Respiratory Physiology and its Clinical Application

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Preface

This book is intended for the medical student and practicing physician with the hope that it will furnish information of practical use and lead to better understanding of a relatively new and difficult field of laboratory medicine. There are many excellent sources available concerning normal respiratory physiology, but as yet there is no single source where the interested physician without previous experience may turn to obtain information as to the methodology, indications for clinical use, limitations, and interpretations of pulmonary function tests. Similarly, the new knowledge resulting from the widespread use of these tests in recent years has in many instances necessitated a revision of older concepts concerning the pathologic physiology of chronic pulmonary diseases. This book is written as a primer for the interested neophyte with the desire to fulfill these needs. An attempt has been made to assemble and interpret, in an applied and clinical frame of reference, pertinent material concerning respiratory physiology in normal and disease states. Those tests have been emphasized which can be carried out by the practicing physician with a general hospital laboratory and a small amount of equipment available to him. Other more complicated tests are discussed briefly and pertinent references cited for further reading. Pathologic physiology, the cornerstone of clinical medicine, is stressed,

and signs and symptoms related wherever possible to the results of specific pulmonary function tests.

This book is not an exhaustive treatise and I have purposely tried to be brief. The references have been chosen carefully for their originality and readability. It is hoped that they will compensate for the brevity of some of the discussions and give the interested reader with further needs a good start in the literature. Symbols and mathematical exercises have been kept to a minimum and the concepts they embody discussed in words. This has been done with a feeling of compassion for the average doctor who is not a mathematician and has little time for abstractions.

In short, this book is written for the interested clinician with the hope that some of the trepidation and skepticism surrounding respiratory physiology and pulmonary function tests will be dispelled, and the pathologic physiology of chronic pulmonary disease more easily understood.

ACKNOWLEDGMENTS

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Part I

1

Introduction

Recent interest in respiratory physiology and pulmonary-function tests has resulted from a number of factors. The rapid development of aviation and submarine medicine has been made possible largely by the increasing knowledge of respiratory physiology. Widespread use of routine chest x-rays in the detection of pulmonary disease, and the increasing number of individuals in the population reaching old age, in whom chronic cardiopulmonary disease is so common have resulted in the need for objective methods to evaluate the functional status of the lungs. Indications for and the results of specific therapy, both medical and surgical, require objective assessment. The stimulus to clinical investigation has come from the basic work accomplished in the laboratories of Fenn, Comroe, and Cournand. Clinical investigation, in turn, has been facilitated by the development of apparatus allowing rapid, accurate determination of respiratory and certain foreign gases. Still, pulmonary-function tests have been slow to gain favor with the clinician because of (1) the extreme variability of some tests involved and the time consumed performing them; (2) the wide range of normal values which frequently renders isolated determinations useless; (3) the cumbersome and frequently expensive apparatus involved; (4) the relatively infrequent need for their use in actual practice; (5) a certain air of

mystery and mathematics which surrounds their use, requiring many confusing symbols and equations to express something which is invisible (gas) and difficult to conceptualize; and (6) nonstandardization of methods, and, until 1950 terminology, and symbols [22].

The limitations, interpretations, and principles of pulmonary-function tests are similar to those of other organ function tests. Thus, an elevated alkaline phosphatase in the presence of jaundice usually indicates obstruction to the flow of bile. A reduced maximal breathing capacity and timed vital capacity indicate obstruction to the flow of air in the respiratory tract. In either case, an etiologic diagnosis is not possible, but certain common pathologic processes can cause these abnormalities of function and, thus, a rational differential diagnosis can be formulated. Just as no single test defines the various aspects of hepatic and renal function, so no single test describes the various processes which constitute respiration. Certain diseases result in specific patterns of abnormal function tests which can suggest etiologic diagnoses; for example, hepatogenous versus hemolytic jaundice, pyelonephritis versus glomerulonephritis, and in the case of the lung, obstructive emphysema versus the diffusion block syndrome. Isolated, discrete lesions involving the parenchyma of an organ usually cannot be detected by function tests. Just as jaundice is a manifestation of hepatic failure and uremia the end result of renal failure, so arterial oxygen unsaturation, respiratory acidosis, and reduction in breathing reserve are manifestations of pulmonary failure. The cause of the final, clinical picture must be determined by judicious use of all the clinical tools including function tests and special procedures, which complement the history, physical examination, and routine laboratory examinations.

Pulmonary-function tests are of value in the following clinical situations:

Diagnosis: as regards obstructive emphysema; the "alveolar-capillary block" syndrome; idiopathic alveolar hypoventilation; the differentiation of asthma, obstructive emphysema, senile emphysema, and the results of aging; anxiety states and hysterical hyperventilation; the differentiation of cardiac failure and pulmonary failure; various neuromuscular disorders which may present as afflictions of the respiratory apparatus; and the differentiation of primary and secondary polycythemia.

Prognosis: as indicated by the results of specific tests and in the over-all study of the natural history of chronic pulmonary diseases.

Management: of prime importance in guiding the need for specific drug therapy, various types of artificial respiration, and surgical procedures.

Evaluation of therapy: as applied to steroid therapy, new bronchodilators, positive pressure breathing, and the effects of various surgical procedures.

Disability evaluation: the detection and quantitation of disability caused by pulmonary disease as a result of occupational hazards, namely the pneumoconioses [17], and the evaluation of an individual's physical fitness for a specified type of work.

Evaluation of patients for thoracic surgery: whether or not the patient can tolerate thoracotomy, whether the remaining lung can support life comfortably following pneumonectomy, and indications for elective surgery based on functional defects (for example, lung cysts).

Psychological value: the clinical use of pulmonary-function tests has a most salutary effect on both patient and physician. Through his knowledge of the altered physiology underlying the patient's chronic disease, the symptoms and signs are more rationally explained and the doctor is more secure in his ability to qualitate the type of dysfunction and quantitate the degree of disability present. The patient bene-

fits from new interest displayed and the added time spent with him.

The first part of this book deals with the volume of the lungs, the processes which constitute respiration (ventilation, distribution, diffusion, and the work of breathing), and pulmonary function tests. The second part concerns patterns of abnormalities in various diseases and conditions of the lungs and respiratory apparatus. The first twenty references in the bibliography consist of general reviews, articles, and books. The book by Rossier, Bühlman, and Wiesinger [21] is included for those who read German, and for the excellent list of references to both English and European literature which it contains.

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Pulmonary Ventilation and Gas Exchange

PRINCIPLE

The primary function of the lung is gas exchange, the oxygenation of venous blood and elimination of the carbon dioxide added as a result of tissue metabolism. A normal arterial oxygen saturation of 95 percent or greater, an arterial carbon dioxide pressure of 40 mm Hg, and a pH of 7.40 are maintained in relatively narrow ranges by a remarkably sensitive respiratory center, which rapidly adjusts the rate and depth of respiration in response to neurogenic and humoral influences which govern its activity [23]. The volume of air respired per minute is termed the minute volume of pulmonary ventilation and is easily measured. The minute volume of pulmonary ventilation as recorded at the mouth does *not* reflect the final volume of air which participates in gas exchange, however, as part of each tidal volume is expended on the so-called dead space of the respiratory passages where gas exchange does not occur. That fraction of the minute ventilation which participates in gas exchange is termed the alveolar ventilation. In order to calculate this, the volume of the dead space must be known.

THE CONTROL OF PULMONARY VENTILATION

The respiratory center is a collection of neurons situated in the reticular substance of the pons and medulla [12, 23, 24]. It receives afferent impulses from the cerebral cortex and subcortex, hypothalamus, cerebellum, and cranial nerves, as well as proprioceptive impulses from the skin, joints, thoracic muscles, and lungs. Its efferent impulses are mediated through axonal connections between its neurons and cranial nerve nuclei (V, VII, IX, X, XI, XII), and via motor tracts which descend through the cervical and thoracic spinal cord to supply the diaphragmatic, intercostal, and abdominal muscles. An inspiratory center has been localized in the ventral portion of the reticular substance and an expiratory center in the dorsal part. During quiet breathing the rhythmicity and depth of respiration depend on stretch receptors located in the pulmonary parenchyma. With inspiratory stretching of the lung, afferent impulses ascend via the vagus nerve to the expiratory center which then inhibits the efferent discharge of the inspiratory center; inspiration ceases and passive expiration occurs. As the lung deflates, expiratory inhibitor impulses arise, the inspiratory center once again becomes active, and the cycle repeats itself. These inspiratory and expiratory inhibitor stretch reflexes from the lung are known as the Hering-Breuer reflexes.

Pulmonary ventilation is controlled by the level of the arterial pH and carbon dioxide pressure active directly on the medullary respiratory center. The arterial oxygen pressure acts indirectly through the chemoreceptors of the carotid and the aortic bodies, innervated by the glossopharyngeal and vagus nerves respectively. The carbon dioxide pressure of arterial blood is the most important of the chemical determinants of pulmonary ventilation. The neurons of the respiratory center are exquisitely sensitive to the carbon dioxide pressure of arterial blood and as little an in-