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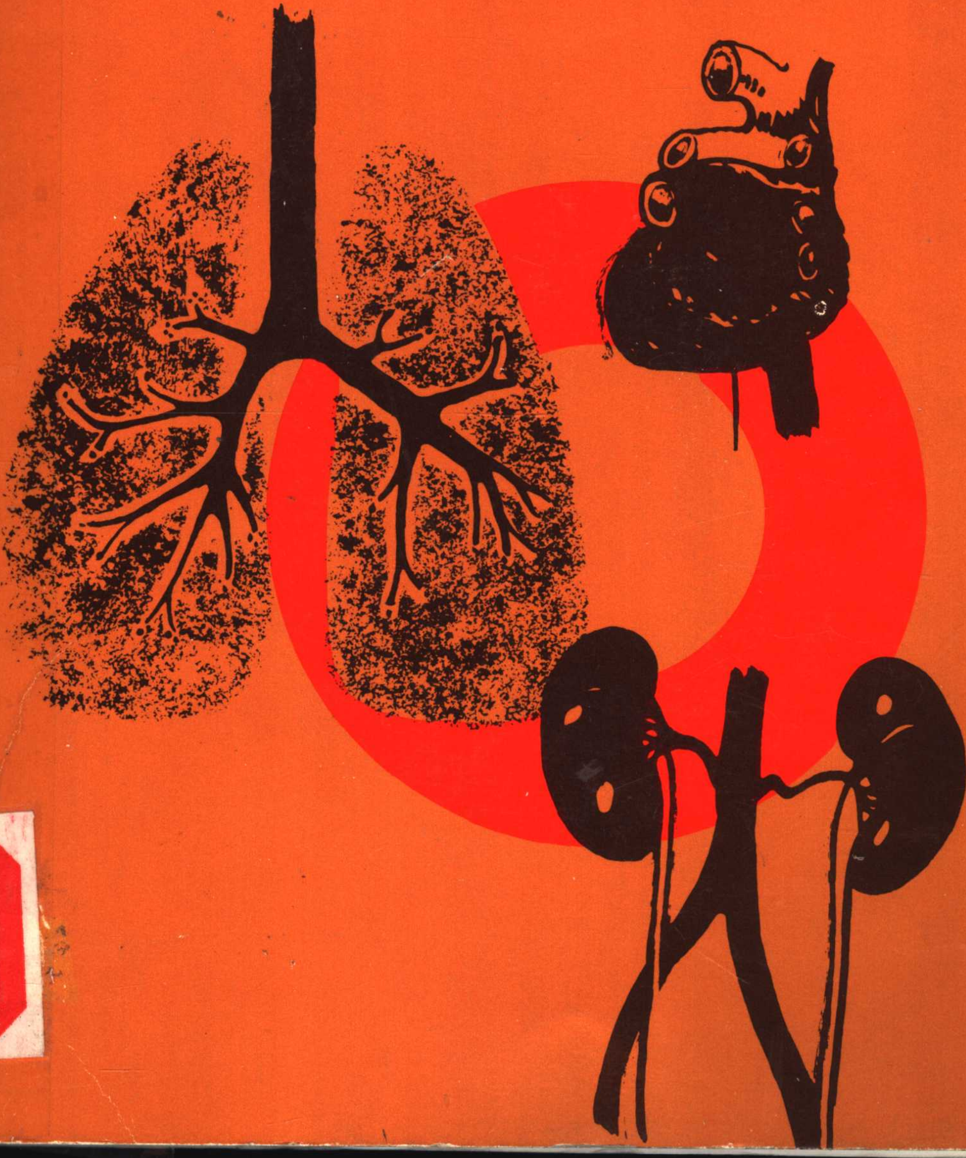

Essentials of physiology for advanced respiratory therapy

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PREFACE

The fantastic growth of critical care therapy over the last decade has drawn and is now partly based on the ability of allied health care personnel. As a result, specialized programs have been recently developed to equip these people to function in critical care units for the acutely ill. One area of particularly rapid growth is that of respiratory care.

The idea behind the development of this book stems from my search for texts suitable for use in our program in intensive respiratory care at the Wilmington Medical Center. The emphasis of our program is not only the respiratory system but also the cardiovascular and renal systems as a triad of organs bound up in the concept of respiratory failure. So the core of our instruction had to be a fairly sophisticated course in the physiology of those three systems, supported by clinical instruction and lectures on various diseases and their management.

We were not able to locate such a text, especially one that stressed the interdependence of the heart, lungs, and kidneys in the clinical situation. This book represents our attempt to provide that core material in a single work.

The material is designed for allied health care personnel who have completed their basic courses of instruction and wish to function in critical care areas where patients have suffered from failure of the heart, lungs, and kidneys singly or more frequently in combination. It was not intended to be a book on either pathology or treatment of disease but a core text upon which instruction in these areas could be based.

A number of people representing a wide spectrum of skills have helped me in preparing this book. Among them are those who have most influenced my attitudes toward intellectual discovery: Joseph Schlachter, Professor E. Wayne Craven, Dr. Tomas Y. Kuon, Dr. Leonard P. Lang, and A. J. McLaughlin, Sr.

Thanks also go to Mrs. Helen St. Clair for help in researching, to Mrs. Ann Niles who typed the manuscript several times, and to Louis Bieda whose illustrations add so much to this book.

I am especially grateful to Drs. Leonard P. Lang and Henry Clagett for reviewing the manuscript, to my brother Gregory for his support, and to Pamela for her understanding.

Arthur J. McLaughlin, Jr.

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Section I

PULMONARY SYSTEM

1 / Functional anatomy of the pulmonary system

The primary purpose of the respiratory tract is to conduct air from the atmosphere to the alveoli, where it comes into contact with pulmonary capillary blood. So that this air is properly prepared to enter the alveoli, the respiratory tract performs other secondary but necessary functions. Humidification, heating, and filtration of particles and soluble gases are performed by the membrane of the upper airways before inhaled gas enters the tracheobronchial tree.

THE UPPER AIRWAYS

The upper airways consist of the nose, mouth, pharynx, and larynx. These areas are bony structures covered with a mucous membrane, the composition of which varies to suit the function of each part. The upper airways do not participate in gas exchange and so constitute a major portion of the anatomical dead space (Fig. 1-1).

The nose

The nose has a rigid structure, cartilaginous in the lower two thirds and bony in the upper third. The rigid framework serves to prevent collapse when air is drawn rapidly in.

A piece of cartilage called the nasal septum divides the nose in half in its anterior portion. The two openings of the nose are called nares, and the borders of the nares are called alae. The channel from each naris to the back of the nose is the choana. It is through the choana that nasogastric and nasotracheal tubes are passed.

Heating and humidification. Above the choana the membrane of the nose is folded over into three projections on each side. The mucosa at this point is made up of squamous, nonciliated cells with serous and mucous glands and is heavily vascularized. The bulk of heating and humidification done in the respiratory tract is accomplished as the inspired air is drawn through the spaces between the nasal tur-

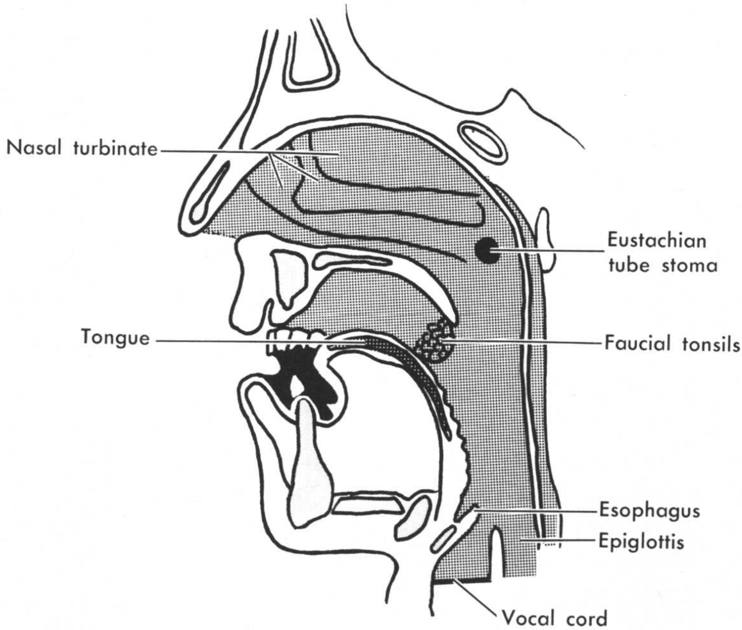

Fig. 1-1. Upper airways to level of vocal cords.

binates. Although the volume of the nose is only about 20 cc, the folds in the nasal membrane increase its surface greatly, to a value of about 160 cm^2. After air passes through the nose, it has been heated to approximately body temperature (37° C), and its relative humidity is about 80%. When one considers that atmospheric air may be at a temperature of 2° C and have a relative humidity of 30% or less, the efficacy of the nose as a heater and humidifier is striking. Huge amounts of water would be necessary to humidify the liters of air inhaled over a 24-hour period at the relative humidity of an average room, but the nose recovers a large portion of heat and water during exhalation.

Filtration. The third function of the nose is to filter inspired air. The most anterior portion of the nose contains hair follicles (vibrissae), which trap large particles when they are inhaled. Filtration is also accomplished by the impaction of foreign particles on the mucous lining of the nose. Soluble gas molecules are absorbed by the mucous membrane.

The mouth

The major function of the mouth is not usually considered to be as an airway. Primarily it is used in mastication of food and ingestion of water as well as in phonation. But the anatomy of the nose makes breathing through the mouth necessary when large volumes of air are moved in and out of the lungs. The nasal turbinates create a high resistance to flow through the nose, about twice that of the mouth. Thus mouth breathing is a basic response to dyspnea or exertion. In infants, however, the interior of the nose does not offer such resistance to air flow; in fact, it offers less resistance than does the mouth, so that normal breathing for infants is nasal breathing.

The pharynx

The pharynx is divided into the nasopharynx above the soft palate; the oropharynx, which is that portion between the soft palate and the tongue; and the laryngopharynx, which is below the base of the tongue.

Nasopharynx. The nasopharynx is lined with ciliated, pseudostratified epithelium. Particles that pass through the nose impact on the wall of the nasopharynx and move downward to a point when they are swallowed. The eustachian tubes communicate with the nasopharynx from the inner ears. These channels serve to equalize pressures in the middle ear. The "adenoids," or pharyngeal tonsils, are also located in the nasopharynx. Inflammation of the pharyngeal tonsils may block the eustachian tubes.

Oropharynx. The oropharynx lies below the nasopharynx and forms the back of the oral cavity. As such, it is a passageway for both air and food. The mucosa does not contain ciliated cells. The faucial tonsils are located in the oropharynx. In children, enlargement of the pharyngeal or faucial tonsils may cause mechanical obstruction of the airway.

Laryngopharynx. The laryngopharynx contains the arytenoid cartilages, aryepiglottic folds, and the epiglottis and so ends at the point where the airways are no longer passages for both air and food. It bifurcates into the larynx and the esophagus.

The larynx

The larynx has classically been called "the voice box" because it contains the vocal cords. It is also the section of the respiratory tract most readily accessible to opening, in an emergency, upper airway obstruction. The thyroid cartilage, referred to as the Adam's apple, is clearly protuberant in men; below it lies the cricothyroid membrane, which connects it to the cricoid cartilage. This is the site for emergency opening of the trachea, properly called a cricothyroidotomy. The cricoid ring itself is the only complete tracheal ring; thus it serves the important function of keeping the trachea open when negative airway pressures are developed in forced breathing. The mucosal lining of the larynx is composed of stratified squamous epithelium above the cords and pseudostratified cuboidal epithelium below the vocal cords; it is nonciliated.

Swallowing. Food does not pass through the larynx on the way to the digestive tract because of the presence of an elastic and cartilaginous structure called the epiglottis, which is attached to the anterior wall at the top of the larynx. After food is chewed and moved into the oropharynx, the epiglottis moves down over the opening to the larynx to prevent food from entering the tracheobronchial tree. Then the pharyngeal sphincter muscle pushes the food downward while the hypopharyngeal sphincter at the opening of the esophagus relaxes, allowing food to enter the esophagus.

Valsalva and Müller maneuvers. Two other maneuvers for which the glottis is necessary are the Valsalva and Müller maneuvers. The Valsalva maneuver refers to a forced expiratory effort against the closed glottis. The Müller maneuver is a forced inspiratory effort against a closed glottis.

Coughing. A second necessary maneuver that is dependent on the functioning larynx is coughing. Coughing is perhaps the most fundamental defensive mechanism of the lungs, and the ability to cough is necessary for the maintenance of normal lung function.

A cough is produced when a positive airway pressure is developed against the closed glottis by contraction of the expiratory muscles and the cords are suddenly opened, allowing the air to escape at speeds up to 500 miles per hour. The coughing reflex is stimulated by the presence of foreign material in the upper airways and bronchi.

THE TRACHEOBRONCHIAL TREE

The tracheobronchial tree is a system of bifurcating tubes made up largely of muscular, cartilaginous, and elastic tissues that conduct air used in ventilation. As the tracheobronchial tree progresses from the begining to its termination, the size of the airways decreases, while the numbers of airways and thus the total cross-sectional area of the

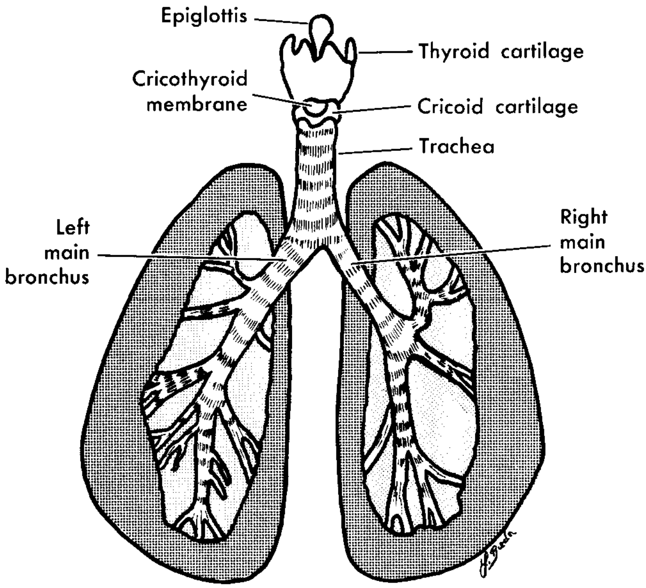

Fig. 1-2. Tracheobronchial tree to level of bronchi.

system increase. The tracheobronchial tree is composed of the trachea, two main stem bronchi, lobar and segmental bronchi, bronchioles, respiratory bronchioles, and alveolar ducts (Fig. 1-2).

The trachea

The trachea begins at the base of the larynx and extends about 11 to 13 cm down into the thoracic cavity. It is about 1.5 to 2.5 cm in diameter and is kept open by the presence of 16 to 20 C-shaped rings of cartilage in its wall. The open part of the C is the posterior portion of the trachea and therefore gives the posterior wall of the trachea a slightly flattened aspect.

Clinically, the normal dimensions of the trachea are important to remember in relation to the use of endotracheal and tracheal tubes. The normal diameter of an adult endotracheal or tracheal tube is usually 6 to 8 cm. The presence of the tube itself creates a large reduction in the size of the airway: the diameter and therefore the radius of the airway are reduced by up to 50%. According to Poiseuille's law, the increased resistance to air flow in the presence of a tube is very large. Because increased resistance to air flow increases the work of breathing and the percent of O_2 needed for breathing in a dramatic manner, a patient with an endotracheal or tracheal tube in place should be watched very closely.

The main stem bronchi

The trachea divides into two main stem bronchi, at the level of the second left and right costal cartilages, at a point called the carina. The right main stem bronchus is shorter and wider than the left and comes off the trachea at a slight (20°) angle so that it appears to be an extension of the trachea.

The left main stem bronchus is at a much greater angle (about 40° to 60°) to the trachea; thus any aspirated material is much less likely to enter the left main bronchus than the right. Endotracheal tubes that are too long will usually enter the right main bronchus as well. If the right main bronchus is intubated and cuffed tubes are inflated, the left lung will receive no ventilation via the tube, and serious results will ensue. Ausculation of both bronchi after intubation is necessary to rule out this possibility.

The bronchi

Airways that subdivide off of the main stem bronchi are named according to the sections of the lung they serve.

The first divisions are the lobar bronchi—three on the right and two on the left—which lead to the five lobes of the lungs. These subdivide into segmental bronchi, which lead to eight lung segments. As the bronchi continue to divide, the fourth through eleventh "generations," or subdivisions, are called subsegmental bronchi, in keeping with previous nomenclature. All bronchi have cartilage in their walls, which decreases in amount from the C-shaped rings in the trachea to small cartilaginous plates in the subsegmental bronchi. Bronchi are lined with membranes having a ciliated epithelium with mucus-producing goblet cells.

The bronchioles

Three characteristics of bronchioles differentiate them from subsegmental bronchi. First, bronchioles by definition are less than 1 mm in diameter. Second, they have no cartilage in their walls. Since there is no cartilaginous structure to maintain patency of the bronchioles, the structure of the musculature and the surrounding lung tissue provide the support to prevent airway collapse during exhalation. Finally,

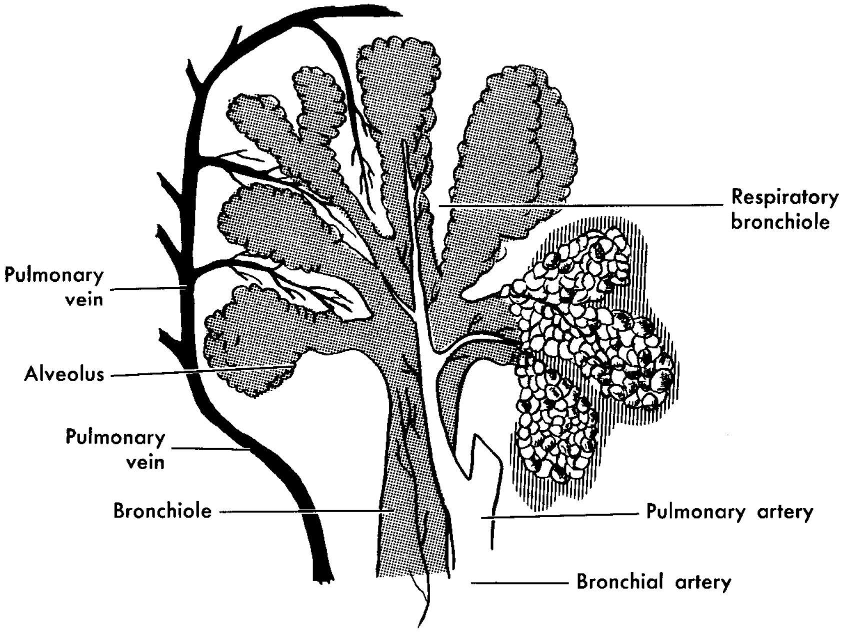

Fig. 1-3. Respiratory gas exchange unit with blood supply.

the mucous membrane lining the bronchioles has no cilia or mucus-producing cells.

As bronchioles become smaller and more distal to the trachea, alveoli (tissue sacs containing air) begin to appear as outgrowths of the bronchiolar walls. Bronchioles of this kind are called respiratory bronchioles because the presence of alveoli allows them to participate in the exchange of respiratory gases. Thus the respiratory bronchioles are the first portion of the respiratory tract that functions as more than conducting tubes, that is, as anatomical dead space (Fig. 1-3).

As more and more alveoli appear in the walls, the bronchiolar walls become indistinguishable and are termed at this point alveolar ducts. From these ducts true alveolar sacs arise, containing clusters of alveoli, the basic units of gas exchange.

The alveoli

It is estimated that the adult lung has over 300 million alveoli, which provide a surface area of 70 to 80 m for gas exchange. Adjacent