THE LUNG

Physiologic Basis of Pulmonary Function Tests

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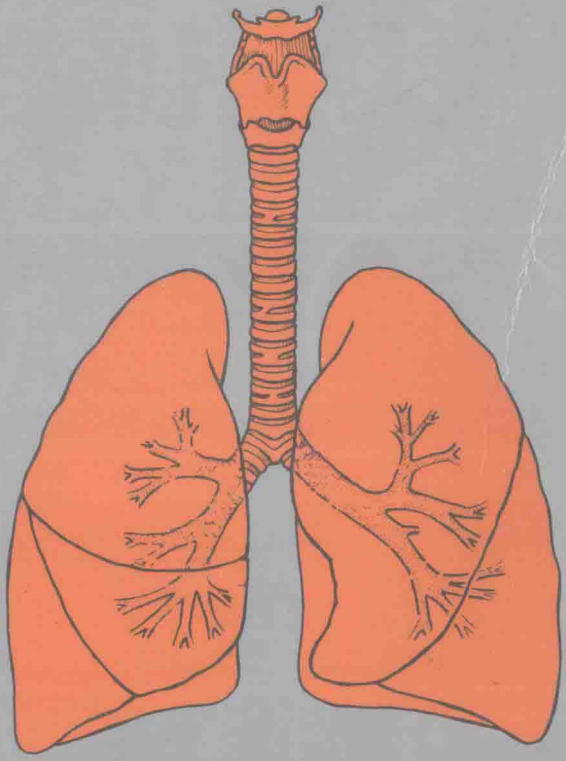

Third Edition

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PHYSIOLOGIC BASIS OF PULMONARY FUNCTION TESTS

THIRD EDITION

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Preface to the First Edition

Pulmonary physiologists understand pulmonary physiology reasonably well. Many doctors and medical students do not. One reason is that most pulmonary physiologists, in their original and review articles, write for other pulmonary physiologists and not for doctors or medical students. This is *not* a book for pulmonary physiologists; it is written for doctors and medical students. Like the Beaumont Lecture* upon which it is based, it has only one purpose—to explain in simple words and diagrams, those aspects of pulmonary physiology that are important to clinical medicine.

A few words of explanation:

1. This is not an illustrated book but a monograph constructed largely around illustrations. Most of the illustrations are schematic; artistic license has been used freely to achieve clarity.
2. Our monograph strives for understanding of physiological principles and broad concepts more than for technical completeness. Details of procedures have been presented in an earlier publication (*Methods in Medical Research* [Chicago: Year Book Publishers, Inc., 1950], Vol. 2).
3. Pulmonary physiology can be explained in words, pictures, or equations. Most physicians shudder at equations; therefore words and pictures predominate and the occasional equation is accompanied by a verbal explanation and full apology. However, all important equa-

* "The Physiological Diagnosis of Pulmonary Disease," delivered by J. H. Comroe, Jr., to the Wayne County Medical Society, Detroit, February 1, 1954.

tions are presented in an Appendix for the enjoyment of those who have difficulty with words and pictures.

4. There are no references in the text. This is not because we wish to slight pulmonary physiologists (including ourselves) but because documentation often breaks the continuity of thought. Selected references are given in the Appendix, but even these represent only a small fraction of important articles that have been written on this subject.
5. The case reports (Part II) have been presented deliberately with minimal clinical detail, and the reader is asked to accept that the diagnoses have been based on adequate clinical study.
6. This is not a primer; a primer would not enable the physician to cope with some of the more baffling concepts such as ventilation/blood flow ratios, diffusing capacity, physiological dead space, distribution, compliance, alveolar ventilation, or transpulmonary pressure. On the other hand, this is not an encyclopedia, and no attempt has been made to include all contributions in this small volume.

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Preface to the Third Edition

The first edition of *The Lung: Clinical Physiology and Pulmonary Function Tests* served as a text of pulmonary function testing and clinical physiology, as its subtitle indicated, and also as a textbook of pulmonary physiology and even of pathophysiology, for medical students, clinicians, and auxilliary medical professionals. We expanded the pathophysiology in the second edition, adding illustrative clinical cases and five chapters on pulmonary evaluation for several clinical specialities.

In considering the content of the third edition we concluded that *The Lung* should return to its origin as a monograph constructed largely on illustrations and focus on the scientific basis of pulmonary function tests. In the 30 years of *The Lung's* existence there has been an explosive expansion of interest in pulmonary function testing. There are excellent small texts on pulmonary function tests, clinical physiology, and pulmonary physiology, and there are several comprehensive textbooks on clinical pulmonary disease that include synopses of pulmonary function testing. The manufacture of pulmonary test equipment has evolved into a major industry.

Clearly, *The Lung* cannot fulfill all of the roles it appeared to fill in the past. Therefore, we eliminated the clinical material and reduced the size of the third edition. We added new illustrations and rewrote the entire text. We are grateful to many for their helpful criticism and hope that this volume will be as useful as the previous editions to clinicians and medical students.

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Contents

PART ONE

1

Introduction to Pulmonary Physiology

The major function of the cardiovascular and respiratory systems is to provide an adequate amount of *arterialized* blood at each moment to all of the tissues of the body. The lungs alone cannot acccomplish this. Several processes are involved: First, mixed venous blood, low in O_2 and high in CO_2, is returned to the right atrium and ventricle to be pumped through the pulmonary circulation. Second, the mixed venous blood flowing through the pulmonary capillaries is arterialized, i.e., receives O_2 from the alveolar gas and gives off excess CO_2. Third, the arterialized blood is distributed to all of the tissues of the body according to their needs. Fourth, exchange of O_2 and CO_2 occurs between the blood in the tissue capillaries and the tissue cells themselves. The first, third, and fourth of these processes are the major function of the cardiovascular system. The second process, the loading of mixed venous blood with enough O_2 at a high enough pressure and the unloading of excess CO_2, is the primary function of the lung; this book discusses only *pulmonary* function.

A large number of physiologic tests has been developed for the qualitative and quantitative evaluation of pulmonary function in patients with suspected abnormalities of the cardiopulmonary system. These are as important to the practice of medicine as are tests of hepatic, renal, cardiovascular, and neuromuscular function. Tests of pulmonary function are of definite value both in diagnosis and in guiding therapy of patients with cardiopulmonary disorders. They have led to

a better understanding of pulmonary physiology in healthy men and women of all age groups and to more precise knowledge of the pathologic physiology and natural course of pulmonary disease. They can aid in the early detection of pulmonary dysfunction and can assist in differential diagnosis in patients. They can be used for the objective evaluation of therapeutic measures and so can contribute to the development of more rational measures of treatment. Various tests are used in screening populations, in outpatient clinics, on hospitalized patients, and in intensive care units. Finally, they can provide objective data in patients who may or may not have pulmonary disability, and thereby help to determine, during the lifetime of the patient, if a specific function of the lung has been impaired.

The use of physiologic tests does not supplant other diagnostic procedures. Physiologic tests indicate only how disease has altered function; they cannot make a pathologic diagnosis. For example, function tests may reveal the existence of a right-to-left shunt but in themselves cannot locate it anatomically as being intracardiac or intrapulmonic. Furthermore, they do not reveal alterations in all types of pulmonary disease, but do so only when the lesion disturbs function and disturbs it sufficiently that present tests can recognize with certainty the deviation from normal values. In general, they cannot detect slight reduction in functioning pulmonary tissue or the presence of small regions in the lungs that have neither ventilation nor blood flow. Results of physiologic tests may be normal in the presence of lesions such as fibrotic cavities, cysts, or carcinomatous nodules unless these lesions occupy so much space that they reduce the lung volume well below normal limits or are located so strategically that they disturb pulmonary function. Pulmonary function studies will not tell where the lesion is, what the lesion is, or even that a lesion exists, if it does not interfere with the function of the lung. Therefore, they supplement and do not replace a good history and physical examination and radiologic, bacteriologic, bronchoscopic, and pathologic studies.

As in the case of physiologic tests of other systems, no single pulmonary function test yields all the information desired in any single patient. The primary function of the lung is, as already stated, to arterialize the mixed venous blood. This involves the addition of adequate amounts of O_2 and the elimination of proper quantities of CO_2. This is achieved by pulmonary gas exchange, which involves a number of processes (Fig 1). The first of these is VENTILATION; this includes both volume and distribution of the air ventilating the alveoli. A large enough volume of inspired air must reach the alveoli each minute, and this air must be distributed evenly to the hundreds of millions of alveoli

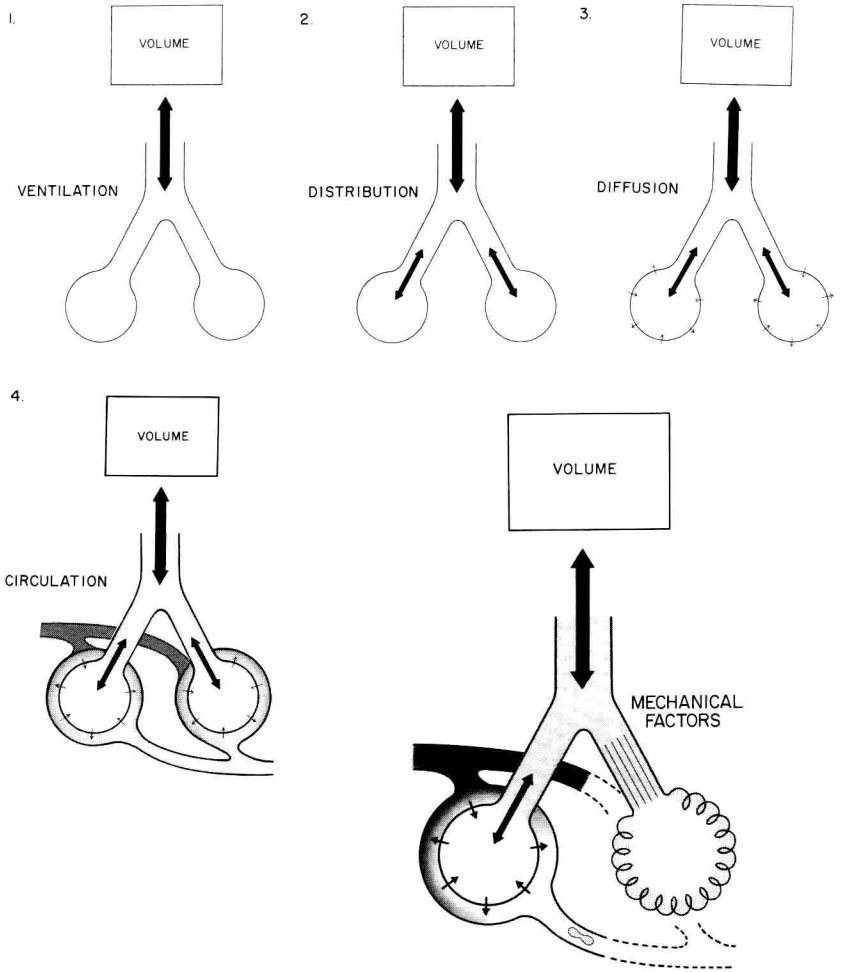

Fig 1.—Processes involved in pulmonary gas exchange. The alveoli, where rapid gas exchange occurs, are represented by rounded areas; leading into these are tubes depicting the conducting airways or anatomic dead space *(light gray in 5)* in which no effective gas exchange occurs. Rectangular blocks indicate the minute volume of breathing. The two arrows entering the alveoli show distribution of total inspired gas *(large arrow)* to various alveoli. In *3* and *4,* small arrows crossing alveolar walls designate the process of diffusion of O_2 out of the alveoli into the blood and of CO_2 from the blood into the alveoli. The shaded channel surrounding the alveoli in 4 represents pulmonary blood flow; it enters the capillary bed as mixed venous blood *(dark)* and emerges as arterialized blood *(light).* In *5,* the left side is a summary of the processes of ventilation, diffusion, and circulation. The right side represents the pulmonary "tissues" responsible for the mechanical properties of the lung: parallel lines in the conducting airways represent the fine airways responsible for airway resistance; the springlike coil surrounding the alveoli represents the elastic tissues of the lung; and stippled areas in the coil are the nonelastic tissues (see chapter 4).

in the lungs; i.e., the volume of air going to each alveolus should be in proportion to the volume of that alveolus. The second of these is the process of DIFFUSION, by which O_2 and CO_2 pass across the alveolocapillary membranes. The third is PULMONARY CAPILLARY BLOOD FLOW; this must be adequate in volume and all of the mixed venous blood must be distributed evenly to all the ventilated alveoli.

This gas exchange should be achieved with a minimal expenditure of energy by the respiratory and circulatory systems. The MECHANICAL FACTORS in ventilation are of great importance, because in some patients adequate pulmonary gas exchange may be achieved only by a considerable increase in the work of the respiratory muscles; indeed, in patients with advanced pulmonary disease, the crucial factor in survival may be whether the maximal effort available can produce adequate ventilation. The work required of the right ventricle in pumping blood through a restricted pulmonary vascular bed may also be of critical importance in survival.

The process of ventilation is controlled through the central and peripheral nervous systems, which coordinate the activity of the muscles involved in inspiration and expiration. The control of respiration therefore merits separate consideration.

Finally, the lung is not just an organ for gas exchange. In fact, it contains more different cell types than any other organ in the body. Recently, several tests of nonrespiratory functions of the lung have been described and are included in this book. Lung cell biology represents a rapidly expanding field of study, and it seems likely that the number of tests available for this area will soon increase.

The quantitative measurement of these processes of lung function requires a large number of physiologic tests. Not all of these are required in the management of each patient. Some of the tests are very simple and may be carried out in a physician's office; others require expensive apparatus or considerable technical experience and are normally carried out in a hospital pulmonary function laboratory; still others are research procedures and at present are available only in a few medical centers. However, some tests should be performed on every patient with known or suspected pulmonary disease, just as an electrocardiogram (ECG) or other physiologic tests are performed on patients with suspected heart disease.

This book is divided into two parts. The first of these considers separately each of the components of pulmonary function (lung volumes, ventilation, pulmonary blood flow, diffusion, control of ventilation, and the mechanics of breathing). The goal of this part is to pre-

sent the scientific basis for understanding the rationale and limitations of tests of pulmonary function. The second part, the Appendix, includes information basic to the development of some tests of pulmonary function but not essential to their understanding, and lists tables of normal values.