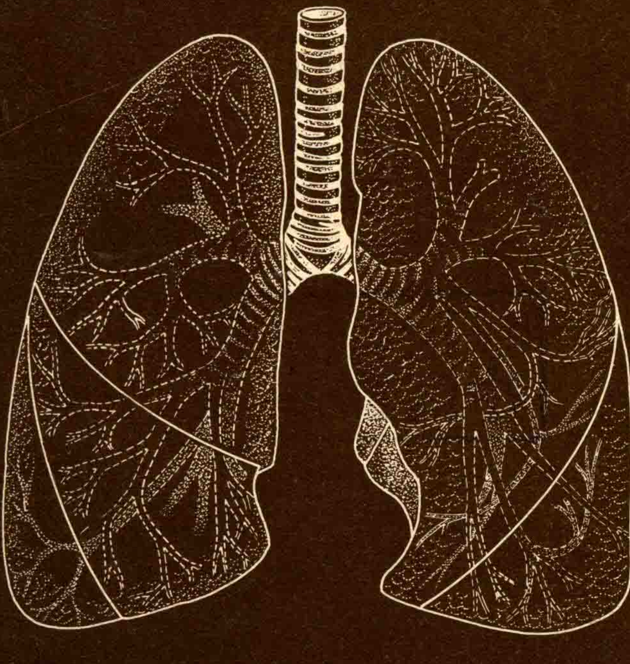
PULMONARY FUNCTION TESTING



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PREFACE

In recent years the knowledge of the physiologic disturbances present in patients suffering from respiratory diseases has increased considerably, and there has been an explosion of new tests of pulmonary function. An increased awareness of the importance of even simple tests of pulmonary function has led to the development of pulmonary function laboratories in most hospitals. Most physicians now recognize that the measurement of the amount of disability present is an essential component of the clinical assessment in any patient who complains of respiratory symptoms. What is not yet accepted is the fact that this does not necessitate referral to a pulmonary function laboratory. Valuable information can be obtained in the office or at the bedside by analysis of the forced expiratory volume, which can be estimated with a simple spirometer while examining the patient. In addition, much can be learned by noting the onset of breathlessness and tachycardia when the patient engages in a form of activity to which he is accustomed, such as climbing a flight of stairs or walking. But these simple assessments yield information that is insufficient in many clinical situations, and more specific laboratory studies of pulmonary function are necessary.

The degree of sophistication and complexity of the pulmonary function tests that are used varies widely, depending on local circumstances. In addition to the simple ventilatory function studies, measurements of the mechanical properties of the lung can be of considerable value, and in patients who are critically ill or suffer from chronic illness, gas exchange and acid-base status are essential.

Used judiciously, the assessment of pulmonary function enables the physician to recognize early disease, to follow its progress, and to prescribe proper therapy directed at improving the disturbances in pulmonary function. When surgery (particularly the removal of lung tissue) is contemplated, the patient's ability to tolerate an anesthetic or narcotic or the removal of lung tissue can be assessed, and this information may be used as a guide to the preparation and postoperative care of the patient.

Many allied health professionals are being asked to perform and interpret most of these tests of pulmonary function without sufficient background training and knowledge. The purpose of this text is to present the background information necessary to understand normal pulmonary function and the disturbances that occur in disease. On this foundation the basis of the various tests that are used to determine pulmonary function and to assess disability are discussed, along with their interpretation. In order to determine how well these principles are understood by the reader, the opportunity for self-assessment with multiple choice questions and case examples is provided.

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Reuben M. Cherniack

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Section I

BASIC CONSIDERATIONS

INTRODUCTION

To those who are not pulmonary physiologists, the vast number of terms, symbols, and abbreviations used in discussing pulmonary physiology or tests of function are often confusing. But in fact there is some logic in the symbols that are used as abbreviations and, once understood, there is usually no difficulty in following any discussion or publication dealing with pulmonary function. Therefore the first chapter of this book is devoted to a summary of the basic terminology you will be expected to know.

In the next few chapters we will deal with the way in which air and blood are transported into the lungs, gas exchange across the alveolocapillary membrane, the transport of oxygen and carbon dioxide in the blood, and the impact of the respiratory system on acid-base balance in the body.

Contraction of the respiratory muscles during inspiration brings fresh ambient air into lungs. The ambient air, whose total pressure is 760 torr at sea level, contains 20.94 per cent oxygen, 0.04 per cent carbon dioxide, and 79 per cent nitrogen, with partial pressures of 159, 0.3, and 600 torr respectively.

The total pressure of the gases in the lung is also equal to the ambient barometric pressure. However, when the air enters the lungs it becomes diluted by and saturated with water vapor that evaporates from the surface of the tracheobronchial tree. Water vapor, like other gases, exerts a partial pressure, but unlike other gases, its partial pressure depends almost entirely on the temperature and is virtually unaffected by the barometric pressure. At normal body temperature (37°C) the partial pressure of water vapor is 47 torr. In the alveoli the gas is further diluted by the presence of carbon dioxide that has passed from blood in the pulmonary capillaries into the alveoli. In the alveolar air there is approximately 15 per cent oxygen, 6 per cent carbon dioxide, and 79 per cent nitrogen.

Because of the presence of water vapor, the pressure of dry alveolar gas will be 47 torr less than the barometric pressure. This is important, because analysis of the gases present in alveolar air or expired air is reported in terms of the dry gas. To calculate the partial pressure of a particular gas in the alveolar or expired gas, its fractional concentration is multiplied by the barometric pressure minus the water vapor pressure.

Thus $$P_A = F_A \times (\text{barometric pressure} - 47)$$

or

$$P_E = F_E \times (\text{barometric pressure} - 47)$$

where P represents the partial pressure and F the fractional concentration of a gas in the alveolar air (A) or the expired air (E). In healthy lungs the partial pressures of oxygen, carbon dioxide, and nitrogen in the alveolar air are approximately 100, 40, and 570 torr.

The blood that enters the pulmonary capillaries has come from the tissues and therefore has a low oxygen content (P_{O_2} about 40 torr) and high carbon dioxide content (P_{CO_2} about 46 torr). Because the partial pressures of the gases in the alveolar air and the capillary blood are different, oxygen diffuses from the alveoli into the capillary blood and carbon dioxide diffuses into the alveoli. The oxygen-depleted and carbon-dioxide-enriched alveolar gas leaves through the airway during the ensuing expiration, while the blood that has taken up oxygen and given off carbon dioxide enters the systemic arteries and travels to the tissues. Here oxygen diffuses into the cells, and the carbon dioxide that has been produced in the cells is taken up by the blood. This venous blood, in turn, is once again transported to the lungs and there it exchanges gases with the alveolar gas.

Chapter 1

ABBREVIATIONS AND DEFINITIONS

ABBREVIATIONS

Many of the abbreviations used in pulmonary physiology consist of a series of primary symbols that relate to a primary variable, such as a physical quantity (volume or pressure) or a calculated parameter. These primary symbols may be modified by superscripts that denote a time derivative or mean value, and are often qualified by secondary symbols noted as subscripts that specify the anatomic location or physiologic derivation of the measurement. They, in turn, may be followed by further symbols to indicate molecular species, and these symbols are separated from the main term by a comma.

PRIMARY SYMBOLS

Gas Exchange

C Concentration in blood phase
D Diffusing capacity
F Fractional concentration of a gas
P Pressure, gas or blood
Q Volume of blood
R Respiratory exchange ratio
S Saturation of Hb in the blood phase
V Gas volume

Pulmonary Mechanics

C Compliance
f Respiratory frequency
G Conductance
R Resistance

SUPERSCRIPTS

A dot above the symbol denotes a time derivative such as $\dot{V}$–volume per unit time (i.e., ventilation in

liters per minute) or $\dot{Q}$ (blood flow per minute).
A line above the symbol denotes a mean value such as $\bar{v}$ – mixed venous.

SECONDARY SYMBOLS OR SUBSCRIPTS

Anatomic Location

aw Airway
bs Body surface
cw Chest wall
es Esophageal
L Lung (pulmonary)
LA Left atrium
LV Left ventricle
PA Pulmonary artery
pl Pleural

Gases

Ar Argon
CO Carbon monoxide
CO_2 Carbon dioxide
N_2 Nitrogen
O_2 Oxygen
SF_6 Sulfur hexafluoride
Xe Xenon

Gas Phase

A Alveolar gas
B Barometric
D Dead space or wasted gas

E	Expired gas
ET	End tidal gas
I	Inspired gas
T	Tidal gas
TG	Thoracic gas

Blood Phase

a	Arterial blood
b	Blood in general
c	Capillary blood
ċ	Pulmonary end-capillary blood
s	Shunt
t	Total
v	Venous blood
$\bar{v}$	Mixed venous blood

Pulmonary Mechanics

ds	Downstream
dyn	Dynamic
el	Elastic
max	Maximal
st	Static
us	Upstream

CONDITIONS

ATPD	Ambient temperature and pressure, dry
ATPS	Saturated with water vapor at ambient temperature and pressure
BTPS	Body conditions: saturated with water vapor at body temperature and ambient pressure

STPD Standard conditions: temperature 0 °C, pressure 760 mm Hg (torr)

DEFINITIONS

Abbreviations are also used for almost all parameters of lung function. The following lists most of these abbreviations and their definition.

LUNG VOLUME COMPARTMENTS

CC Closing capacity
The volume of gas left in the lungs when the rapid change in "marker" gas concentration occurs (this is thought to be the volume at which airway closure begins) from an alveolar plateau during a slow expiratory vital capacity maneuver.

Thus $$CC = CV + RV$$

CV Closing volume
The volume of gas exhaled after there has been a rapid change in the concentration of an inert "marker" gas from an alveolar plateau during a slow expiratory vital capacity maneuver.

ERV Expiratory reserve volume
The maximum volume of air that can be exhaled from the end-expiratory level, or from functional residual capacity (FRC).

FRC Functional residual capacity
The volume of air remaining in the lungs at the end of an

ordinary expiration (i.e., at the resting level or end-expiratory level).

IC Inspiratory capacity
The maximal volume of air that can be inhaled, i.e., to total lung capacity (TLC) from the end-expiratory level i.e., from functional residual capacity (FRC).

IRV Inspiratory reserve volume
The maximal volume of air that can be inhaled, i.e., to total lung capacity (TLC) over and above the tidal volume.

RV Residual volume
The volume of air remaining in the lungs after a maximal expiration.

Thus $$RV = TLC - VC$$

TLC Total lung capacity
The sum of all the compartments of the lung, or the volume of air in the lungs at maximum inspiration.

VC Vital capacity
The maximum volume of air that can be expelled after a maximum inspiration, i.e., from total lung capacity (TLC).

V_T Tidal volume
The volume of air inhaled or exhaled with each breath during breathing.

SPIROMETRY

$FEV_{1.0}$ Forced expiratory volume in one second
The volume of air expelled in one second during a forced