PULMONARY FUNCTION TESTING INDICATIONS AND INTERPRETATIONS

A Project of the California Thoracic Society

Edited by
Archie F. Wilson, M.D., Ph.D.

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Grune & Stratton
(Harcourt Brace Jovanovich, Publishers)
Orlando San Diego New York London
Toronto Montreal Sydney Tokyo

GRUNE & STRATTON, INC.
Orlando, FL 32887

Distributed in the United Kingdom by
GRUNE & STRATTON, LTD.
24/28 Oval Road, London NW 1

Library of Congress Catalog Number 84-73389
International Standard Book Number 0-8089-1692-0

PRINTED IN THE UNITED STATES OF AMERICA
85 86 87 88 10 9 8 7 6 5 4 3 2 1

Preface

Pulmonary Function Testing: Indications and Interpretations is meant to serve as a sequel to *Pulmonary Function Testing: Guidelines and Controversies.* Like its predecessor, this handbook is a product of the California Thoracic Society and was compiled prior to, during, and immediately after a postgraduate course that was given by leaders in this field. The chapters were written by individual members of the Pulmonary Physiology Committee after prolonged discussion with the faculty of the postgraduate course and other committee members.

It was our purpose to provide a handbook that would be useful to the pulmonary clinician who uses the laboratory to study disordered respiratory physiology for clinical purposes. We have included not only discussions of all tests likely to be obtained in both community and medical center pulmonary function laboratories but also applications of the testing to a number of nontraditional sites including the work place, intensive care units, and exercise and sleep laboratories. Evaluation of respiration testing for preoperative assessment, occupational disability, and pediatric patients is included. We have also discussed the use of the computer in pulmonary function interpretation.

We hope this handbook will provide a clear guide to diagnosis of pulmonary disorders by function testing. We also hope that we have adequately pointed the way to understanding both the limitations and some of the new areas in which pulmonary function testing is likely to expand.

Acknowledgments

Special thanks to Elma Plappert for her many years of guidance and support as Executive Secretary of the California Thoracic Society; Roberta Langenfeld for her secretarial support; and Karla Peterson for her editorial assistance.

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Terms and Abbreviations

The variety of abbreviations used in clinical pulmonary function reports (e.g., MEF 50%, FEF 50%, Vmax 50%, and $\dot{V}$ 50%) often leads to considerable confusion, especially for physicians without specific training in pulmonary medicine. Although not perfect, the terminology and abbreviations suggested by an American College of Chest Physicians/American Thoracic Society (ACCP/ATS) joint committee are the best available and should be used whenever possible. Those most relevant to subsequent chapters are given below. Abbreviations marked with an asterisk were not cited by the ACCP/ATS joint committee, but are used in this book.

A	Alveolar
a	Arterial
an	Anatomic
ATPD	Ambient temperature and pressure, dry
ATPS	Ambient temperature and pressure, saturated with water vapor at these conditions
B	Barometric
BTPS	Body conditions: Body temperature, ambient pressure, and saturated with water vapor at these conditions
C	A general symbol for compliance, volume change per unit of applied pressure
c	Capillary
C/V_L	Specific compliance
CD*	Cumulative inhalation dose. The total dose of an agent inhaled during bronchial challenge testing; it is the sum of the products of concentration multiplied by the number of breaths at that concentration
C_{dyn}	Dynamic compliance, compliance measured at point of zero gas flow at the mouth during active breathing. The respiratory frequency should be designated; e.g., $C_{dyn}40$
C_{st}	Static compliance, compliance determined from measurements made during conditions of prolonged interruption of air flow
D	Dead space or wasted ventilation (qualifying symbol, e.g., V_D)

D/V_A	Diffusion per unit of alveolar volume
D_k	Diffusion coefficient or permeability constant as described by Krogh; it equals $D \cdot (P_B - P_{H_2O})/V_A$
D_m	Diffusing capacity of the alveolar capillary membrane (STPD)
D_x (or DL_{CO})	Diffusing capacity of the lung expressed as volume (STPD) of gas (x) uptake per unit alveolar-capillary pressure difference for the gas used. Unless otherwise stated, carbon monoxide is assumed to be the test gas, i.e., D is D_{co}. A modifier can be used to designate the technique, e.g., D_{SB} is single breath carbon monoxide diffusing capacity and D_{SS} is steady state CO diffusing capacity. (Editor's note: This recommendation has not widely been accepted. DL_{CO}, $DL_{CO}SB$, and $DL_{CO}SS$ are still the most commonly used abbreviations.)
E	Expired
ERV	Expiratory reserve volume; the maximal volume of air exhaled from the end-expiratory level
est	Estimated
f	Respiratory frequency per minute
F	Fractional concentration of a gas
FEF_{max}	The maximal forced expiratory flow achieved during an FVC
$FEF_{25-75\%}$	Mean forced expiratory flow during the middle half of the FVC (formerly called the maximum mid-expiratory flow rate)
$FEF_{75\%}$	Instantaneous forced expiratory flow after 75% of the FVC has been exhaled
$FEF_{200-1200}$	Mean forced expiratory flow between 200 ml and 1200 ml of the FVC (formerly called the maximum expiratory flow rate)
FEF_x	Forced expiratory flow, related to some portion of the FVC curve. Modifiers refer to the amount of the FVC already *exhaled* when the measurement is made
FET_x	The forced expiratory time for a specified portion of the FVC; e.g., $FET_{95\%}$ is the time required to deliver the first 95% of the FVC and $FET_{25-75\%}$ is the time required to deliver the $FEF_{25-75\%}$
$FEV_t/FVC\%$	Forced expiratory volume (timed) to forced vital capacity ratio, expressed as a percentage
FIF_x	Forced inspiratory flow. As in the case of the FEF, the appropriate modifiers must be used to designate the volume at which flow is being measured. Unless otherwise specified, the volume qualifiers indicate the volume inspired from RV at the point of the measurement
FRC	Functional residual capacity; the sum of RV and ERV (the volume of air remaining in the lungs at the end-expiratory position). The method of measurement should be indicated as with RV

G_{aw}	Airway conductance, the reciprocal of R_{aw}
G_{aw}/V_L	Specific conductance, expressed per liter of lung volume at which G is measured (also referred to as SG_{aw})
I	Inspired
IRV	Inspiratory reserve volume; the maximal volume of air inhaled from the end-inspiratory level
IC	Inspiratory capacity; the sum of IRV and V_T
L	Lung
max	Maximal
MIP*	Maximal inspiratory pressure
MEP*	Maximal expiratory pressure
MVV_x	Maximal voluntary ventilation. The volume of air expired in a specified period during repetitive maximal respiratory effort. The respiratory frequency is indicated by a numerical qualifier; e.g., MVV_{60} is MVV performed at 60 breaths per minute. If no qualifier is given, an unrestricted frequency is assumed
p	Physiological
P	Pressure, blood or gas
PA*	Pulmonary artery
PD*	Provocative dose; the dose of an agent used in bronchial challenge testing which results in a defined change in a specific physiologic parameter. The parameter tested and the percent change in this parameter is expressed in cumulative dose units over the time following exposure that the positive response occurred. For example, $PD_{35}SG_{aw}$ = x units/y minutes, where x is the cumulative inhalation dose and y the time at which a 35% fall in SG_{aw} was noted
PEF	The highest forced expiratory flow measured with a peak flow meter
P_{st}	Static transpulmonary pressure at a specified lung volume; e.g., P_{st}TLC is static recoil pressure measured at TLC (maximal recoil pressure)
Q_c	Capillary blood volume (usually expressed as V_c in the literature, a symbol inconsistent with those recommended for blood volumes). When determined from the following equation, Q_c represents the effective pulmonary capillary blood volume, i.e., capillary blood volume in intimate association with alveolar gas: $$1/D = 1/D_m + 1/(\Theta \cdot Q_c)$$
R	A general symbol for resistance, pressure per unit flow
R_{aw}	Airway resistance
rb	Rebreathing
RQ*	Respiratory quotient

R_{us} Resistance of the airways on the alveolar side (upstream) of the point in the airways where intraluminal pressure equals Ppl, measured under conditions of maximum expiratory flow

RV Residual volume; that volume of air remaining in the lungs after maximal exhalation. The method of measurement should be indicated in the text or, when necessary, by appropriate qualifying symbols

SBN* Single breath nitrogen test; a test in which plots of expired N_2 concentration versus expired volume after inspiration of 100% O_2 are recorded. The closing volume and slope of Phase III are two parameters measured by this test

STPD Standard conditions: temperature 0° C, pressure 760 mm Hg, and dry (0 water vapor)

t Time

T Tidal

TGV* Thoracic gas volume; the volume of gas within the thoracic cage as measured by body plethysmography

TLC Total lung capacity; the sum of all volume compartments or the volume of air in the lungs after maximal inspiration. The method of measurement should be indicated, as with RV

V Gas volume. The particular gas as well as its pressure, water vapor conditions, and other special conditions must be specified in text or indicated by appropriate qualifying symbols

v Venous

$\bar{v}$ Mixed venous

$\dot{V}_A$ Alveolar ventilation per minute (BTPS)

$\dot{V}_{CO_2}$ Carbon dioxide production per minute (STPD)

$\dot{V}_D$ Ventilation per minute of the physiologic dead space (wasted ventilation), BTPS, defined by the following equation:

$$\dot{V}_D = \dot{V}_E(PaCO_2 - P_ECO_2/(PaCO_2 - P_ICO_2)$$

V_D The physiologic dead-space volume defined as $\dot{V}_D/f$

V_Dan Volume of the anatomic dead space (BTPS)

$\dot{V}_E$ Expired volume per minute (BTPS)

$\dot{V}_I$ Inspired volume per minute (BTPS)

Viso$\dot{V}$* Volume of isoflow; the volume when the expiratory flow rates become identical when flow-volume loops performed after breathing room air and helium-oxygen mixtures are compared

$\dot{V}_{O_2}$ Oxygen consumption per minute (STPD)

$\dot{V}_{max}X$ Forced expiratory flow, related to the total lung capacity or the actual volume of the lung at which the measurement is made. *Modifiers refer to the amount of lung volume remaining when the measurement is made.* For example: $\dot{V}_{max}$ 75% is instantaneous forced expiratory flow when the lung is at 75% of its

TLC. $\dot{V}_{max}3.0$ is instantaneous forced expiratory flow when the lung volume is 3.0 liters. [Editor's note: It is still common to find reports in which modifiers refer to the amount of VC remaining.]

V_T — Tidal volume; TV is also commonly used

XA or Xa — A small capital letter or lowercase letter on the same line following a primary symbol is a qualifier to further define the primary symbol. When small capital letters are not available on typewriters or to printers, large capital letters may be used as subscripts, e.g., X_A = XA

Blood-Gas Measurements

Abbreviations for these values are readily composed by combining the general symbols recommended earlier. The following are examples:

$PaCO_2$	Arterial carbon dioxide tension
$C(a-v)O_2$	Arteriovenous oxygen content difference
CcO_2	Oxygen content of pulmonary end-capillary blood
F_ECO*	Fractional concentration of CO in expired gas
$P(A-a)O_2$	Alveolar-arterial oxygen pressure difference; the previously used symbol, $A\text{-}aDO_2$ is not recommended
SaO_2	Arterial oxygen saturation of hemoglobin
Q_{SP}	Physiologic shunt flow (total venous admixture) defined by the following equation when gas and blood data are collected during ambient air breathing: $$Qsp = \frac{CcO_2 - CaO_2}{CcO_2 - CvO_2} \cdot Q$$
$P_{ET}O_2$	PO_2 of end tidal expired gas
$TCPO_2$	Transcutaneous PO_2

Contents

The Limitations of Pulmonary Function Testing

JOHN F. MURRAY

Pulmonary function tests are widely used in the evaluation and management of patients with known or suspected disorders of respiration. The clinical application of these studies rests on knowledge of pulmonary physiology, which has a sound experimental foundation, although we need more information about the relationship between the structure and function of the lungs in health and disease. Despite having a scientific basis, the results of pulmonary function tests must be interpreted empirically, and the temptation to use certain abnormalities to deduce the presence of specific underlying pathologic changes has proved irresistible, albeit often misleading. In a recent editorial, Butler[1] reviewed the inherent limitations that may involve each step of the testing continuum: the apparatus, the patient, the technician, and the interpreter. The purpose of this discussion is (1) to consider why we perform pulmonary function tests and what we are trying to measure; (2) to remind the reader about certain measurement inaccuracies that are frequently overlooked; and (3) to emphasize the enormous problems that plague interpretation, particularly those concerning the concept of *normality* and how to isolate a *specific abnormality.*

WHAT ARE WE MEASURING?

The main reasons for performing pulmonary function studies are listed in Table 1-1. Each of these indications deals with some aspect of the consequences of how particular disorders affect respiratory function. Thus, to examine in

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ISBN 0-8089-1692-0