance of work. The principal waste product of this process of metabolism, which takes place in the cells, is carbon dioxide. The entire process of taking in air from the environment, transporting oxygen to the cells, and removing the carbon dioxide from the cells and exhausting it into the atmosphere is considered to be the process of respiration [2]. This chapter discusses the physiology of respiratory system in brief and the commonly used techniques for detecting any malfunctioning of respiratory system.

2.2 Respiratory Physiology

Air enters the human body through mouth and nose and then passes through the larynx and the trachea. Larynx houses the vocal cords that vibrate when air is forced through it. Trachea is a vertical tube that enters the chest cavity and it is kept open by rings of cartilage to allow passage of air to and from the lungs. In the chest cavity, the trachea splits into two smaller tubes called the bronchi. Each bronchus then divides
again forming the bronchial tubes. The bronchial tubes lead directly into the lungs where they divide into many smaller tubes which connect to tiny sacs called alveoli. The alveoli have very thin walls which are crisscrossed with the finest of blood vessels called capillaries. The average adult's lungs contain about 300 millions of alveoli.

The respiratory system can be sectioned into two portions: conducting portion and respiratory portion. The conducting portion provides a passageway for air and functions to condition the incoming air, by warming, moistening and cleaning it. It consists of the pharynx, larynx, trachea, bronchi, and bronchioles. The respiratory portion, which consists of respiratory bronchioles, alveolar ducts and alveolar sacs, serves to rid the body of carbon dioxide and pick up oxygen. A schematic representation of the respiratory system is shown in Fig. 2.1.

The inhaled air passes into the alveoli and then the oxygen in the air diffuses through the capillaries into the arterial blood. Meanwhile, the blood from the veins
releases its carbon dioxide into the alveoli. The carbon dioxide follows the same path out of the lungs when one exhales. The oxygen is distributed among various cells of the body by the blood circulation system, which also returns the carbon dioxide to the lungs. The entire process of inspiring and expiring air, exchange of gases, distribution of oxygen to the cells, and collection of carbon dioxide from the cells forms pulmonary function.

2.2.1 Mechanics of Breathing

The mechanics of breathing involve muscles that change the volume of the thoracic cavity to generate inspiration and expiration [3]. The two sets of muscles involved are the diaphragm, the wall separating the abdomen from the thoracic (chest) cavity that moves up and down, and the muscles surrounding the thoracic cavity that moves the rib cage in and out.

Inspiration results from the contraction of the diaphragm and intercostal muscles. The enlarged cavity housing the lungs undergoes a pressure reduction with respect to the pressure outside the body. Since the lungs are passive, they expand because of the positive external pressure. The closed nature of the thoracic chamber allows air to enter the lungs through the mouse and nose.

Expiration results from the relaxation of the diaphragm and intercostal muscles. The elastic recoil of the lungs creates a higher than atmospheric intrapulmonic pressure that forces air out of the lungs.

2.3 Diagnosis of Respiratory System

The primary function of respiratory system can be stated as two folds: first, the oxygenation of mixed venous blood; second, the removal of carbon dioxide from that
same blood. These two functions depend on the integrity of the airways, the pulmonary vascular system, the alveolar septa, the respiratory muscles, and the respiratory control mechanisms. The functioning of respiratory system is affected by various factors, thus degrading its performance. The assessment of the type and degree of functional impairment is important in the diagnosis, management, and prognosis of pulmonary disorders. Pulmonary function tests can be performed to assess the performance of respiratory system, but no single measurement technique has been devised that can adequately and completely evaluate the performance of the respiratory system.

The evaluation of pulmonary function may be indicated for the following reasons [4]:

- To determine the presence of lung disease or abnormality of lung function
- To determine the extent of abnormalities
- To determine the extent of impairment caused by abnormal lung function
- To determine the progression of the disease
- To determine the nature of the physiological disturbance

The general areas of pulmonary function testing are

1. Spirometry, which measures pulmonary volumes and flows,
2. Helium dilution test or body plethysmograph for measuring the functional residual capacity and residual volume,
3. Tests such as single breath nitrogen elimination technique to measure the evenness of distribution of inspired oxygen,
4. Tests to evaluate gas diffusion across the alveolar-capillary membrane,
5. Exercise testing,
6. Lung sound analysis, and
7. Blood gas analysis, which tests the effects of physiologic lung changes on the homeostasis of gas exchange by the tissues.
2.3.1 Spirometry

Spirometry, a relatively simple and informative PFT for characterizing pulmonary function, is well established in clinical medicine. It measures the flow rate and volume of air obtained in a patient's breathing effort using an equipment called spirometer. Spirometer can monitor quiet breathing and thereby measure tidal volume, and also trace deep inspirations and expirations to give information about vital capacity and other dynamic parameters. Spirometry provides an insight into the status of the respiratory system that can be used for classifying and staging pulmonary disorders. It can detect respiratory abnormalities and help to differentiate the various disease processes that result in ventilatory impairment. One of the most important advantages of spirometry is that it enables to detect COPD before the symptoms become apparent. The British Thoracic Society and International Lung Health Education Program recommend the use of spirometry in the prevention and early diagnosis of pulmonary disease.

Spirometry is performed with the subject in a seated position. The most important test in spirometry is forced expiratory manoeuvre. Applying noseclips, the subject is instructed to take normal breaths 3-4 times through a mouthpiece connected to the spirometer. Then he is asked to take a full inspiration, hold it briefly, then exhale as forcefully and completely as possible.

There are a number of indications for the performance of a spirometry test on a patient [4], including

- dyspnea or shortness of breath
- chronic cough
- wheezing
- occupational exposure to inhaled environmental hazards
• early detection of congestive heart disease
• therapeutic management of bronchodilators
• pre-operative examination of patients undergoing thoracic or upper abdominal surgery

2.3.2 Lung Parameters

The various important lung parameters that are measured using a spirometer are [3–5]:

• Tidal volume (TV): The volume of air inspired or expired during each normal, quiet respiratory cycle.

• Vital capacity (VC): The largest volume of air measured on complete expiration after the deepest inspiration without forced or rapid effort. It is actually the difference between the maximum inspiratory level and maximum expiratory level.

• Total lung capacity (TLC): TLC is the volume of air contained in the lungs at the end of a maximal inspiration. It is the sum of vital capacity and residual volume.

• Forced vital capacity (FVC): The maximum volume of air that can be expired as forcefully and rapidly as possible after maximal inspiration.

• Residual volume (RV): It is the volume of gas remaining in the lungs at the end of maximal expiration.

• Functional residual capacity (FRC): FRC is the volume of air remaining in the lungs at the resting expiratory level.

• Forced inspiratory vital capacity (FIVC): The maximum volume of air that can be inspired as forcefully and rapidly as possible after maximal expiration.
• Forced expiratory volume in T seconds (FEV\textsubscript{T}): It is the volume of air expired over a given time interval of T seconds during the performance of an FVC manoeuvre. The interval is stated as a subscript to FEV. Those intervals in common use are FEV\textsubscript{0.5}, FEV\textsubscript{1}, FEV\textsubscript{2} and FEV\textsubscript{3}.

• FEV\textsubscript{1}%: FEV\textsubscript{1} expressed as a percentage of FVC.

• Peak expiratory flow (PEF): It is the maximum flow rate attained at any time during an FEV manoeuvre.

• FEF\textsubscript{25%}: Forced expiratory flow (FEF) at the point when 25% of FVC is exhaled.

• FEF\textsubscript{75%}: Forced expiratory flow at the point when 75% of FVC is exhaled.

• FEF\textsubscript{25–75%}: It is the average rate of flow during the middle half of an FEV manoeuvre.

• Forced inspiratory volume in T seconds (FIV\textsubscript{T}): It is the volume of air inspired over a given time interval of T seconds during the performance of a forced inspiratory manoeuvre. The interval is stated as a subscript to FIV.

• FIV\textsubscript{1}%: FIV\textsubscript{1} expressed as a percentage of FVC.

• Peak inspiratory flow (PIF): It is the maximum flow rate attained at any time during a forced inspiratory manoeuvre.

Most of the lung parameters described above are depicted in Fig. 2.2. Lung volumes such as inspiratory capacity (IC), inspiratory reserve volume (IRV), and expiratory reserve volume (ERV) are also indicated in Fig. 2.2.

A measure of the overall output of the respiratory system is the respiratory minute volume. This is a measure of the amount of air inspired during one minute.
Fig. 2.2. Lung volumes and capacities - a diagrammatic representation

at rest. It is obtained by multiplying the tidal volume by the number of respiratory cycles per minute. Another useful measurement for assessing the integrity of breathing mechanism is the maximal voluntary ventilation. This is a measure of the maximum amount of air that can be breathed in and blown out over a sustained interval. A ratio of maximal breathing capacity to the vital capacity is also computed. With each breath, most of the air enters the lungs to fill the alveoli. However, a certain amount of air is required to fill the various cavities of the air passage. This air called dead space air, and the space it occupies is called the dead space.

Apart from computing the above mentioned static and dynamic lung parameters, the flow during forced expiratory manoeuvre is plotted as a function of expired
volume to generate the maximum expiratory flow volume (MEFV) curve. MEFV curve is also of clinical interest to the physician. It may be noted that the lung parameters are functions of an individual's physical and mental characteristics and the condition of his respiratory system.

In the presentation of various respiratory volumes, the term BTPS is often used, indicating that the measurements were made at body temperature and ambient pressure, with the gas saturated with water vapour.

### 2.3.3 Mechanical Properties

The operation of the lungs can be understood using mechanical properties. The mechanical properties normally considered are discussed below.

**Airway Resistance**

It is the ratio of the change in pressure drop along the conduit to the change of flow through it while the change in volume of the conduit is zero. It is the opposition to flow caused by the forces of friction.

**Airway Compliance**

It is the ratio of the change in volume of the structure to the change in pressure difference across it while all flows and derivatives are zero. Compliance refers to the ability of the elastic structure of the lung to distend.

**Lung Elasticity**

It is the ability of the lung’s elastic tissues to recoil during expiration. The lungs should return to their rest state easily to ensure sufficient exhaust of gases.
2.4 Summary

The physiology of respiratory system and the techniques for detecting pulmonary impairments have been discussed briefly in this chapter. The following chapters discuss about the proposed novel methods for diagnosis and analysis of respiratory system.