Gas Exchange Function of Normal and Diseased Lungs

Progress in Respiration Research

Vol. 16

Series Editor: H. Herzog, Basel

S. Karger • Basel • München • Paris • London • New York • Sydney

Gas Exchange Function of Normal and Diseased Lungs

Volume Editors
J. Piiper and P. Scheid, Göttingen

100 figures and 15 tables, 1981

S. Karger • Basel • München • Paris • London • New York • Sydney

Progress in Respiration Research

Vol. 14: Asthma
Editor: H. Herzog, Basel

Vol. 15: Clinical Importance of Surfactant Defects
Editor: P. von Wiehert, Hamburg

National Library of Medicine, Cataloging in Publication
Contents

List of Participants IX
Introduction XV

Special Lectures
Chairmen: J. Milic-Emili, C. Albers

Otis, A.B. (Gainesville, Fla.): History of Pulmonary Gas Exchange in the 19th Century 1
Lenfant, C. (Bethesda, Md.): Respiratory Physiology Research: Its Future 10

Ventilation Distribution and Dead Space
Chairmen: J.M.B. Hughes, N.C. Staub

Cumming, G. (Midhurst): Measurement of Alveolar Gas Mixing Efficiency 14
Kindig, N.B.; Perry, M.E., and Filley, G.F. (Denver, Colo.): Gas-Mixing Dead Space Measurement with Paired Tracers 31
Milic-Emili, J. (Montreal): Interregional Distribution of Inspired Gas 33
Roussos, C.; Macklem, P.T., and Engel, L. (Montreal): Mechanisms Underlying Unequal Distribution of Inspired Gas: Lung, Chest Wall 44
D’Angelo, E. and Agostoni, E. (Milano): Respiratory Muscle Action and Local Swings of Pleural Pressure 54
Intrapulmonary Gas Mixing
Chairmen: G. Cumming, H.-K. Chang, R.S. Sikand

Scheid, P. (Göttingen): Mathematical Models for Intrapulmonary Gas Mixing
Hansen, J.E. (Torrance, Calif.): The Human Acinus in Three Dimensions
Worth, H. and Piiper, J. (Göttingen): Diffusion in Gas Mixtures Similar to Alveolar Gas
Adaro, F. and Piiper, J. (Göttingen): Interpretation of Simultaneous Intrapulmonary Equilibration of Gases of Differing Diffusivities
Smidt, U. and Worth, H. (Moers): Gas Mixing in Patients
Arieli, R. and Van Liew, H.D. (Buffalo, N.Y.): Post Inspiratory Mixing in the Lung
Ôkubo, T.; Shibata, H.; Fuyuki, T., and Takishima, T. (Sendai): Effects of Gravity and Branching on Longitudinal Gas Mixing in Airways, Studied by a Glass Tube Model

Blood/Gas Equilibration
Chairmen: P. Haab, H.H. Loeschcke, G.F. Filley

Piiper, J. (Göttingen): Blood-Gas Equilibration in Lungs and Pulmonary Diffusing Capacity
Meyer, M. (Göttingen): Pulmonary Diffusing Capacity for O2 and CO in Man at Rest and During Exercise by Rebreathing Stable Isotopes
Burns, B. and Shepard, H. (Baltimore, Md.): Membrane Diffusion: Comparison between Dithionite DO2 and DLco.
Holland, R.A.B. (Kensington): Kinetics of O2 and CO Reactions in Blood 152
Gurtner, G.H. and Peavy, H.H. (Baltimore, Md.): Evidence for Facilitated Transport of O2 and CO in the Lungs 161

Contents VII

Meyer, M.; Scheid, P., and Piiper, J. (Göttingen): No Evidence for Facilitated Pulmonary Transfer of Carbon Monoxide 166
Hill, E.P. and Enns, T. (La Jolla, Calif.): CO2 Diffusing Capacity in Isolated Lungs 172
Crandall, E.D. (Los Angeles, Calif.): Kinetics of CO2 in Blood 181
Klocke, R.A. (Buffalo, N.Y.): Factors Involved in the Kinetics of the Bohr Shift 198
Effros, R.M.; Mason, G., and Silverman, P. (Torrance, Calif.) The Significance of Pulmonary Endothelial Carbonic Anhydrase 203
Gros, G.; Wittmann, B., and Guggenberger, L. (Essen): Carbamate Kinetics of Blood Proteins 205

Gas Exchange in Inhomogeneous Lungs
Chairmen: J.B. West, C. Lenfant, H. Herzog

Haab, P. (Fribourg): Estimation of Diffusion Limitation in Inhomogeneous Lung 214
Geiser, J. (Fribourg): Analysis of Diffusing Capacity in Lungs with Continuous Distributions of VA, Q and DL 220
Kawashiro, T.; Yamaguchi, K., and Yokoyama, T. (Tokyo): Simultaneous TwoCompartmental Analysis of Ventilation-Perfusion Unevenness and Diffusing Capacity in the Lungs 222
Yokoyama, T.; Kawashiro, T., and Yamaguchi, K. (Tokyo): Two-Compartmental Analysis of Ventilation-Perfusion Unevenness in Diseased Lungs and Triple
Olszowka, Å.J. (Buffalo, N.Y.): Would Increasing the Number of Gases Used Improve the Resolution of Inert Gas Techniques? 250


Rehder, K. (Rochester, Minn.): Pulmonary Gas Exchange during Anesthesia and Mechanical Ventilation 255

Riedel, M.; Widimsky, J., and Staněk, V. (Prague): Ventilation and Gas Exchange in Chronic Thromboembolic Disease 258

Dantzker, D.R. and Bower, J.S. (Ann Arbor, Mich.): Gas Exchange in Obliterative Pulmonary Vascular Disease 264

Staub, N.C. and Conhaim, R.L. (San Francisco, Calif.): An Anatomical Basis for Very Low Ventilation/Perfusion Units in the Lung 267


Fedde, M.R. (Manhattan, Kans.): Introduction to the Avian Respiratory System 280

Powell, F.L. and Wagner, P.D. (San Diego, Calif.): Inert Gas Transfer in Avian Lungs 283

White, F.N.; Spragg, R.G., and Ackerman, R.A. (La Jolla, Calif.): Ventilation Distribution in the Turtle Lung 285
Adjustment to Environmental Conditions and Exercise
Chairman: P. Bouverot

West, J.B. and Wagner, P.D. (La Jolla, Calif.): Pulmonary Gas Exchange at High Altitude 287
Lechner, A.J. and Banchero, N. (Denver, Colo.): Lung Morphometry in Guinea Pigs Acclimated to Cold or to Hypoxia 302
Cruz, J.C. (Denver, Colo.): Alveolar-Arterial Oxygen Tension Gradients in High Altitude Residents and in Polycythemic Patients 308
Marconi, C. and Cerretelli, P. (Geneva): Gas Exchange Adjustments in Running Dogs 311

Subject Index 317

List of Participants

Adaro, Fernando, Arenales 1497 9° (1061), Buenos Aires (Argentina)
Ahmad, H. R., Lehrstuhl für Physiologie I, Ruhr-Universität Bochum, Buscheystrasse, D-4630 Bochum-Querenburg (FRG)
Albers, Claus, Institut für Physiologie der Universität Regensburg, Universitätsstrasse 31, D-8400 Regensburg (FRG)
Aquin, Lynn, Department of Physiology, University of Colorado, Medical Center, 4200 East Ninth Avenue, Denver, CO 80262 (USA)
Arieli, Ran, Department of Physiology, State University of New York at Buffalo, 120 Sherman Hall, Buffalo, NY, 14214 (USA)
Banchero, Natalio, Department of Physiology, University of Colorado, Medical Center, 4200 East Ninth Avenue, Denver, CO 80262 (USA)
Barnikol, Wolfgang, Physiologisches Institut der Universität, Saarstrasse 21, D-6500 Mainz (FRG)
Bartels, Heinz, Physiologisches Institut der Medizinischen Hochschule, Karl-WichertAllee 9, D-3000 Hannover (FRG)
Ben Jebria, Abdellaziz, Hôpital Saint-Antoine, Centre de Recherche Inserm, 184, rue du Faubourg-St-Antoine, F-75571 Paris Cédex 12 (France)
Besch, Emerson L., Department of Metabolism, College of Veterinary Medicine, University of Florida, Gainesville, FL 32610 (USA)
Bouverot, Pierre, Laboratoire de Physiologie Respiratoire, CNRS, 23, rue Becquerel, F-67087 Strasbourg (France)
Burns, Barry, Department of Anesthesiology, The Johns Hopkins Hospital, Baltimore, MD 21205 (USA)
Cerretelli, Paolo, Département de Physiologie de l’Université, 20, rue de l’Ecole-deMédecine, CH-1211 Genève 4 (Switzerland)
Chang, Hsin-Kang, Biomedical Engineering Unit and Department of Physiology, McGill University, 3655 Drummond Street, Montreal, Quebec H3G 1Y6 (Canada)
Chiang, Shou-Teh, Department of Physiology, School of Medicine, National Yang-Ming Medical College, Shih-Pai, Taipei, Taiwan (112) (Republic of China)

List of Participants X

Crandall, Edward D., Department of Medicine, School of Medicine, UCLA, Los Angeles, CA 90024 (USA)
Cruz, Julio, Pulmonary Research Laboratory, University of Colorado, Medical Center, Denver, CO 80262 (USA)
Cumming, Gordon, Midhurst Medical Research Institute, Midhurst, Sussex GU2d OBL (Great Britain)
D’Angelo, Edgardo, Laboratorio di Fisiologia Umana, Università di Milano, Via Mangiagalli 32,1-20133 Milano (Italy)
Dantzker, David R., Department of Medicine, Pulmonary Division, The University of Michigan, Medical School, Ann Arbor, MI 48109 (USA)
Denison, David, Lung Function Unit, Brompton Hospital, Fulham Road, London SW3 6HP (Great Britain)
Derks, C., Les Laboratoires Servier, Recherche Médicale et Création de Médicaments, Direction de Recherche et Développement, 22, rue Garnier, F-92201 Neuilly-sur-Seine Cédex (France)
Engel, Ludwig A., Department of Medicine, Westmead Hospital, Westmead, NSW 2145 (Australia)
Fedde, M. Roger, Department of Anatomy and Physiology, Kansas State University, Manhattan, KS 66506 (USA)
Filley, Giles F., Container C-321, University of Colorado, Medical Center, Denver, CO 80262 (USA)
Fukuchi, Yoshinosuke, Department of Geriatrics, Faculty of Medicine, University of Tokyo, Hongo, Tokyo (Japan)
Gatz, Randall N., Battelle, Centres de Recherche de Genève, 7, route de Drize, CH-1227 Carouge-Genève (Switzerland)
Geiser, Jiirg, Institut de Physiologie de l’Université, CH-1700 Fribourg (Switzerland)
Goerg, R., I. Medizinische Klinik und Poliklinik rechts der Isar der Technischen Universität, Ismaninger Strasse 22, D-8000 München 80 (FRG)
Gros, Gerolf, Institut für Physiologie des Universitätsklinikums der Gesamthochschule Essen, Hufelandstrasse 55, D-4300 Essen (FRG)
Guénard, Hervé, Unité d’Enseignement et de Recherche de Biologie et Physiopathologie des Facteurs d’Ambiance, Université de Bordeaux II, 146, rue Léo-Saignat, F-33076 Bordeaux Cédex (France)
Gurtner, Gail H., Division of Environmental Physiology, School of Hygiene and Public Health, The Johns Hopkins University, 615 North Wolfe Street, Baltimore, MD 21205 (USA)
Haab, Pierre, Institut de Physiologie de l’Université, CH-1700 Fribourg (Switzerland)
Hansen, James E., Harbor General Hospital Campus, School of Medicine, UCLA, 1000 Carson Street, Torrance, CA 90509 (USA)
Hatzfeld, Claire, Hôpital Saint-Antoine, Centre de Recherche Inserm, 184, rue du Faubourg-St-Antoine, F-75571 Paris Cédex 12 (France)
Heisler, Norbert, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)

List of Participants XI

Herzog, Heinrich, Medizinische Universitätsklinik, Abteilung für Atmungskrankheiten, Kantonsspital, Spitalstrasse 21, CH-4031 Basel (Switzerland)
Hill, Esther P., Section of Physiology M-0023, Department of Physiology, University of California San Diego, La Jolla, CA 92093 (USA)
Hlastala, Michael P., Department of Medicine, Division of Respiratory Diseases, University of Washington, Seattle, WA 98195 (USA)
Holland, Robert A. B., School of Physiology and Pharmacology, The University of New South Wales, Box 1, Post Office, Kensington, NSW 2033 (Australia)
Hook, Christian, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)
Hughes, George M., Research Unit for Animal Respiration, University of Bristol, Woodland Road, Bristol BS8 IUG (Great Britain)
Hughes, J. Michael B., Royal Postgraduate Medical School, Hammersmith Hospital, University of London, London W12 OHS (Great Britain)
Jones, Hazel, Royal Postgraduate Medical School, Hammersmith Hospital, University of London, London W12 OHS (Great Britain)
Juhos, Laszlo Th., Department of Physiology, Stanford University, Stanford, CA 94305 (USA)
Kappos, Andreas, Abteilung für Pneumologie, Zentrum der Inneren Medizin, Klinikum der Johann-Wolfgang-Goethe-Universität, Theodor-Stern-Kai 7, D-6000 Frankfurt 70 (FRG)
Kawashiro, Takeo, Department of Medicine, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo (Japan)
Kelly, Suzanne, Meakins Christie Laboratories, Royal Victoria Hospital, McGill University Clinic, 687 Pine Avenue West, Montreal, Quebec H3A 1A1 (Canada)

Kiley, James P., Department of Anatomy and Physiology, Kansas State University, Manhattan, KS 66506 (USA)

Kindig, Neal B., Webb-Waring Lung Institute, University of Colorado Medical Center, 4200 East Ninth Avenue, Denver, CO 80262 (USA)

Klocke, Robert A., Department of Medicine, School of Medicine, State University of New York at Buffalo, 462 Grider Street, Buffalo, NY 14215 (USA)

Knoblauch, Andreas, Spital Limmattal, Urdorferstrasse 100, CH-8952 SchlierenZürich (Switzerland)

Lacquet, Ludovic M., Katholieke Universiteit Leuven, Akademisch Ziekenhuis, B-3042 Pellenberg (Belgium)

Lechner, Andrew J., Department of Physiology, University of Colorado, Medical Center, 4200 East Ninth Avenue, Denver, CO 80262 (USA)

Lenfant, Claude, National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD 20205 (USA)

Loeschcke, Hans H., Lehrstuhl für Physiologie I, Ruhr-Universität Bochum, Buscheystrasse, D-4630 Bochum-Querenburg (FRG)

Luttman, Alwin, Lehrstuhl für Physiologie I, Ruhr-Universität Bochum, D-4630 Bochum-Querenburg (FRG)

Magnussen, Helgo, Medizinische Universität-Poliklinik, Wilhelmstrasse 35-37, D-5300 Bonn (FRG)

List of Participants XII

Marconi, Claudio, Laboratorio di Fisiologia Umana, Università di Milano, Via Mangiagalli 32, 20133 Milano (Italy)

Matalon, Sady V., Department of Physiology, State University of New York at Buffalo, 120 Sherman Hall, Buffalo, NY 14214 (USA)

Meyer, Michael, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)

Milic-Emili, Joseph, Department of Physiology, McGill University, PO Box 6070, Station ‘A’, Montreal, Quebec H3C 1Y6 (Canada)

Mochizuki, Masaji, Department of Physiology, School of Medicine, Yamagata University, Yamagata (Japan)

Mückenhoff, K., Lehrstuhl für Physiologie I, Ruhr-Universität Bochum, Buscheystrasse, D-4630 Bochum-Querenburg (FRG)

Newell, Jonathan C., Center for Biomedical Engineering, Rensselaer Polytechnic Institute, Troy, NY 12181 (USA)

Okubo, Takao, The 1st Department of Internal Medicine, Tohoku University, School of Medicine, Seiryo-Machi 1-1, 980 Sendai (Japan)
Olszowka, Albert J., Department of Physiology, State University of New York at Buffalo, 120 Sherman Hall, Buffalo, NY 14214 (USA)
Otis, Arthur B., College of Medicine, University of Florida, Gainesville, FL 32610 (USA)
Paiva, Manuel, Institut de Recherche Interdisciplinaire en Biologie Humaine et Nucléaire, Faculté de Médecine, Université Libre de Bruxelles, B-1000 Bruxelles (Belgium)
Piiper, Johannes, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)
Powell, Frank L., Section of Physiology M-0023, Department of Medicine, University of California San Diego, La Jolla, CA 92093 (USA)
Rehder, Kai, Department of Anesthesiology, Mayo Clinic, Rochester, MN 55901 (USA)
Reischl, Peter, Department of Community and Environmental Medicine, California College of Medicine, University of California Irvine, Irvine, CA 92717 (USA)
Riedel, Martin, Department of Medicine II, Institute for Clinical and Experimental Médecine, Buéjovická 800, 14622 Praha (Czechoslovakia)
Riepl, Gerhard, Medizinische Universitätssklinik, D-8700 Würzburg (FRG)
Roussos, Charis, Meakins Christie Laboratories, Royal Victoria Hospital, McGill University Clinic, 687 Pine Avenue West, Montreal, Quebec H3A 1A1 (Canada)
Sackner, Marvin A., Division for Pulmonary Diseases, Mt. Sinai Medical Center, Miami Beach, FL 33140 (USA)
Scheid, Peter, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)
Sikand, Rajinder S., Section of Pulmonary Diseases, The Hospital of St. Raphael, 1-50 Chapel Street, New Haven, CT 06511 (USA)
Smidt, Udo, Krankenhaus Bethanien, D-4130 Moers (FRG)
Staub, Norman C., School of Medicine, Cardiovascular Research Institute, University of California San Francisco, San Francisco, CA 94143 (USA)

List of Participants XIII

Stokke, Trond, Abteilung Physiologie, Max-Planck-Institut für experimentelle Medizin, Hermann-Rein-Strasse 3, D-3400 Göttingen (FRG)
Sybrecht, Gerhard, Medizinische Hochschule, Organis. Nr. 6870, Karl-WichertAllee 9, D-3000 Hannover (FRG)
Torre-Bueno, José, Department of Physiology, Duke University Medical Center, Box 3823, Durham, NC 27710 (USA)
Van Liew, Hugh D., Department of Physiology, State University of New York at Buffalo, 120 Sherman Hall, Buffalo, NY 14214 (USA)
Wagner, Peter D., Section of Physiology M-0023, Department of Medicine, University
Introduction

This volume contains the papers presented at the Symposium on Gas Exchange Function of Normal and Diseased Lungs that was held in Gottingen, July 8-11, 1980. The meeting was a Satellite Symposium of the XXVIIIth International Congress of Physiological Sciences, which took place in Budapest (Hungary), July 13-19, 1980.

The topics discussed in five sessions were: (1) ventilation distribution and dead space; (2) intrapulmonary gas mixing; (3) blood/gas equilibration; (4) gas exchange in inhomogeneous lungs; (5) adjustment to environmental conditions and exercise. Several aspects were considered in each topic, e.g. methodology, theoretical and experimental approaches, pathophysiology.

The symposium was attended by 94 scientists whose names and professional affiliations are given in the List of Participants. In composing the program we have attempted to blend review lectures with original papers on recent scientific achievements. Time for the meeting being limited, the desire of the great majority of participants to present their material could only be satisfied by offering a special format of poster presentation, whereby an author was given 5 minutes during the pertinent session to introduce his poster.

These proceedings contain manuscripts of all presentations (reviews, free oral communications, poster presentations). Space being limited in
this volume, discussions could not be included with the papers. This is particularly regrettable as the formal discussion during the sessions, as well as the many dialogs between the sessions, constituted an essential part of the meeting. In this sense, all participants of the meeting can be regarded as active, even if they were not listed in the program with a formal communication.

Introduction XVI

Our colleague and dear friend Daniel Bargeton (Paris) was expected to participate in this symposium. This was, however, made impossible as he died on the 25th of June. His death was received with regret by the attendants, most of which had known him as a scientist. The manuscript of his contribution is included in this volume.

It is our distinct pleasure to acknowledge the generous financial support provided by the Deutsche Forschungsgemeinschaft (German Research Council), Bad Godesberg, and by the Max-Planck-Gesellschaft. Furthermore, we would like to thank Mrs. Elfriede Hansen and Mrs. Irmgard Barteczko, secretaries of the Department of Physiology, for their unwearying and excellent help at all stages of the planning of the meeting and of the preparation of the publication. Thanks are also due to all members of the Department of Physiology for their cooperation.

We are grateful to Dr. H. Herzog, editor of Progress in Respiration Research, for the opportunity to publish the proceedings as a volume in this series. Particular thanks are due to Mrs. Denise Greder and Mr. R. Steinebrunner, Karger Publishing Company, for their cooperation.

Göttingen, August 1980 Johannes Piiper
Peter Scheid