Ganong's Review of Medical Physiology

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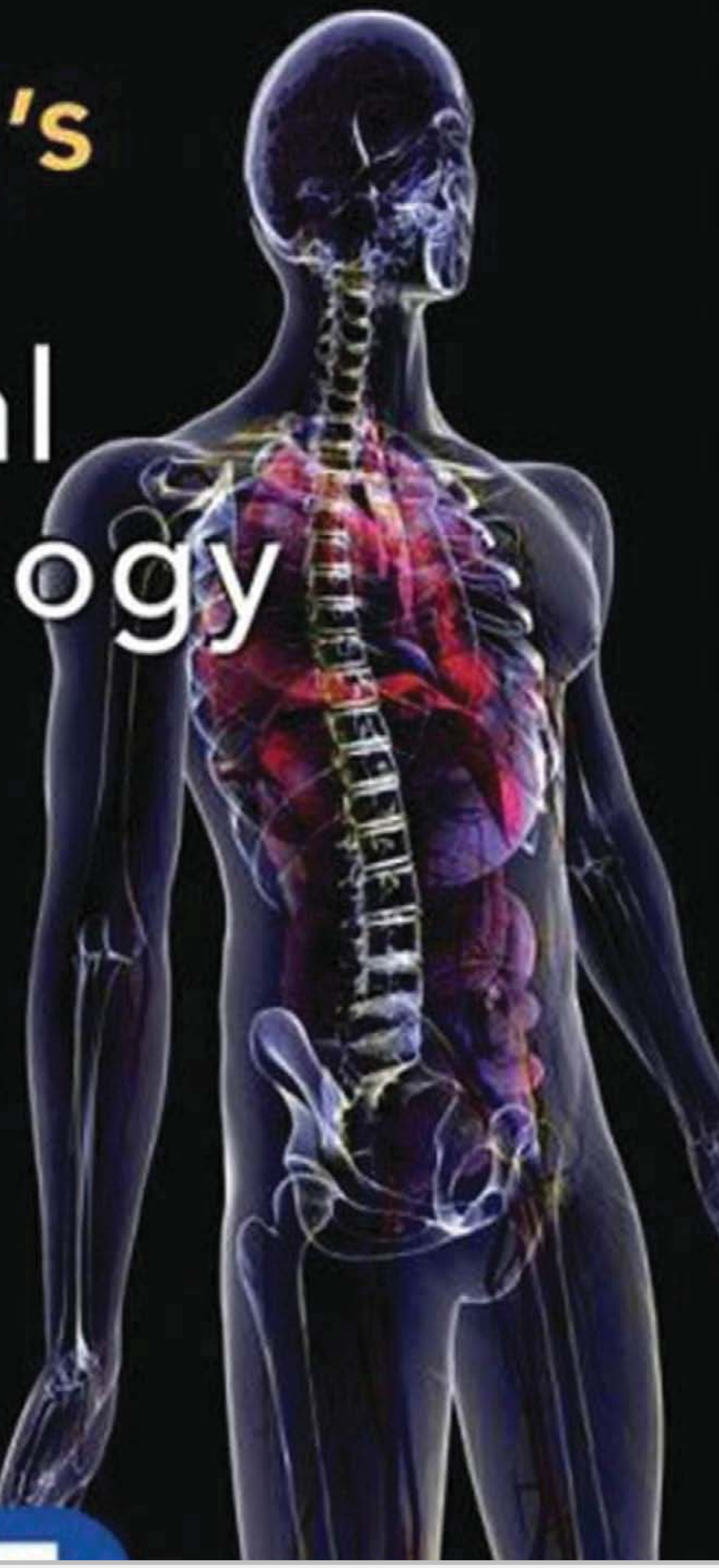

Kim Barrett
Heddwen Brooks
Scott Boitano
Susan Barman

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Twenty-Third Edition

Kim E. Barrett, PhD
Professor
Department of Medicine
Dean of Graduate Studies
University of California, San Diego
La Jolla, California

Susan M. Barman, PhD
Professor
Department of Pharmacology/Toxicology
Michigan State University
East Lansing, Michigan

Scott Boitano, PhD
Associate Professor, Physiology
Arizona Respiratory Center
Bio5 Collaborative Research Institute
University of Arizona
Tucson, Arizona

Heddwen L. Brooks, PhD
Associate Professor
Department of Physiology
College of Medicine
University of Arizona
Tucson, Arizona

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CHAPTER

35

Pulmonary Function

OBJECTIVES

After studying this chapter, you should be able to:

- Define partial pressure and calculate the partial pressure of each of the important gases in the atmosphere at sea level.
- List the passages through which air passes from the exterior to the alveoli, and describe the cells that line each of them.
- List the major muscles involved in respiration, and state the role of each.
- Define the basic measures of lung volume and give approximate values for each in a normal adult.
- Define compliance, and give examples of diseases in which it is abnormal.
- Describe the chemical composition and function of surfactant.
- List the factors that determine alveolar ventilation.
- Define diffusion capacity, and compare the diffusion of O_2 with that of CO_2 in the lungs.
- Compare the pulmonary and systemic circulations, listing the main differences between them.
- Describe basic lung defense and metabolic functions.

INTRODUCTION

Respiration, as the term is generally used, includes two processes: **external respiration,** the absorption of O_2 and removal of CO_2 from the body as a whole; and **internal respiration,** the utilization of O_2 and production of CO_2 by cells and the gaseous exchanges between the cells and their fluid medium. Aspects of external respiratory physiology are presented throughout this section. In this chapter, the processes responsible for the uptake of O_2 and excretion of CO_2 in the lungs are explored. The next chapter is concerned with the transport of O_2 and CO_2 to and from the tissues. The final chapter in this section examines some key factors that regulate respiration. Throughout each chapter, clinical implications of specific physiology will be presented.

PROPERTIES OF GASES

The pressure of a gas is proportional to its temperature and the number of moles per volume:

$$P = \frac{nRT}{V} \quad \text{(from equation of state of ideal gas)}$$

where

P = Pressure
n = Number of moles
R = Gas constant
T = Absolute temperature
V = Volume

PARTIAL PRESSURES

Unlike liquids, gases expand to fill the volume available to them, and the volume occupied by a given number of gas molecules at a given temperature and pressure is (ideally) the same regardless of the composition of the gas. Therefore, the pressure exerted by any one gas in a mixture of gases (its **partial pressure**) is equal to the total pressure times the fraction of the total amount of gas it represents.

The composition of dry air is 20.98% O_2, 0.04% CO_2, 78.06% N_2, and 0.92% other inert constituents such as argon and helium. The barometric pressure (PB) at sea level is 760 mm Hg (1 atmosphere). The partial pressure (indicated by the symbol P) of O_2 in dry air is therefore 0.21 × 760, or 160 mm Hg at sea level. The PN_2 and the other inert gases is 0.79 × 760, or 600 mm Hg; and the PCO_2 is 0.0004 × 760, or 0.3 mm Hg. The water vapor in the air in most climates reduces these percentages, and therefore the partial pressures, to a slight degree. Air equilibrated with water is saturated with water vapor, and inspired air is saturated by the time it reaches the lungs. The PH_2O at body temperature (37 °C) is 47 mm Hg. Therefore, the partial pressures at sea level of the other gases in the air reaching the lungs are PO_2, 149 mm Hg; PCO_2, 0.3 mm Hg; and PN_2 (including the other inert gases), 564 mm Hg.

Gas diffuses from areas of high pressure to areas of low pressure, with the rate of diffusion depending on the concentration gradient and the nature of the barrier between the two areas. When a mixture of gases is in contact with and permitted to equilibrate with a liquid, each gas in the mixture dissolves in the liquid to an extent determined by its partial pressure and its solubility in the fluid. The partial pressure of a gas in a liquid is the pressure that, in the gaseous phase in equilibrium with the liquid, would produce the concentration of gas molecules found in the liquid.

METHODS OF QUANTITATING RESPIRATORY PHENOMENA

Modern spirometers permit direct measurement of gas intake and output. Since gas volumes vary with temperature and pressure and since the amount of water vapor in them varies, these devices have the ability to correct respiratory measurements involving volume to a stated set of standard conditions. The four most commonly used standards and their abbreviations are shown in Table 35–1. It should be noted that correct measurements are highly dependent on the ability for the practitioner to properly encourage the patient to fully utilize the device. Modern techniques for gas analysis make possible rapid, reliable measurements of the composition of gas mixtures and the gas content of body fluids. For example, O_2 and CO_2 electrodes, small probes sensitive to O_2 or CO_2, can be inserted into the airway or into blood vessels or tissues and the PO_2 and PCO_2 recorded continuously. Chronic assessment of oxygenation is carried out noninvasively with a **pulse oximeter,** which is usually attached to the ear.

TABLE 35–1 Standard conditions to which measurements involving gas volumes are corrected.

STPD	0 °C, 760 mm Hg, dry (standard temperature and pressure, dry)
BTPS	Body temperature and pressure, saturated with water vapor
ATPD	Ambient temperature and pressure, dry
ATPS	Ambient temperature and pressure, saturated with water vapor

ANATOMY OF THE LUNGS

THE RESPIRATORY SYSTEM

The respiratory system is made up of a gas-exchanging organ (the lungs) and a "pump" that ventilates the lungs. The pump consists of the chest wall; the respiratory muscles, which increase and decrease the size of the thoracic cavity; the areas in the brain that control the muscles; and the tracts and nerves that connect the brain to the muscles. At rest, a normal human breathes 12 to 15 times a minute. About 500 mL of air per breath, or 6 to 8 L/min, is inspired and expired. This air mixes with the gas in the alveoli, and, by simple diffusion, O_2 enters the blood in the pulmonary capillaries while CO_2 enters the alveoli. In this manner, 250 mL of O_2 enters the body per minute and 200 mL of CO_2 is excreted.

Traces of other gases, such as methane from the intestines, are also found in expired air. Alcohol and acetone are expired when present in appreciable quantities in the body. Indeed, over 250 different volatile substances have been identified in human breath.

AIR PASSAGES

After passing through the nasal passages and pharynx, where it is warmed and takes up water vapor, the inspired air passes