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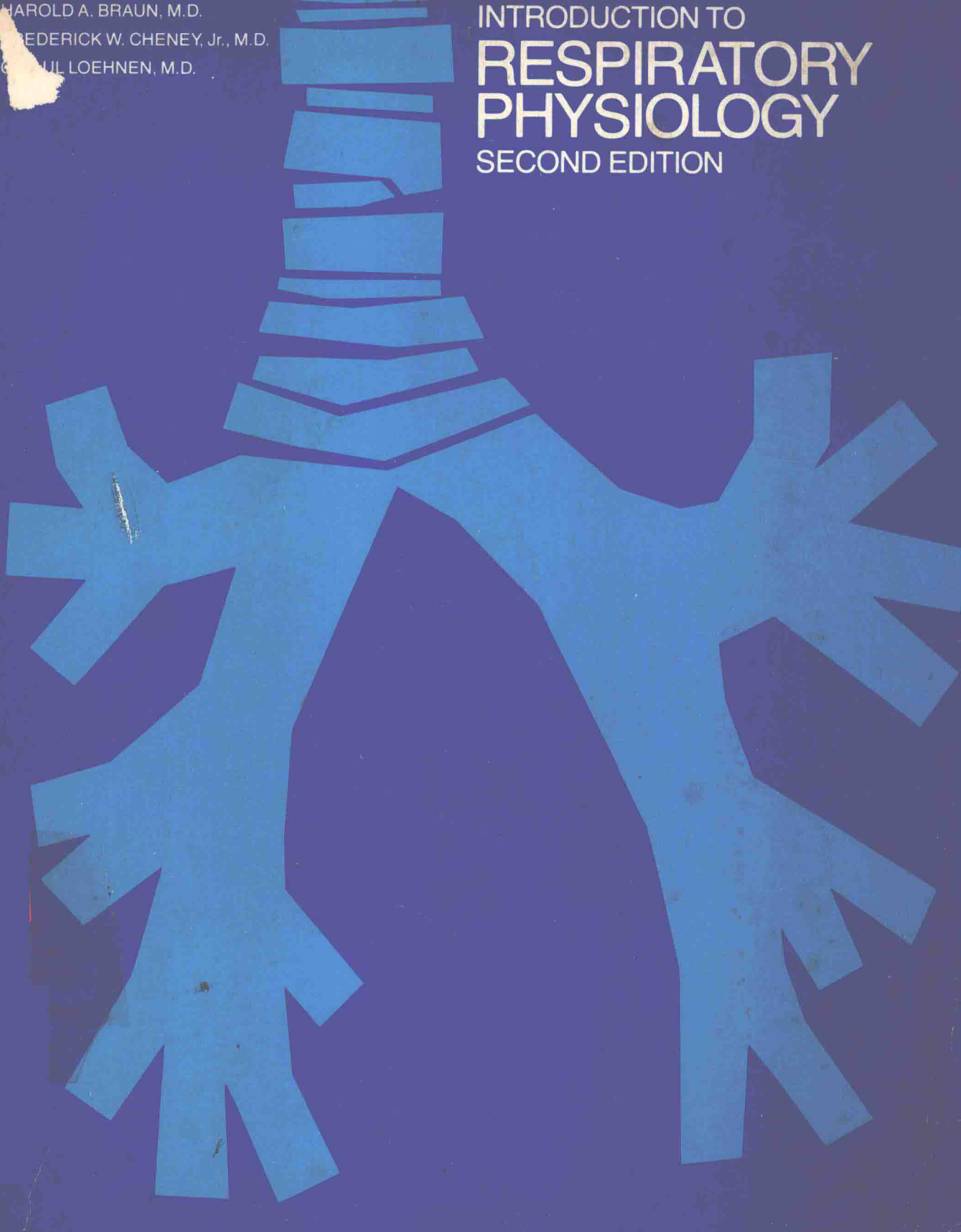
# INTRODUCTION TO RESPIRATORY PHYSIOLOGY

SECOND EDITION



# Introduction to Respiratory Physiology

## Second Edition

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# Introduction to Respiratory Physiology

# Preface

The cooperative endeavor of a clinical cardiologist, a university professor with major responsibility in the teaching of respiratory care, and a chest physician, this book is intended to simplify the basic physiologic knowledge that is the foundation of respiratory care. Its writing has evolved from our need to provide study material when we conduct training programs for respiratory therapists, nurses, and physicians who have not had specialized training in pulmonary medicine. Readers will find this material especially useful in conjunction with formal classroom work. In that regard, the problems at the end of each chapter should not be overlooked. They are presented to illustrate physiologic concepts, to reinforce what this book and others teach, and to help the reader recognize when further explanation is needed in the classroom.

H.A.B.

F.W.C.

C.P.L.

**NOTICE**

The indications and dosages of all drugs in this book have been recommended in the medical literature and conform to the practices of the general medical community. The medications described do not necessarily have specific approval by the Food and Drug Administration for use in the diseases and dosages for which they are recommended. The package insert for each drug should be consulted for use and dosage as approved by the FDA. Because standards for usage change, it is advisable to keep abreast of revised recommendations, particularly those concerning new drugs.

# Introduction to Respiratory Physiology

# Contents

# 1. Some Basic Concepts Regarding Respiration

*Terminology*
(For complete list, see Glossary.)

| | |
|---|---|
| A | Alveolar |
| a | Arterial |
| $CO_2$ | Carbon dioxide |
| $O_2$ | Oxygen |
| P | Partial pressure. The pressure exerted by each of the constituents of a mixture of gases. The total of these pressures equals the barometric pressure ($P_B$). |
| $P_AO_2$ | Alveolar oxygen tension |
| $PaO_2$ | Arterial oxygen tension |
| torr | Pressure of 1 mm of mercury at standard gravity and 0°C. Torr is the same as millimeters of mercury. |

Respiratory physiology is the study of those processes that make it possible for the body to obtain $O_2$ and eliminate $CO_2$. Details will best fit into place if there is an understanding of the major components of the respiratory process.

## COMPONENTS OF THE RESPIRATORY PROCESS—AN OVERVIEW

### Metabolism Uses $O_2$, Produces $CO_2$

Life depends upon $O_2$ intake and $CO_2$ elimination. Thus the body can be seen as an enormous gas exchanging system. Within the tissues, cells receive $O_2$, carry out metabolic work, and produce energy plus $CO_2$.

### Gas Transport Systems

To move $CO_2$ and $O_2$, two gas transport systems are at work. The *thoracic bellows* move respiratory gas into and out of the lungs. The *heart* pumps blood through the *circulation*. This blood carries $O_2$ to the tissues and carries $CO_2$ from the tissues to the lungs.

### Pulmonary Ventilation

The movement of air into and out of the lungs is called pulmonary ventilation. During inspiration, the chest cavity enlarges as a result of contraction of the diaphragm and intercostal muscles. Intrathoracic pressure falls below atmospheric pressure, and air is sucked into the lungs. Expiration ordinarily is passive, since the thoracic cage is permitted to return to its resting size.

**Control of Ventilation**

Control of ventilation is the task of a complex system involving the respiratory centers in the brain. These centers integrate information from other areas in the brain and from sensors of $O_2$, $CO_2$ and hydrogen ion. Sensors to stretch in muscles and joints also send stimuli to the respiratory centers.

**Pulmonary Perfusion**

The circulation of blood through the pulmonary capillaries is called pulmonary perfusion.

**Ventilation-Perfusion Relationship**

Ventilation and perfusion of lung units should be matched. What would happen, for example, if all blood flow (perfusion) went to the right lung and all air flow (ventilation) went to the left lung? Disturbance in the ventilation-perfusion relationship is the primary defect in most patients with respiratory failure.

**Diffusion**

Diffusion refers to the passive movement of gas molecules in response to a pressure difference. The amount of gas that moves across a membrane is proportional to the area of that membrane and inversely proportional to its thickness. Efficient diffusion is possible in the lungs because of the very large surface area (50 to 100 square meters) involved, and the short distance (0.5 $\mu$) between gas in the alveolus and blood in the pulmonary capillary.

**THE OXYGEN CASCADE**

Figure 1-1 illustrates the "cascade" or flow of $O_2$ from ambient air through the lungs and blood to the cells. Like water flowing downhill, $O_2$ moves down a pressure gradient. The pressure fraction of $O_2$ in the air is 21% of the total air

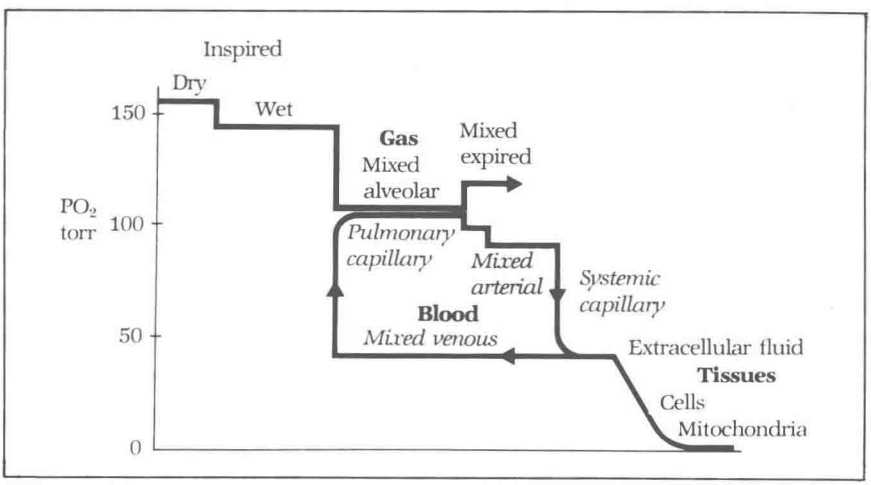


*Figure 1-1.* Oxygen transport. The small drop in $PO_2$ ($O_2$ tension, defined in Chap. 3) as blood leaves the pulmonary capillary is related to shunt and to ventilation-perfusion imbalance, explained in Chapter 7.

pressure or barometric pressure (760 torr at sea level). Thus, the pressure of $O_2$ in air is 21/100 × 760, or 159 torr.

When air is inhaled it becomes saturated with water vapor. Water vapor exerts a pressure of 47 torr, thus reducing the total pressure of dry gas to 713 torr (760 − 47 = 713). The $O_2$ pressure of inspired, moist tracheal air thus drops to 21/100 × 713, or 150 torr.

Air now moves into the alveoli, where it rapidly comes into equilibrium with the gases already present. Alveolar gas contains $CO_2$ that has diffused from the blood into the alveoli. Thus the $O_2$ pressure at the alveolar level drops further as a result of dilution by $CO_2$.

Because of the excellent diffusing properties of the lung and the large $O_2$ pressure gradient between alveolar gas and pulmonary capillary blood, little pressure is lost with the transfer of $O_2$ into the blood. Oxygen pressure gradually drops as the blood moves through the systemic capillaries where $O_2$ diffuses into the extracellular fluid and finally reaches the cell.

## CARBON DIOXIDE TRANSPORT

Carbon dioxide has its highest pressure at the cellular level, where it enters the systemic capillaries and is transported to the lungs. Alveolar ventilation discharges it into the ambient air, where $CO_2$ partial pressure is negligible.

## PROBLEMS

1. Efficient diffusion across the alveolar-capillary membrane requires a large surface area, substantial pressure difference on two sides of the membrane, and _____.
2. The symbol for carbon dioxide is _____.
3. The symbol for carbon dioxide pressure in arterial blood is _____.
4. The symbol $P_AO_2$ refers to $O_2$ pressure in _____.
5. Consult the section on symbols and abbreviations for an explanation of these symbols. Then write the meaning of the following equation:

$$\dot{V}_A = \dot{V}_E - \dot{V}_D$$

## ANSWERS

1. Efficient diffusion requires:
   a. Large surface area
   b. Large pressure gradient
   c. Small transport distance
2. Carbon dioxide: $CO_2$
3. Arterial $CO_2$ pressure: $PaCO_2$
4. $P_AO_2$: Alveolar $O_2$ pressure (or tension)
5. Alveolar ventilation equals minute ventilation minus dead space ventilation.

## SELECTED READINGS

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# 2. Chest Anatomy As It Relates to Lung Function

The respiratory system includes the two lungs and a series of air passages, namely, the nasal cavities, the pharynx, the larynx, and the trachea and its divisions. Air passes into the lungs through this system of branching tubes that become narrower, shorter, and more numerous as they penetrate deeper into the lungs (Fig. 2-1).

## TRACHEOBRONCHIAL DIVISIONS

The trachea divides into *bronchi* to the right and left lungs. These two main bronchi then divide into branches to the major pulmonary lobes: three on the right and two on the left (Fig. 2-2).

The *lobar branches* subdivide in predictable fashion, forming *segmental bronchi.* Divisions continue, like the branching of a tree, to form the *terminal bronchioles.* From these arise the *respiratory bronchioles*, characterized by occasional alveoli budding from their walls. The next subdivision gives rise to *alveolar ducts*, completely lined by alveoli. From the ducts come the *alveolar sacs* (Fig. 2-3).

Airway function from the nasal cavities to the respiratory bronchioles is purely conduction of gas, for there are no alveoli. The volume of this portion of the airway is the anatomic dead space and is approximately 2 ml/kg of body weight.

A good knowledge of the anatomy of the tracheobronchial tree can be helpful for diagnosis and therapy. For example, an inhaled foreign body is more likely to enter the right lung than the left, because of the angle of origin of the right main bronchus. Similarly, if an endotracheal tube is inserted beyond the carina (where the trachea divides), it probably will enter the right bronchus.

## THE PLEURA

Each lung is covered by a membrane called the visceral pleura. At the root of the lung the visceral pleura is continuous with another membrane, the parietal pleura, which lines the chest wall, diaphragm, and mediastinum. In health, these membranes are in contact with each other, but there is a potential space between them called the pleural cavity (see Fig. 2-1).

## THE PULMONARY VASCULATURE

As illustrated in Figure 2-4, the pulmonary artery also divides many times, eventually reaching the pulmonary capillaries. These surround the alveoli, forming an almost continuous sheet of blood in the interalveolar septa (alveolar

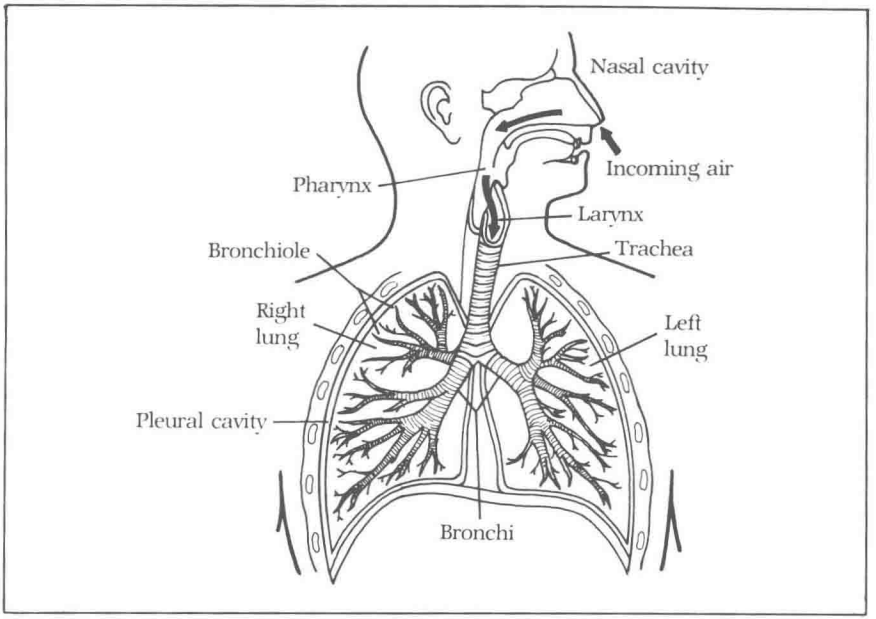


*Figure 2-1.* Respiratory system.

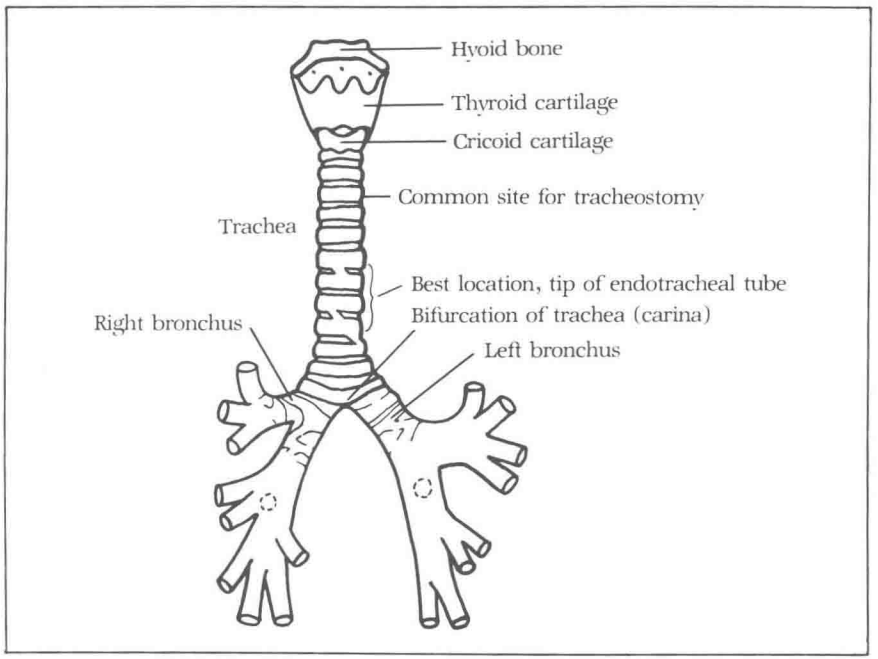


*Figure 2-2.* Tracheobronchial divisions.

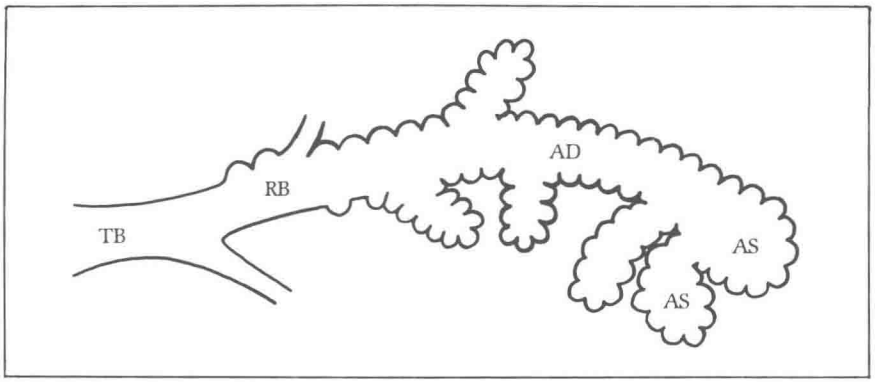


*Figure 2-3.* Terminal airway. TB, terminal bronchiole; RB, respiratory bronchiole; AD, alveolar duct; AS, alveolar sac.

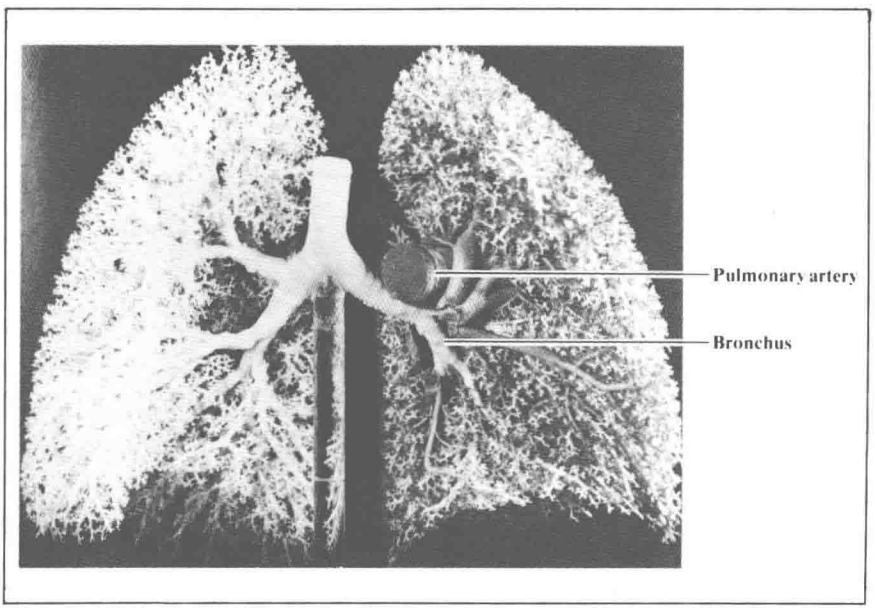


*Figure 2-4.* Cast of the lungs. Airways are shown in the right lung, vasculature in the left lung. (Reproduced, with permission, from E. R. Weibel, The Ultrastructure and Morphometry of the Human Lung. In T. W. Shields (Ed.), *General Thoracic Surgery*. Philadelphia: Lea & Febiger, 1972.)

walls). About 75% of the actual area of the interalveolar septum is occupied by capillaries. This arrangement provides extremely efficient gas exchange, for capillary blood comes into close approximation with alveolar gas (Fig. 2-5).

## THE CIRCULATORY SYSTEM

Venous blood returning to the heart enters the right atrium through the superior or inferior vena cava. After passing through the tricuspid valve, the blood enters

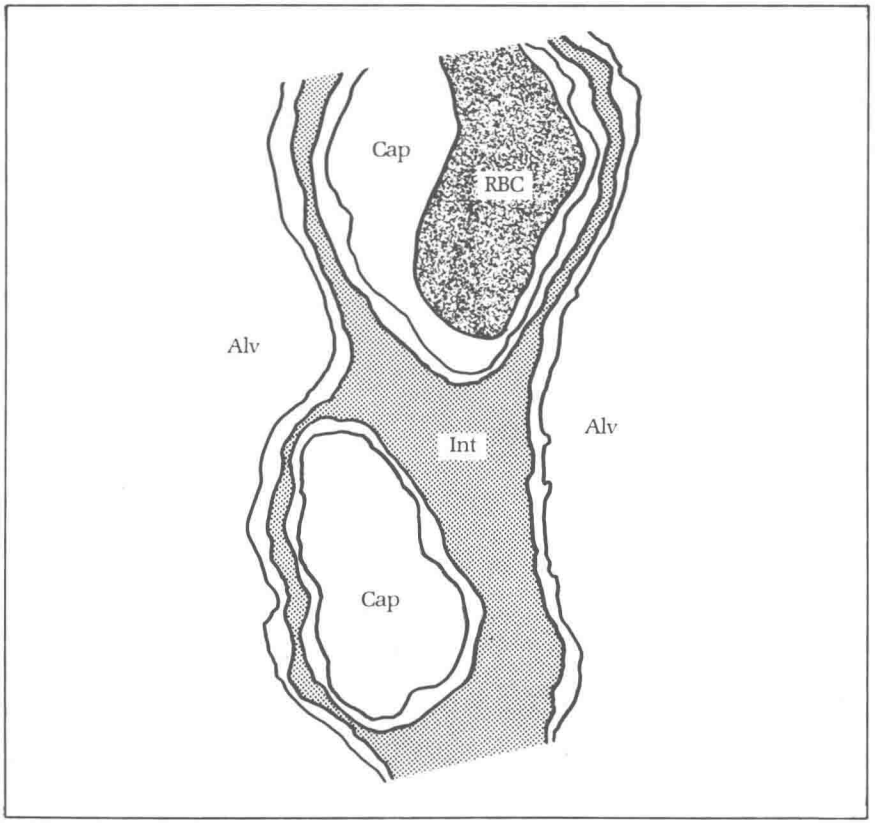


*Figure 2-5.* Alveolar wall. Alv, alveolus; Cap, capillary; Int, interstitium; RBC, red blood cell.

the right ventricle and then is pumped through the pulmonary valve into the pulmonary artery. Oxygenation occurs in the pulmonary capillaries. Blood then flows through the pulmonary veins to the left atrium, through the mitral valve to the left ventricle, and through the aortic valve to the aorta. Arterial circulation distributes it to all the organ systems. The heart muscle obtains its blood supply from the coronary arteries, which come directly from the aorta.

**Pulmonary and Systemic Circulation**

The pulmonary artery receives the whole output of the right ventricle. Although the pulmonary and systemic flows are equal, the pulmonary arterial pressure and vascular resistance are only one-sixth as great as in the systemic vasculature.

**PROBLEMS**

1. In the sketch below (Fig. 2-6), draw in and label the following structures:
   larynx
   trachea
   carina

right main bronchus
left main bronchus
heart
diaphragm
liver and stomach

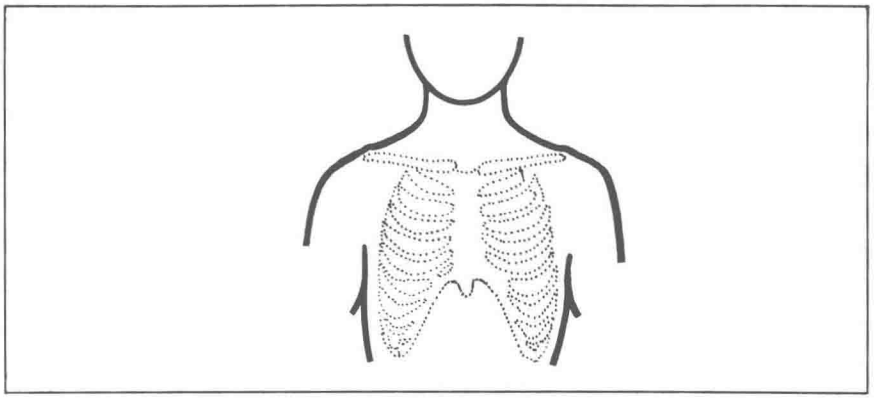

*Figure 2-6.*

2. On Figure 2-7, indicate the following: site where tracheostomy usually is done; optimal location of the tip of the endotracheal tube; carina; right and left main stem bronchi.

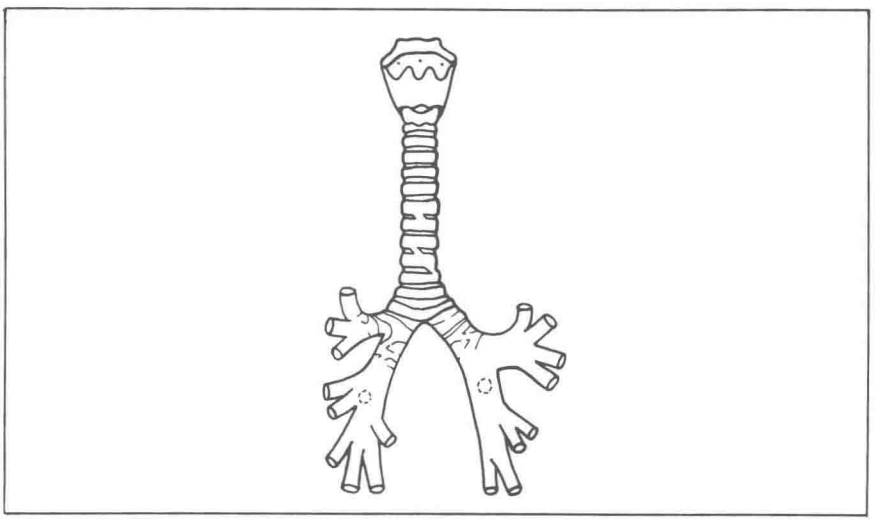

*Figure 2-7.*