

General Thoracic Surgery

Edited by

THOMAS W. SHIELDS, M.D., D.Sc. (Hon.)

Second Edition

General Thoracic Surgery

Edited by

THOMAS W. SHIELDS, M.D., D.Sc. (Hon.)

Professor of Surgery, Northwestern University
Medical School, Chicago, Illinois; Chief of Surgery,
VA Lakeside Medical Center, Chicago, Illinois;
Attending Surgeon, Northwestern Memorial Hospital,
Chicago, Illinois

Second Edition



LEA & FEBIGER Philadelphia • 1983

Lea & Febiger
600 Washington Square
Philadelphia, PA 19106
U.S.A.

**Technical note:* The "original magnifications," listed with each of the photographs of microscopic material, represent the ratio between the size of the photographic image on the original negative and the size of the microscopic specimen itself, and should be used only as an approximate indication, since they do not reflect subsequent magnifications and/or reductions in the final reproduction of the photographs.

Library of Congress Cataloging in Publication Data

Main entry under title:

General thoracic surgery.

Includes bibliographies and index.

1. Chest—Surgery. I. Shields, Thomas W.

[DNLM: 1. Thoracic surgery. WF 980 G326]

RD536.G45 1982 617'.54 82-17942

ISBN 0-8121-0782-9

First Edition, 1972

Copyright © 1983 by Lea & Febiger. Copyright under the International Copyright Union. All rights reserved. This book is protected by copyright. No part of it may be reproduced in any manner or by any means without written permission from the publisher.

PRINTED IN THE UNITED STATES OF AMERICA

Print No. 3 2 1

230
5892

11402

Foreword

18
177223

66 #3月31

text

It is a rare experience, even a unique one, to be privileged once again to write the Foreword to the second edition of General Thoracic Surgery, under the continuing editorship of Tom Shields and his talented coauthors. There are now 18 sections comprising 75 chapters, almost half again as much material as in the first edition (14 sections with 49 chapters).

Of prime importance, in my opinion, is the addition of entirely new chapters on the esophagus, making it now the Compleat Text in General Thoracic Surgery. Owing to the unusual structuring of the volume, these writings on the esophagus are by no means consecutive. In the section on anatomy, for instance, there are chapters on embryology, and on surgical anatomy; in the section on physiology, physiologic studies of the esophagus; in the section on diagnostic procedures, endoscopic examinations of the esophagus; in the section on operative procedures, resection of the esophagus, and colon replacement; in the section on thoracic trauma, trauma to the esophagus, and foreign body removal; in the section on the esophagus itself, eight fascinating chapters including malignancies; and in the section on radiation therapy, the specifics of radiation in carcinoma of the esophagus. Despite this division of material, the reader particularly interested in the esophagus can gain thorough and detailed information in consecutive sections of this second edition.

Elsewhere there are new chapters on ventilatory support of the postoperative patient; preoperative evaluation; radionuclide studies; trauma to the thoracic wall, lung, and heart; thoracic outlet syndrome, diaphragmatic pacing, and infections of the mediastinum. The three final sections comprise chapters on all new material: principles of radiation therapy, and radiation therapy of the lung and esophagus; principles of chemotherapy, and chemotherapy in bronchial carcinoma; immunology of bronchial carcinoma, and immunotherapy of lung cancer.

I emphasize these contributions because they are basic and, it is to be hoped, of continuing, increasing, and lasting importance in therapy.

Finally, I have reviewed the chapters originally contributed to the first edition. Almost without exception, recent additions have been incorporated and the writings are now current.

To summarize, the second edition will continue to be a valuable accession to the libraries of general thoracic surgeons.

Paul C. Samson, M.D.†
Emeritus Clinical Professor
Piedmont, California of Surgery (Thoracic)
†deceased

Preface

The second edition of General Thoracic Surgery has been prepared not only to update the material originally presented in the first edition, but to make the text more complete by including extensive coverage of the esophagus. The anatomy, physiology, diagnostic procedures, operations on and diseases of this structure are presented in similar detail as that presented for the lung. New chapters also have been added for more complete coverage of the chest wall, diaphragm, and mediastinum. The aspects of radiation therapy, chemotherapy, and immunology that the general thoracic surgeon should be cognizant of have been incorporated into the text.

Although the organization of the book is somewhat different from that traditionally observed, it is hoped that this will serve to unify the concepts of general thoracic surgery.

The major effort again has been made to decrease the repetition in this edition but this could not be eliminated completely. Hopefully when repetition is observed it will serve to emphasize a more important point in the knowledge and practice of general thoracic surgery.

As with the first edition, I have been able to enlist the aid of many outstanding thoracic surgeons and physicians to accomplish this task. I wish to thank each for their contributions; each of which ensures the value of this volume to the young thoracic surgeon. Unfortunately, four of these colleagues have succumbed prior to the final printing of the book. To the families and friends of Paul Adkins, Gerald Grumet, William Lees, and Paul Samson, I extend my sincere condolences.

Chicago, Illinois

Thomas W. Shields

Preface to the First Edition

This volume was prepared to present a comprehensive text on the surgical diseases of the chest wall, pleura, diaphragm, trachea, lung, and mediastinal structures. Initially, an overview of the anatomy and of the physiology of these structures is given. The investigation of the patient's disease and the management of the patient in the perioperative period are considered next. The various operative approaches and the standard surgical procedures are discussed and these are followed by chapters concerned with the disease entities of the aforementioned structures.

The major objectives are to present a summation of the current knowledge and the clinical concepts of the surgical management of trauma and diseases of the thorax. The pathophysiologic alterations produced and the correction of these by appropriate intervention are emphasized throughout. Presentations of the clinical features, pathologic changes, surgical management, operative results, and prognosis of the various disease

states are included as an integral part of the whole.

Outstanding surgeons, physicians, and scientists have cooperated in the preparation of the text. As with most multi-authored books, repetition could not be completely eliminated; however, I have tried to keep it at a minimum. In most instances, the repetition serves to emphasize important information relative to the entire subject. Interestingly, conflicting statements are few, and only an occasional footnote has been appended to point out such differences in opinion.

This book hopefully will serve as a source of information for the young thoracic surgeon and the person in surgical training. It also should serve as a reference for surgeons, as well as physicians, outside the field of general thoracic surgery who wish to ascertain the current views held by the specialty.

Chicago, Illinois

Thomas W. Shields

Contributors

Paul C. Adkins, M.D.†

*Professor and Chairman, Department of Surgery,
George Washington University Medical School,
Washington, D.C.*

Homeros Aletras, M.D.

*Professor of Surgery, University of Thessaloniki,
Thessaloniki, Greece*

Fikri Alican, M.D.

*Formerly, Assistant Professor of Surgery, University of
Mississippi Medical Center, Jackson, Mississippi*

Leslie B. Arey, Ph.D.

*Robert L. Rea Professor of Anatomy, Emeritus,
Northwestern University Medical School, Chicago,
Illinois*

Walter L. Barker, M.D.

*Associate Professor of Surgery, University of Illinois
College of Medicine, Chicago, Illinois*

John M. Beal, M.D.

*J. Roscoe Miller Distinguished Professor, Department
of Surgery, Northwestern University Medical School,
Chicago, Illinois*

Edward J. Beattie, Jr., M.D.

*Professor of Surgery, Cornell University Medical
College, New York, New York*

Philip E. Bernatz, M.D.

*Stuart W. Harrington Professor of Surgery, Mayo
Medical School, Rochester, Minnesota*

Charles E. Blevins, Ph.D.

*Professor and Chairman, Department of Anatomy,
Indiana University School of Medicine, Indianapolis,
Indiana*

Edward A. Brunner, M.D.

*Professor and Chairman, Department of
Anesthesiology, Northwestern University Medical
School, Chicago, Illinois*

Peter H. Burri, M.D.

*Professor of Anatomy, Institute of Anatomy, University
of Berne, Berne, Switzerland*

Steven K. Carter

*Vice President, Anticancer Research, Pharmaceutical
Research and Development Division, Bristol-Myers
Company, New York, New York*

H. William Clatworthy, Jr., M.D.

*Professor of Surgery, Ohio State University College of
Medicine, Columbus, Ohio*

David W. Cugell, M.D.

*Professor of Medicine, Northwestern University
Medical School, Chicago, Illinois*

Thomas J. Deeley, M.B.

*Director, Radiotherapy Service, University Hospital of
Wales, Cardiff, Wales*

Tom R. DeMeester, M.D.

*Professor of Thoracic and Cardiovascular Surgery,
University of Chicago, Chicago, Illinois*

F. Henry Ellis, Jr., M.D.

*Clinical Professor of Surgery, Harvard University
Medical School, Boston, Massachusetts*

†deceased

Lois F. Ellison, M.D.

Professor of Medicine and Surgery, Medical College of Georgia, Augusta, Georgia

Robert G. Ellison, M.D.

Leon Henri Charbonnier Professor and Chief of Thoracic and Cardiac Surgery, Medical College of Georgia, Augusta, Georgia

L. Penfield Faber, M.D.

Professor of Surgery, Rush Medical College, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois

Thomas B. Ferguson, M.D.

Professor of Cardiothoracic Surgery, Washington University School of Medicine, St. Louis, Missouri

James E. Fish, M.D.

Assistant Professor of Medicine, Johns Hopkins University Medical School, Baltimore, Maryland

Robert T. Fox, M.D.

Professor of Clinical Surgery, Emeritus, Northwestern University Medical School, Chicago, Illinois

James L. Franklin, M.D.

Associate Professor of Internal Medicine, Rush-Presbyterian-St. Luke's Medical Center, Chicago, Illinois

Gary G. Ghahremani, M.D.

Professor of Radiology, Department of Radiology, Northwestern University Medical School, Chicago, Illinois

Joan Gil, M.D.

Associate Professor of Medicine and Anatomy, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

Robert J. Ginsberg, M.D.

Associate Professor of Surgery, University of Toronto Faculty of Medicine, Toronto, Canada

William W. L. Glenn, M.D.

Professor of Surgery, Yale University School of Medicine, New Haven, Connecticut

Douglas R. Gracev, M.D.

Associate Professor of Medicine, Mayo Medical School, Rochester, Minnesota

Hermes C. Grillo, M.D.

Professor of Surgery, Harvard University Medical School, Boston, Massachusetts

Gerald N. Grumet, M.D.†

Assistant Professor of Clinical Medicine, Northwestern University Medical School, Chicago, Illinois

Richard P. Harbord, M.D.

Formerly, Associate Professor of Anesthesiology, Northwestern University Medical School, Chicago, Illinois

James D. Hardy, M.D.

Professor and Chairman, Department of Surgery, University of Mississippi School of Medicine, Jackson, Mississippi

Robert D. Henderson, M.B.

Professor of Surgery, University of Toronto Faculty of Medicine, Toronto, Canada

John Homi, M.D.

Chairman and Professor of Anaesthetics and Intensive Care, University of the West Indies, Kingston, Jamaica

Robert W. Jamplis, M.D.

Clinical Professor of Surgery, Stanford University School of Medicine, Stanford, California

James W. Kilman, M.D.

Professor of Surgery, Ohio State University College of Medicine, Columbus, Ohio

Hiram F. Langston, M.D.

Clinical Professor of Surgery, Emeritus, Northwestern University Medical School, Chicago, Illinois

William M. Lees, M.D.†

Clinical Professor of Surgery, Stritch Medical School, Loyola University, Chicago, Illinois

Bernard J. Leininger, M.D.

Assistant Professor of Surgery, Stritch Medical School, Loyola University, Chicago, Illinois

Richard M. Levin, M.D.

Associate Professor of Anesthesia, Northwestern University Medical School, Chicago, Illinois

F. John Lewis, M.D.

Professor of Surgery (retired), Northwestern University Medical School, Chicago, Illinois

George G. Lindesmith, M.D.

Clinical Professor of Surgery, University of Southern California School of Medicine, Los Angeles, California

Nael Martini, M.D.

Professor of Surgery, Cornell University Medical College, New York, New York

†deceased

Patricia M. McCormack, M.D.

Assistant Professor of Surgery, Cornell University Medical College, New York, New York

Lawrence L. Michaelis, M.D.

Professor of Surgery and Chief of Cardiothoracic Surgery, Northwestern University Medical School, Chicago, Illinois

Wallace T. Miller, M.D.

Professor and Vice-Chairman, Department of Radiology, University of Pennsylvania, Philadelphia, Pennsylvania

Gordon F. Murray, M.D.

Professor of Surgery and Associate Chief, Division of Cardiothoracic Surgery, University of North Carolina School of Medicine, Chapel Hill, North Carolina

H. Christian Nohl-Oser, M.D.

Late Hunterian Professor, Royal College of Surgeons, England

Donald L. Paulson, M.D.

Clinical Professor, University of Texas Health Science Center at Dallas (Southwestern) Medical School, Dallas, Texas

W. Spencer Payne, M.D.

James C. Masson Professor of Surgery, Mayo Medical School, Rochester, Minnesota

F. Griffith Pearson, M.D.

Professor of Surgery, University of Toronto Faculty of Medicine, Toronto, Canada

James G. Pearson

Professor and Director, Department of Radiation Oncology, Cross Cancer Institute, University of Alberta Hospital, Edmonton, Alberta, Canada

Carlos A. Perez, M.D.

Professor of Radiology, Washington University School of Medicine, St. Louis, Missouri

Richard M. Peters, M.D.

Professor of Surgery and Bioengineering, University of California Medical Center, San Diego, California

Raymond W. Postlethwait, M.D.

Professor of Surgery, Duke University, Durham, North Carolina

Mark M. Ravitch, M.D.

Professor of Surgery, University of Pittsburgh Medical School, Pittsburgh, Pennsylvania

Maruf A. Razzuk, M.D.

Associate Professor of Thoracic and Cardiovascular Surgery, University of Texas Health Science Center, Dallas, Texas

Roy E. Ritts, Jr., M.D.

Professor of Microbiology and Oncology, Mayo Medical School, Rochester, Minnesota

Cesar Rodriguez Rodriguez, M.D.*

Medico Jefe del Departamento de Enfermedades Toraxicas del Hospital General J. I. Baldó, Caracas, Venezuela

Steven R. Rosen, M.D.

Assistant Professor of Medicine, Northwestern University Medical School, Chicago, Illinois

Roger H. Secker-Walker, M.D.

Professor of Medicine, College of Medicine, University of Vermont, Burlington, Vermont

Barry A. Shapiro, M.D.

Professor and Director, Department of Anesthesia, Northwestern University Medical School, Chicago, Illinois

Thomas W. Shields, M.D.

Professor of Surgery, Northwestern University Medical School, Chicago, Illinois

David B. Skinner, M.D.

Dallas B. Phemister Professor and Chairman, Department of Surgery, The University of Chicago Pritzker School of Medicine, Chicago, Illinois

H. M. Sommers, M.D.

Professor of Pathology, Northwestern University Medical School, Chicago, Illinois

Harold Stern, M.D.

Associate Clinical Professor of Cardiothoracic Surgery, Yale Medical School, New Haven, Connecticut

Panagiotis N. Symbas, M.D.

Professor of Surgery, Cardiothoracic Surgical Division, Emory University School of Medicine, Atlanta, Georgia

Timothy Takaro, M.D.

Clinical Professor of Surgery, Duke University School of Medicine, Durham, North Carolina

Allan L. Toole, M.D.

Assistant Clinical Professor of Cardiothoracic Surgery, Yale Medical School, New Haven, Connecticut

Gabriel F. Tucker, Jr., M.D.

*Professor, Department of Otolaryngology and
Maxillofacial Surgery, Northwestern University
Medical School, Chicago, Illinois*

Harold C. Urschel, Jr., M.D.

*Clinical Professor in Thoracic and Cardiovascular
Surgery, University Texas Health Science Center,
Dallas, Texas*

Robert M. Vanecko, M.D.

*Associate Clinical Professor of Surgery, Northwestern
University Medical School, Chicago, Illinois*

John R. Walton, M.H.A.

*Administrative Director, Department of Respiratory
Therapy, Northwestern Memorial Hospital, Chicago,
Illinois*

Ewald R. Weibel, M.D.

*Professor and Chairman, Department of Anatomy,
University of Berne, Berne, Switzerland*

Winfield J. Wells, M.D.

*Assistant Clinical Professor of Surgery, University of
Southern California School of Medicine, Los Angeles,
California*

Earle W. Wilkins, Jr., M.D.

*Clinical Professor of Surgery, Harvard University
Medical School, Boston, Massachusetts*

Carolyn J. Wilkinson, M.D.

*Assistant Professor of Anesthesia, Northwestern
University Medical School, Chicago, Illinois*

Thom E. Williams, Jr., M.D.

*Associate Professor of Surgery, Ohio State University
Medical School, Columbus, Ohio*

Contents

Section 1. Anatomy

1. Embryology of the Lungs and Esophagus 3
Leslie B. Arey
2. Ultrastructure and Morphometry of the Human Lung 18
Peter H. Burri, Joan Gil, and Ewald R. Weibel
3. Anatomy of the Thorax and Pleura 43
Charles E. Blevins
4. Surgical Anatomy of the Lungs 61
Thomas W. Shields
5. Lymphatics of the Lung 72
H. Christian Nohl-Oser
6. Surgical Anatomy of the Esophagus 82
Tom R. DeMeester

Section 2. Physiology

7. Pulmonary Gas Exchange 95
Douglas R. Gracey and David W. Cugell
8. Mechanics of Breathing 105
James E. Fish and David W. Cugell
9. Physiology and Physiologic Studies of the Esophagus 115
F. Henry Ellis, Jr.

Section 3. Roentgenographic Studies of the Chest

10. Roentgenographic Evaluation of the Chest 129
Wallace T. Miller
11. Roentgenographic Evaluation of the Esophagus 162
Gary G. Ghahremani
12. Radionuclide Studies of the Lung 170
Roger H. Secker-Walker

Section 4. Diagnostic Procedures

13. Laboratory Procedures in the Diagnosis of Thoracic Diseases 183
H. M. Sommers

14. Endoscopic Examinations	203
<i>L. Penfield Faber and James L. Franklin</i>	
15. Surgical Diagnostic Procedures	220
<i>Thomas W. Shields and Robert T. Fox</i>	
Section 5. Assessment of the Thoracic Surgical Patient	
16. Preoperative Evaluation	233
<i>Lois T. Ellison</i>	
Section 6. Anesthetic Management of the Thoracic Surgical Patient	
17. Preanesthetic Evaluation and Preparation	243
<i>Edward A. Brunner</i>	
18. Conduct of Anesthesia.....	254
<i>John Homi</i>	
19. Anesthesia for Pediatric Thoracic Surgery.....	267
<i>Richard M. Levin</i>	
20. General Principles of Postoperative Management.....	274
<i>Carolyn J. Wilkinson</i>	
21. Ventilatory Support of the Postoperative Patient	281
<i>Barry A. Shapiro and John R. Walton</i>	
22. Physiotherapy for the Thoracic Surgical Patient.....	294
<i>Richard P. Harbord</i>	
Section 7. Operative Procedures	
23. Thoracic Incisions.....	305
<i>William M. Lees</i>	
24. Pulmonary Resections	315
<i>Thomas W. Shields</i>	
25. Thoracoplasty	331
<i>Robert T. Fox and Thomas W. Shields</i>	
26. Decortication of the Lung.....	338
<i>Hiram T. Langston and Thomas W. Shields</i>	
27. Tracheal Anatomy and Surgical Approaches.....	341
<i>Hermes C. Grillo</i>	
28. Resection of the Esophagus	354
<i>Thomas W. Shields and Raymond W. Postlethwait</i>	
29. Replacement of the Esophagus with the Stomach	363
<i>Raymond W. Postlethwait</i>	
30. Replacement of the Esophagus with the Colon.....	367
<i>John M. Beal</i>	
Section 8. Thoracic Trauma	
31. Trauma to the Chest Wall, Pleura, and Thoracic Viscera	375
<i>Richard M. Peters</i>	
32. Trauma to the Esophagus	390
<i>Thomas W. Shields and Robert M. Vanecko</i>	
33. Foreign Bodies in the Esophagus or Respiratory Tract	401
<i>Gabriel F. Tucker, Jr.</i>	

Section 9. The Chest Wall

34. Chest Wall Deformities 415
Mark M. Ravitch
35. Infections of the Chest Wall 440
F. John Lewis and Lawrence L. Michaelis
36. Thoracic Outlet Syndrome 446
Harold C. Urschel and Maruf A. Razzuk
37. Tumors of the Chest Wall 453
Paul C. Adkins

Section 10. The Diaphragm

38. The Diaphragm 467
Thomas E. Williams, Jr., Thomas W. Shields, and James W. Kilman
39. Diaphragm Pacing 487
William W. L. Glenn

Section 11. The Pleura

40. Pleural Effusion and Infections of the Pleura 503
Hiram T. Langston and Walter L. Barker
41. Primary Tumors of the Pleura 521
Thomas W. Shields and Bernard J. Leininger
42. Metastatic Tumors of the Pleura 536
Thomas W. Shields

Section 12. The Trachea

43. Benign and Malignant Diseases of the Trachea 545
Hermes C. Grillo

Section 13. The Lung

44. Bacterial Infections of the Lung 563
Thomas B. Ferguson
45. Pulmonary Tuberculosis and Other Mycobacterial Infections of the Lung 589
Thomas W. Shields
46. Thoracic Actinomycetic and Mycotic Infections 604
Timothy Takaro
47. Pulmonary and Pleural Amebiasis 633
Cesar Rodriguez
48. Hydatid Disease of the Lung 645
Homer Aletas and Panagiotis N. Symbas
49. Congenital Lesions of the Lung 658
George G. Lindesmith and Winfield J. Wells
50. Congenital Vascular Lesions of the Lung 667
Philip E. Bernatz
51. Bullous and Bleb Diseases of the Lung 674
Robert G. Ellison

52. Diffuse Lung Diseases	695
<i>Harold Stern and Allan L. Toole</i>	
53. Bronchial Adenoma	712
<i>Donald L. Paulson and Robert J. Ginsberg</i>	
54. Carcinoma of the Lung	729
<i>Thomas W. Shields</i>	
55. Less Common Tumors of the Lung	770
<i>Nael Martini and Edward J. Beatie, Jr.</i>	
56. Secondary Tumors in the Lung	780
<i>Nael Martini, Patricia M. McCormack, and Thomas W. Shields</i>	
57. Transplantation of the Lung	790
<i>James D. Hardy and Fikri Alican</i>	

Section 14. The Esophagus

58. Congenital Anomalies of the Esophagus	807
<i>H. William Clatworthy, Jr. and James W. Kilman</i>	
59. Motor Disturbances of Deglutition	819
<i>Earle W. Wilkins, Jr.</i>	
60. Esophageal Hiatal Hernia and Gastroesophageal Reflux	833
<i>David B. Skinner</i>	
61. Benign Strictures of the Esophagus	845
<i>Robert D. Henderson</i>	
62. Esophageal Diverticula	859
<i>W. Spencer Payne</i>	
63. Benign Tumors, Cysts, and Duplications of the Esophagus	873
<i>Thomas W. Shields</i>	
64. Squamous Cell Carcinoma of the Esophagus	880
<i>Robert J. Ginsberg and F. Griffith Pearson</i>	
65. Less Common Malignant Tumors of the Esophagus	898
<i>Gordon F. Murray</i>	

Section 15. The Mediastinum

66. Infections of the Mediastinum and the Superior Vena Caval Syndrome	915
<i>Robert W. Jamplis</i>	
67. Primary Tumors and Cysts of the Mediastinum	927
<i>Thomas W. Shields</i>	
68. Surgery of the Thymus Gland	955
<i>W. Spencer Payne and Philip E. Bernatz</i>	

Section 16. Radiation Therapy

69. Basic Principles of Radiation Therapy in Cancer of the Lung and Esophagus	971
<i>Carlos A. Perez</i>	
70. Radiation Therapy in Carcinoma of the Lung	984
<i>Thomas J. Deeley</i>	
71. Radiation Therapy in Carcinoma of the Esophagus	993
<i>James G. Pearson</i>	

Section 17. Chemotherapy

72. Principles of Chemotherapy 1007
Gerald N. Grumet and Steven R. Rosen
73. Chemotherapy of Carcinoma of the Lung 1017
Stephen K. Carter

Section 18. Immunotherapy

74. Immunology of Human Bronchial Cancer 1033
Roy E. Ritts, Jr.
75. Immunotherapy of Lung Cancer 1040
Roy E. Ritts, Jr.

Instrument Suppliers 1047

Index 1049

Section 1

Anatomy

1 Embryology of the Lungs and Esophagus

Leslie B. Arey

THE LUNGS

Evolutionary Advances

The first appearance of lungs among vertebrates was in *Dipnoi*, or lungfishes. With the exception of the *Dipnoi*, lungs occur only in tetrapods and are a basic characteristic of all such vertebrates. The proximal segment of the trachea in tailed amphibians and higher vertebrates specialized as a larynx, and the wall of the trachea became strengthened by cartilage. The actual respiratory portion of the system shows progressive complexity in the several classes of vertebrates through bushlike branching and reduplication of the mucosal lining. The interior of the lungs in some urodeles is wholly smooth; in others, the lining is only partially smooth. Anuran amphibians have internally ridged lungs, and the resulting recesses are lined with still smaller recesses, the alveoli. In some lizards, and in all turtles and crocodiles, septa extend inward and subdivide the lung into a spongy mass supplied by branching ducts. The lungs of birds are not arranged as blindly ending respiratory trees. Instead, anastomosing tubules produce complete air circuits, and smoothly lined extensions—the so-called air sacs—in-vade every major part of the body. Successive reduplication of the inner respiratory surfaces achieves the high degree of complexity of the mammalian lung, which is characteristically lobated except in some types, such as whales and elephants. The mechanisms by which air is made to enter and leave the lungs differ in the several groups of tetrapods, and only in mammals are there paired pleural cavities separated from a peritoneal cavity by a single, complete diaphragm.

Development of the Human Lung

Early Development

The earliest indication of the future respiratory tract occurs in human embryos 3 mm long. Such specimens possess about 20 mesodermal somites and are in the fourth week of development (Fig. 1-1). The respiratory primordium is then in the form of a groove that runs lengthwise in the floor of the pharynx, just caudal to the region where paired pharyngeal pouches are developing (Fig. 1-1A). Lateral furrows next cut off a short tube (Fig. 1-1B, C). The larynx soon organizes about the cranial end of this tube, whereas the caudal end becomes rounded, and, in 4-mm embryos, this so-called lung bud begins to bifurcate (Fig. 1-1D). At the 5-mm stage it is easy to recognize a cranial laryngeal region, an intermediate tracheal tube, and two primary bronchi (Fig. 1-2A). The latter are potentially more than bronchi, since by growth and repeated bifurcation they ultimately will produce all the branches, twigs, air sacs, and alveoli of the respiratory tree. The right primary bronchus extends more directly caudad than does the veering left bronchus, and this difference is maintained in subsequent branchings.

Since the smaller left branch of the two primary ones diverges more from the parent stem than does the larger right branch, this early difference has a practical sequel. The conducting airways of the future left lung come to occupy as little room as possible, and, as noted by Barnett (1957), space in the thorax is thereby made for the off-center heart. This outcome is not the result of simple mechanical crowding because the essential asymmetry occurs much too early.