# Respiration in Health and Disease

# Respiration in Health Disease

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Respiration in Health and Disease

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# PREFACE TO THE SECOND EDITION

In the original edition of this text emphasis was placed on the mechanisms of development of symptoms and physical signs and on the correlation of clinical, radiologic and morphologic manifestations with disturbances in respiratory function. Since then, several books stressing pulmonary function in respiratory disease have appeared, but none of them have been directed primarily toward the student in medicine and related health sciences. This, together with the fact that there have been many advances in our understanding of basic mechanisms of disturbed function has led to publication of a second edition. Therapy was not included in the initial edition because it was felt that an understanding of basic disturbances in respiratory disease would lead to the appropriate management. However, the absence of a discussion of the principles of management was soon recognized as a serious omission. The principles of management of patients suffering from acute or chronic respiratory failure have therefore been included. In addition, the defenses of the respiratory system, stress situations in which many of the respiratory symptoms occur, and special aspects related to the newborn infant and child have been added.

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#### INTRODUCTION

The main functions of the respiratory system are to supply oxygen to the cells of the body and to remove carbon dioxide from them. Net movement of gases by diffusion occurs at two principal sites—in the lungs and in the tissues. In mammals the exchange of oxygen and carbon dioxide between the body and its environment cannot occur at a rate sufficient to sustain life by simple diffusion alone; therefore, a gas transport system for the conduction of oxygen and carbon dioxide between the atmosphere and lungs, on the one hand, and between the lungs and the tissues, on the other, is required. A schematic representation of this transport system is shown in Figure 1.

Bulk or convective transport occurs between the lungs and the tissues (circulation) and between the lungs and the environment (ventilation). In contrast to diffusion, which is passive, ventilation and circulation require that active work be done by the heart and the respiratory muscles in order to generate the mechanical energy needed to produce bulk flow of gas or blood. Since this energy is liberated as a result of muscular activity, it is possible to regulate convective transport by influencing the activity of cardiac and respiratory muscles.

In the tissues the oxygen diffuses from the blood to its intracellular binding site while the carbon dioxide diffuses from the cells to the blood. The blood entering the lungs comes from the tissues where oxygen has been extracted and carbon dioxide has been added, resulting in a low oxygen partial pressure (PO<sub>2</sub>) and a high CO<sub>2</sub> partial pressure (PCO<sub>2</sub>). The blood which enters the lungs is exposed to gas in the alveoli across the pulmonary capillary walls.

When the respiratory muscles contract, fresh air is inspired into the alveoli so that the alveolar PO<sub>2</sub> is raised and PCO<sub>2</sub> is lowered. Because of the differences between the partial pressures of oxygen and carbon dioxide in the alveoli and in the blood perfusing the lung, there is a net diffusion of oxygen into the blood and carbon dioxide into the alveoli. As the diffusion of oxygen from the lungs into the blood proceeds, there is a decrease in the alveolar PO<sub>2</sub>, and the net diffusion of carbon dioxide from the blood into the alveoli results in an increase in the alveolar PCO<sub>2</sub>. When the respiratory muscles relax, expiration occurs, and the oxygen-depleted and carbon dioxide-

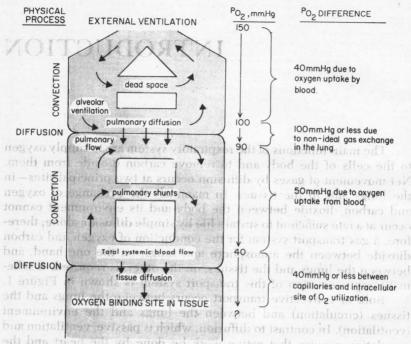


FIGURE 1. Gas transport system between atmosphere and lungs, and lungs and tissues, and the fall in arterial partial pressure of oxygen along the transport system.

d as a result of muscular activity, it is possible to regulate

enriched alveolar gas leaves through the airway. With each succeeding inspiration, the alveolar gas is once again refreshed. Depending on the state of activity of the body, this cycle is repeated 10 to 50 times a minute.

The processes involved in the events which occur during respiration will be described in some detail in the following pages in order to set the stage for a discussion of the disturbances in function produced by disease and the functional interventions which constitute therapy.

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#### Section One

## BASIC CONSIDERATIONS

THE RESPIRATORY PUMP

THE PULMONARY CIRCULATION

OXYGEN AND CARBON DIOXIDE EXCHANGES BETWEEN GAS AND BLOOD

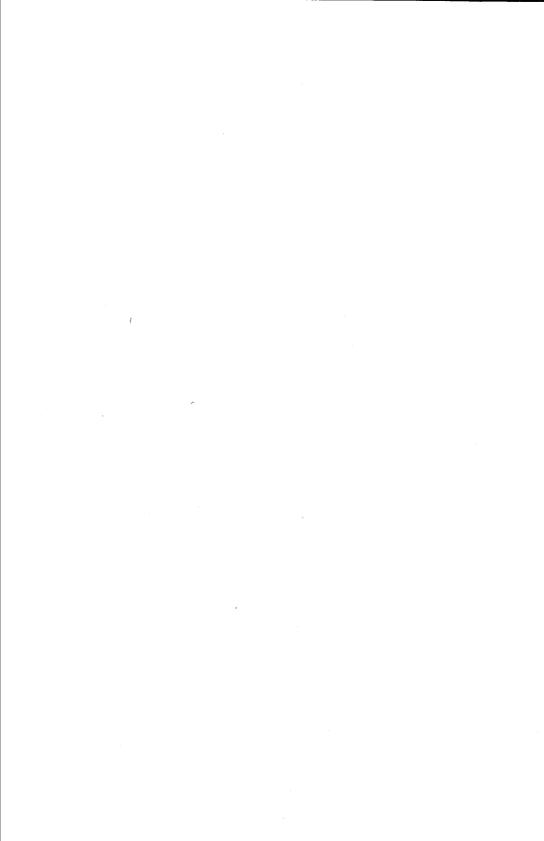
THE CONTROL OF BREATHING

RESPIRATION UNDER STRESS

SPECIAL ASPECTS RELATED TO THE NEWBORN INFANT

THE APPLICATION OF PULMONARY PHYSIOLOGY TO CLINICAL PULMONARY FUNCTION TESTING

THE DEFENSES OF THE RESPIRATORY SYSTEM



# The Respiratory Pump

Expansion of the chest occurs when the inspiratory muscles contract and air enters the lungs and distends the tracheobronchial tree (Fig. 2). During inspiration, all portions of the tracheobronchial tree become enlarged, but the greatest relative expansion takes place in the distal portions of the bronchi. On fluoroscopic examination, both roots of the lungs are seen to descend during inspiration, owing to the elongation of the trachea. In addition, fluoroscopy with radio-paque media placed in the bronchi demonstrates that the bronchi lengthen and increase in diameter during inspiration, whereas during expiration they return to their original length and diameter.

The bronchi divide into successively smaller branches, down to the terminal bronchioles and the respiratory bronchioles, which can be recognized by their alveolar outpouchings. The respiratory bronchioles radiate into the alveolar ducts, which in turn give rise to

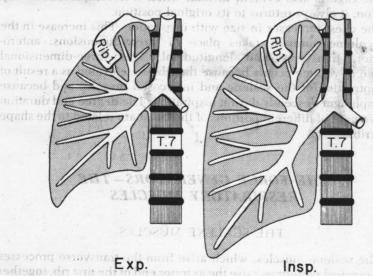


FIGURE 2. The change in size of the tracheobronchial tree during respiration.

the alveolar sacs. These sacs consist of groups of alveoli which have a radius of approximately 55 to 65 microns. It has been estimated that there are three to four billion alveoli in the human lungs and that they occupy an area of 70 to 100 square meters. During inspiration the alveolar ducts become elongated and widen, and the openings into the alveolar sacs increase in size.

## THE SUPPORTING STRUCTURES—THE THORACIC CAGE

The human thorax is constructed in such a manner that it has sufficient rigidity to protect the vital organs it contains, and it provides the pliability which enables it to function as a bellows during the ventilatory cycle. The rigidity results from the bony composition of the ribs; there is pliability because each rib is attached to a resilient cartilage which is fixed to either the sternum or the seventh rib and, in addition, has moveable joints at its vertebral and sternal ends. The first seven ribs are attached to the sternum, and the cartilages of the next three ribs are attached to the cartilage of the seventh rib. The remaining two ribs, the "floating ribs," have no connection with the sternum or other ribs.

The sternum is held in position by its connection with the ventral ends of the ribs, which are under continuous elastic tension, even when the respiratory muscles are relaxed. The elasticity of the thoracic cage is also evident in that, when it is compressed in any direction, it always returns to its original position.

The chest increases in size with inspiration. This increase in the lung volume normally takes place in three dimensions: anteroposterior, transverse and longitudinal. This three-dimensional increase in volume occurs because the ribs are elevated as a result of the contraction of the scalene and intercostal muscles and because the diaphragm descends during inspiration. The degree and duration of movement of different portions of the chest are related to the shape of the ribs.

# THE FORCE GENERATORS—THE RESPIRATORY MUSCLES

#### THE SCALENE MUSCLES

The scalene muscles, which arise from the transverse processes of the cervical vertebrae, raise the anterior end of the first rib, together with the manubrium sternum, when they contract during inspiration. This elevation of the first rib not only increases the anteroposterior diameter of the upper outlet of the thorax but also stabilizes the upper chest cage so that contraction of the intercostal muscles results in elevation of the remaining ribs.

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The first to the sixth ribs are connected with one another by the intercostal muscles, whose fibers run downward and forward. Since the first rib is fixed by the scalene muscles, contraction of the intercostal muscles results in an upward and forward movement of the remaining five ribs. There is very little lateral movement of the first four ribs, which overlie the upper lobes of the lungs, and this portion of the chest cage increases in size primarily in an anteroposterior direction (Fig. 3, third rib).

The fifth and sixth ribs, which are situated approximately over the middle lobe of the right lung and the lingular segment of the left

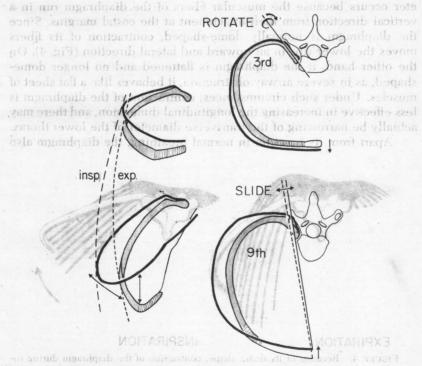


FIGURE 3. Anteroposterior and superior views of an upper and lower rib during inspiration and expiration.

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