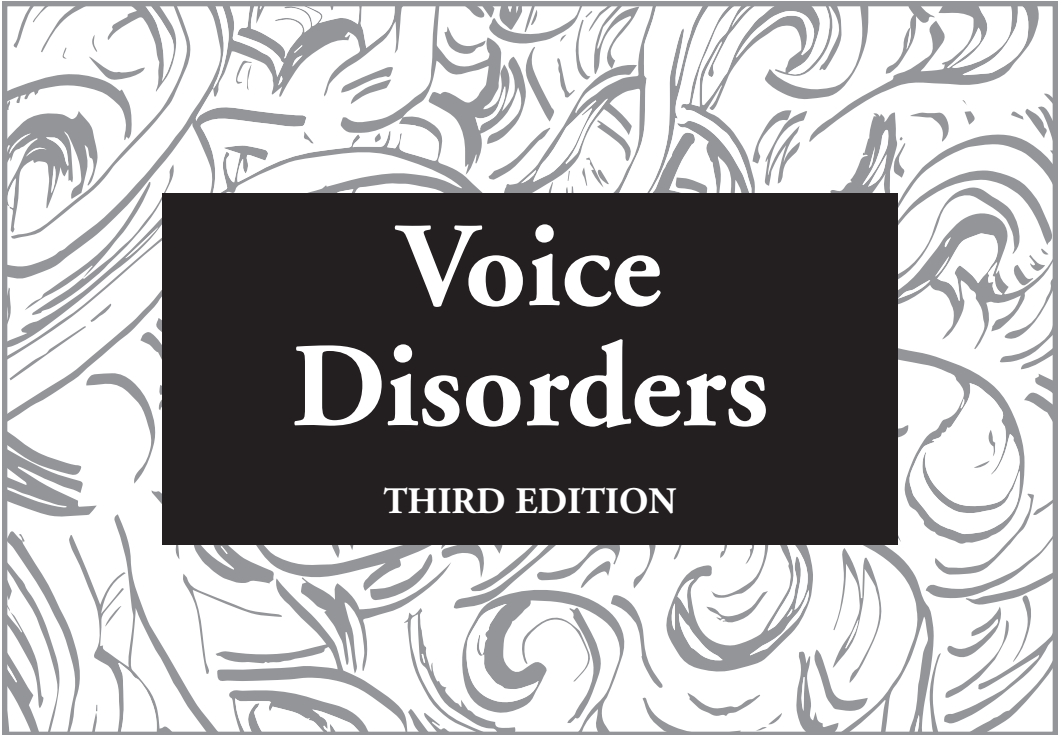


Voice Disorders

THIRD EDITION



Voice Disorders

THIRD EDITION

Christine Sapienza, PhD
Bari Hoffman Ruddy, PhD



5521 Ruffin Road
San Diego, CA 92123

e-mail: info@pluralpublishing.com
Website: <http://www.pluralpublishing.com>

Copyright © by Plural Publishing, Inc. 2018

Typeset in 11/13 Adobe Garamond by Flanagan's Publishing Services, Inc.
Printed in the United States of America by McNaughton & Gunn

All rights, including that of translation, reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, recording, or otherwise, including photocopying, recording, taping, Web distribution, or information storage and retrieval systems without the prior written consent of the publisher.

For permission to use material from this text, contact us by
Telephone: (866) 758-7251
Fax: (888) 758-7255
e-mail: permissions@pluralpublishing.com

Every attempt has been made to contact the copyright holders for material originally printed in another source. If any have been inadvertently overlooked, the publishers will gladly make the necessary arrangements at the first opportunity.

Library of Congress Cataloging-in-Publication Data

Names: Sapienza, Christine M., author. | Hoffman Ruddy, Bari, author.
Title: Voice disorders / Christine Sapienza, Bari Hoffman Ruddy.
Description: Third edition. | San Diego, CA : Plural Publishing, [2018] |
Includes bibliographical references and index.
Identifiers: LCCN 2016038476 | ISBN 9781597567183 (alk. paper) | ISBN
1597567183 (alk. paper)
Subjects: | MESH: Voice Disorders | Voice—physiology |
Larynx—physiopathology
Classification: LCC RF510 | NLM WV 500 | DDC 616.85/56—dc23
LC record available at <https://lcn.loc.gov/2016038476>

Contents

| | |
|--|-------------|
| <i>Foreword by Thomas Murry, PhD</i> | <i>xi</i> |
| <i>Preface</i> | <i>xiii</i> |
| <i>Acknowledgments</i> | <i>xvii</i> |
| <i>Contributors</i> | <i>xix</i> |
| <i>Companion Website</i> | <i>xxi</i> |
| | |
| 1 Respiratory Anatomy and Physiology | 1 |
| The Lungs | 1 |
| The Trachea | 2 |
| The Bronchi | 2 |
| The Thorax | 3 |
| The Ribs | 3 |
| The Diaphragm | 3 |
| The Abdominal Wall | 4 |
| Sternum | 5 |
| Clavicle | 5 |
| Driving Forces of the Respiratory System | 5 |
| How Does the Human Body Generate These Respiratory Forces? | 6 |
| Passive and Active Forces of the Respiratory System | 8 |
| The Respiratory System and Voice Production | 13 |
| Relaxation Pressure Curve | 13 |
| Using the Right Terminology | 18 |
| Biofeedback Techniques | 19 |
| Summary | 19 |
| References | 19 |
| | |
| 2 Laryngeal Anatomy and Physiology | 21 |
| Laryngeal Anatomy | 21 |
| Laryngeal Structure: Pieces and Parts | 25 |
| Laryngeal Muscles | 29 |
| What Are the Vocal Folds Made of, Exactly? | 34 |
| Laryngeal Ligaments and Membranes | 41 |
| Extrinsic Membranes | 42 |
| Intrinsic Membranes | 42 |
| Ligaments | 43 |
| Aryepiglottic Folds | 43 |
| Cavities | 43 |
| Arterial Supply of the Larynx | 43 |
| Laryngeal Nerve Supply | 44 |
| Laryngeal Development (Infancy to Adulthood) | 46 |
| Adult Male and Female Differences in Laryngeal Anatomy | 48 |

| | |
|--|-----------|
| Age Effects on Laryngeal Anatomy | 49 |
| Phonation | 49 |
| Mechanisms for Changing Pitch | 52 |
| What Is a Vocal Register? | 53 |
| Mechanism for Changing Loudness | 54 |
| Summary | 54 |
| References | 55 |
| 3 Vocal Health | 59 |
| Phonotrauma | 59 |
| Basic Issues Related to Vocal Health | 60 |
| Recovery Process | 61 |
| Contributors to Poor Vocal Health | 61 |
| Summary | 71 |
| References | 73 |
| 4 Evaluation | 75 |
| The Specialty of Otolaryngology | 76 |
| Case History | 77 |
| The Physical Examination | 78 |
| Laryngoscopic Techniques | 78 |
| Instrumental Assessment | 82 |
| Imaging | 83 |
| Digital Laryngostroboscopy | 83 |
| Videokymography | 85 |
| Aerodynamics | 88 |
| Classic Methods for Collection of Aerodynamic Signals | 89 |
| Laryngeal Aerodynamic Variations | 95 |
| Laryngeal Aerodynamics as a Function of Aging | 96 |
| Laryngeal Aerodynamic Differences as a Function of Sex | 96 |
| Laryngeal Aerodynamic Changes as a Function of Speech Task | 96 |
| Using Aerodynamics for Examination of Voice Disorders | 97 |
| Acoustic Analysis of Voice | 98 |
| Intensity | 107 |
| Voice Range Profile | 108 |
| Short-Term Perturbation | 109 |
| Relative Noise Level | 111 |
| Spectral Measures | 112 |
| Fast Fourier Transform (FFT) | 112 |
| Vowel Spectrum | 113 |
| Long-Term Average Spectrum | 115 |
| Cepstral Peak | 115 |
| Electroglottography | 116 |
| Electromyography | 117 |
| Auditory-Based Measures of Voice Quality | 117 |
| Perceptual Rating Scales | 119 |

| | |
|---|------------|
| Voice Handicap Scales and Quality of Life Scales | 120 |
| Voice Handicap Index | 121 |
| Voice-Related Quality of Life Scale | 122 |
| Hygiene and Safety of Equipment | 122 |
| Summary | 123 |
| References | 123 |
| Appendix 4–1. Case History Form—Voice | 128 |
| Appendix 4–2. Videostroboscopy Rating Form | 131 |
| Appendix 4–3. Position Statement: Evidence-Based Practice in Communication Disorders | 133 |
| Appendix 4–4. Relevant Paper: The Roles of Otolaryngologists and Speech-Language Pathologists in the Performance and Interpretation of Stroboscoped Videolaryngoscopy | 135 |
| Appendix 4–5. Voice Handicap Index | 136 |
| Appendix 4–6. Voice-Related Quality of Life Measure | 139 |
| | |
| 5 Vocal Pathology | 141 |
| Etiology of Voice Disorders | 141 |
| Vocal Lesions | 143 |
| Pathology Classifications | 143 |
| Incidence of Voice Disorders | 144 |
| Structural Pathologies of the Vocal Folds | 147 |
| Vascular Lesions | 174 |
| Functional Voice Disorders | 176 |
| Idiopathic | 180 |
| Autoimmune | 181 |
| Summary | 186 |
| References | 186 |
| | |
| 6 Neurologically Based Voice Disorders | 195 |
| Neurologic Voice Disorders | 195 |
| Other Neurologic Cases | 217 |
| Summary | 218 |
| References | 218 |
| | |
| 7 Vocal Rehabilitation | 225 |
| Addressing Patient Diversity in Vocal Rehabilitation | 226 |
| Clinical Competence | 227 |
| The Road to Therapy | 227 |
| Communication Strategies | 229 |
| Adherence | 230 |
| Voice Therapy | 231 |
| The Evolving Process of Voice Therapy | 232 |
| Goals of Voice Therapy | 232 |
| Definition of Treatment Efficacy | 233 |

| | |
|--|------------|
| Voice Therapy Approaches: What Are They? | 235 |
| Specific Treatments for Other Populations | 256 |
| Therapy Approaches for Gender Reassignment Voice Changes | 262 |
| Voice Therapy for School-Age Children with Voice Disorders | 262 |
| Technology and Gaming in Voice Therapy | 263 |
| Biofeedback Techniques | 264 |
| Defining a Voice Outcome | 265 |
| Criteria for Termination of Therapy | 265 |
| Telehealth Options | 265 |
| Definition of Treatment Effectiveness | 265 |
| Summary | 266 |
| References | 266 |
| Appendix 7–1. Voice Stimuli | 275 |
| | |
| 8 Management: Phonosurgery | 281 |
| Surgical Treatment of Dysphonia | 281 |
| Office-Based Procedures | 282 |
| General Considerations in the Surgical Approach to the Larynx | 283 |
| Microlaryngoscopy with Nodule Removal | 286 |
| Microflap Dissection | 286 |
| Laser Laryngoscopy | 288 |
| Laryngeal Microdebrider Dissection | 289 |
| Injection Augmentation | 290 |
| Laryngeal Framework Surgery | 291 |
| Selected Clinical Cases | 292 |
| Suggested References for Reading | 295 |
| Appendix 8–1. Postoperative Vocal Fold Microlaryngoscopy Surgery Instruction | 296 |
| | |
| 9 Team Management of Head and Neck Cancer | 299 |
| Introduction | 299 |
| Head and Neck Cancer Statistics | 299 |
| Head and Neck Cancer Sites | 300 |
| Head and Neck Cancer Types | 300 |
| Head and Neck Squamous Cell Cancers | 300 |
| General Cancer Staging | 301 |
| Primary Tumor Staging | 302 |
| Cancer Spread | 304 |
| Surgical Treatment Options for Treating Head and Neck Cancer | 305 |
| Organ Preservation Through Radiation and/or Chemotherapy | 307 |
| Combined Management Approaches | 309 |
| Multidisciplinary Clinical and Research Team | 310 |
| Surgical Options for Laryngeal Cancer | 313 |
| The Role of the Speech-Language Pathologist Prior to Laryngectomy | 313 |
| The Role of the Speech-Language Pathologist Following Laryngectomy | 316 |
| Types of Partial Laryngectomy Procedures | 319 |
| Postoperative Strategies | 320 |

| | |
|---|------------|
| Communication Following Total Laryngectomy | 320 |
| Developing a System to Track Outcomes With the Head and Neck Cancer Population | 331 |
| Future Directions | 332 |
| Conclusions | 332 |
| Useful Websites | 332 |
| References | 333 |
| Appendix 9–1. Case Example: Management of SCCA In Situ in a Professional Performer: An Interdisciplinary Approach | 337 |
| Appendix 9–2. Case Example: Management of Recurrent Laryngeal Cancer Spanning Over 10 Years | 343 |
| Appendix 9–3. Voicing Practice Exercises: Handout for the Laryngectomized Patient | 352 |
| 10 Vocal Performance | 355 |
| The Singing Voice | 355 |
| The Voice Care Team | 356 |
| Performer Classifications | 356 |
| Etiology of Dysphonia in Vocal Performers | 361 |
| Compensatory/Cover Techniques Used by Vocal Performers | 361 |
| Singers and “Support” | 362 |
| Clinical Assessment of Vocal Performers | 363 |
| The Medical, Social, and Singing History | 363 |
| Speaking Voice Assessment | 364 |
| Vocal Load | 364 |
| Singing Voice Assessment | 364 |
| Training and Techniques Specific to Performance Voice | 365 |
| Case Examples | 366 |
| Singing Health | 367 |
| Professional Associations | 371 |
| Case Studies | 372 |
| Summary | 380 |
| References | 380 |
| Appendix 10–1. Singer’s History Form | 383 |
| Appendix 10–2. Singing Voice Handicap Index (S-VHI) | 387 |
| Appendix 10–3. Evaluation of the Ability to Sing Easily (EASE) | 389 |
| Appendix 10–4. Glossary of Singing Terms | 391 |
| 11 Drug Types and Effects on Voice | 393 |
| Drug Interactions | 393 |
| Patient-Specific Factors | 394 |
| Drug Administration | 394 |
| Drug Classes | 395 |
| Psychoactive Medications | 401 |
| Drug Compliance | 404 |
| Herbal Supplements/Alternative Medicines | 406 |
| Special Populations | 408 |

| | |
|------------------------------------|-----|
| Summary | 409 |
| Recommended Readings | 409 |
| References | 409 |
| Appendix 11–1. Chapter 11 Glossary | 411 |

12 Immune System Response to Diseases and Its Impact on Laryngeal Function **413**

| | |
|-----------------------------------|-----|
| Introduction | 413 |
| Innate Immunity and Wound Healing | 414 |
| Adaptive Immunity | 416 |
| Fibroblasts' Immune Functions | 418 |
| Immunologic Barriers to Treatment | 419 |
| Biomaterials | 420 |
| Cell Based Therapies | 420 |
| Conclusions | 421 |
| References | 421 |

13 Laryngeal Reflexes **425**

| | |
|--------------------------------------|-----|
| Sensory Receptors | 425 |
| Free Nerve Ending Receptors | 425 |
| Encapsulated Nerve Endings | 427 |
| Pathway of Sensory Information | 428 |
| Laryngeal Reflexes | 428 |
| Upregulation of Sensory Afferents | 432 |
| Down Regulation of Sensory Afferents | 434 |
| References | 435 |

| | |
|-----------------|-----|
| <i>Glossary</i> | 439 |
| <i>Index</i> | 461 |

Foreword

In *Voice Disorders, Third Edition*, Christine Sapienza and Bari Hoffman Ruddy bring nearly 20 years of clinical experience to the readers. They are highly successful educators and have opened a whole new area of voice treatment with their work in respiratory and laryngeal physiology. Their latest research is now on laryngeal biomechanical modelling and patient and caregiver burden discussion. In this edition, they demonstrate empiricism in their work and practicality in their teachings, striving to educate students how to synthesize complex material and present it to patients and other clinicians.

This third edition of *Voice Disorders* builds on the earlier editions and offers the student and clinician a comprehensive study of the respiratory, laryngeal, and neurological subsystems that make up voice production. The authors balance voice science with voice treatments, examining traditional interventions as well as recent advances in cellular therapies, muscle strength training, and treatments for special populations such as singers and actors and those with complex medical conditions. With this third edition of *Voice Disorders*, the study of voice disorders comes out of its infancy and into the modern era of comprehensive care for the voice.

It is that unique mix of basic science and treatment strategies that Sapienza and Ruddy are known for. They successfully brought this mix into their first edition of *Voice Disorders* in 2009. That edition was highly successful with a large readership, and brought compliments from the instructors using it in their classroom. The second edition of *Voice Disorders* was built on that framework with its detailed descriptions of the anatomy, physiology, and clinical presentations of voice disorders. The third

edition brings the study of voice disorders up to date with additional chapters on laryngeal reflexes, immunology, and the effects of medications on the voice. After reviewing this third edition, I was not surprised to see this well-rounded textbook on voice from this pair of scientists and clinicians. In fact, to some extent, each of them is both a scientist and a clinician. They have kept abreast of the latest developments in the medical, behavioral, and patient-oriented aspects of this rapidly changing discipline. Unlike the early days of Grant Fairbanks, the clinician now needs medical, surgical, and behavioral knowledge of the vocal mechanism and of the structures and systems that contribute to voice production. Additionally, the authors update the unique role of the speech-language pathologist and his/her relationship with the other members of the voice care team—research scientist, psychologist, surgeon, singing specialist, and vocal coach etc. Each of those individuals has varying roles in the care of patients with voice disorders and it is often the speech-language pathologist who provides the leadership of the team.

The authors have again chosen to begin their text with a chapter on respiration. That unique feature makes this book quite distinctive from many other books on voice. This chapter provides an in-depth study of the respiratory system and its unique relationship with phonation. Respiratory structures, from the lungs to the subglottis, and their anatomy, physiology, and contribution to phonation are explained with wonderful drawings and graphs. The chapter is written with great detail, yet easy enough to understand, thanks to the well-written text to go along with the drawings. This book extends the study of respiratory anatomy and physiology specifically

as it relates to breathing for phonation. This chapter serves as a basis for the remainder of the book and so it should, as the respiratory system serves as the foundation for the larynx and vocal fold vibration.

There are other fabulous features about this third edition, as well. Case studies are presented to elucidate the importance of proper assessment and management. Hoffman Ruddy and Sapienza update the reader on new medications and their effects on the voice and on the treatment of voice disorders. The student will learn the classes of medications and their effects on the voice.

The third edition expands the approaches to voice therapy, and better defines clinical decision making with information about humanistic communication strategies, adherence, and the multitude of variables that influence patient outcomes. The authors have chosen to categorize therapy approaches in terms of type, such as symptomatic, combined modality, and hygienic. For each approach, they describe specific treatment methods, case examples and expected outcomes.

It is not surprising that the management of singers has its own chapter. Both Hoffman Ruddy and Sapienza are well-known to the performing community. Hoffman Ruddy's dissertation with Sapienza laid the groundwork for their partnership in the performing community early on. In the chapter on vocal performance, they describe the relationship of the vocal pathologist to the singer, performer, and other professionals who also take care of singers. This may be the only book used by the voice rehabilitation team in which descriptions of the Alexan-

der Technique and the Feldenkrais Method are found in one place. It is special sections like this that make this book a textbook for today's speech-language pathologist who wants to be up-to-date in treating voice disorders.

The authors have substantially updated the chapter on head and neck cancer, with new case study presentations statistics on the disease, information on safety for the laryngectomy patient, and more images to guide the reader in understanding the various modes of communication after laryngectomy. The authors also introduce robotic surgery in this chapter and include images from the operating room and video footage of several surgical procedures.

Although not customary in a foreword, I would like to say something about the authors. I have known Dr. Sapienza since her early postgraduate days and have been impressed with the degree of her effort and expertise that she has put in to every project, research proposal, and class syllabus. She reflects the term "teacher-scientist-clinician" perfectly. Dr. Hoffman Ruddy, the doctoral student of Dr. Sapienza, has become her own leader in the area of voice science as evidenced by her research and presence at meetings around the world. Since they are both teachers, they understand the needs of students and have developed educational approaches to nourish those needs in the classroom as well as in the research lab. Both authors exert a high level of energy into their work and this book offers a prime example. Both have transformed their keen levels of observation, testing, and analysis into a book that is rich with their experience and knowledge.

Thomas Murry, PhD
Professor, Otolaryngology-Head and
Neck Surgery
Co-Director, Loma Linda University
Voice and Swallowing Center
Loma Linda University Health Center
Loma Linda, California

Preface

The human ability to produce voice, shape it into meaningful tones and sounds, and use it for so many varied purposes is truly special. For those who have the opportunity to study voice, you will experience teachings from many disciplines, and observe outcomes both clinically and from the literature that exemplify a truly emerging relationship between knowledge and practice.

With enhancements in medical technologies and medical care, treatment plans are reaching an efficiency that optimizes vocal recovery in a favorable and timely manner. Continual education is critical to stay contemporary and abreast of new techniques/technologies and respond to the ever changing clinical environment. You will find an increasing responsibility to collaborate and communicate with all members of the patient's health care team and a need to familiarize yourself with the ever-changing medical models. You must continue to educate yourself to keep up with the advances in technology. This need may not be due solely to a rapidity of change in your discipline, but also to the swiftness of change in other disciplines (imaging, molecular biology, surgery etc.).

The physical, social, and spiritual issues surrounding your patients will require more skills and fluid knowledge in human anatomy and physiology, neuroanatomy and physiology, instrumentation, computer applications and multitudes of topics surrounding medical management issues including phonosurgical options and drug treatments. Learning how to communicate with your patient, understanding marriage and family systems and the dynamics of variables such as race, gender identity, and religion will be some of the more intricate complexities surrounding

your patient's care. Sometimes, the changes to which we, as clinicians, must adapt to, are sweeping and sometimes they occur slowly over time.

In writing this textbook we wanted you, the student, to have access to contemporary information that could be easily read. We took pride in developing the original anatomical figures for the text so they would portray the structures precisely. Additionally, we wanted to give you the opportunity to have laryngeal examinations of vocal pathology for your reference, including opportunity to view phonosurgical procedures and outcomes. In short, we wrote the book in a manner that would enable you and your instructor to have the best resources in one source.

The third edition of *Voice Disorders* is written so that you, the student, can comprehend complex material by using side outs for complex terms, providing a comprehensive glossary of terms and case examples throughout the chapters, such as those found in the vocal pathologies and voice therapy chapter, chapter on singer's voice and the comprehensive chapter on head and neck cancer. With updated statistics on the demographics of voice users, this new edition now helps you learn the clinical pathways that lead to the most efficient, cost effective outcomes. The pathophysiology of disease is thoroughly explained, helping to guide you on choices for best treatment outcomes. By clearly documenting the important anatomical and physiological properties of voice, you can determine the best course of treatment action, and the case examples, with accompanying audio samples, will help you identify and practice your assessment skills. Two newly distinct chapters are now included on laryngeal reflexive behavior

and the immune system. And, while these chapters contain high-level information, the material is a treasure of knowledge synthesized for your level of learning. Finally, we have updated our information for Web sources, and all additional resources have been updated.

Cherish your time to learn. The care of the voice has already evolved from a traditionally behaviorally oriented discipline to one that has responsibilities within the medical domain. For example, the role of the voice pathologist has broadened and includes vocal imaging specialist, researcher, therapist guiding recovery and restoration of healthy voice, trainer guiding effective voice use, counselor and/or more. Our field has developed ad hoc position statements defining the role of the *Speech-Language Pathologist and Teacher of Singing in the Remediation of Singers with Voice Disorders* (1992). We have guidelines for training in endoscopy and laryngostroboscopy and guidelines for the Role of the Speech Language Pathologist (2001), with respect to the Evaluation and Treatment of Tracheoesophageal Fistualization/Puncture and Prosthesis (2004). These position statements indicate that a certain level of skill must be obtained prior to administering particular assessment and treatment techniques.

Specific to the assessment and treatment of voice, we find ourselves challenged with cases involving syndromic complexities and are asked to delve into histories involving multiple disease processes or polypharmacies. Also, the reorganization of the health care industry has created an extensive array of changes in the organization, ownership, and regulation of health care providers and in the delivery of services. Cost concerns, increasing competition, influence of investor priorities, technological advances, changing social attitudes, and an aging and increasingly diverse population, are factors that sustain this dynamic condition.

There is a requirement to objectively document the outcomes of specific treatments

in order to provide hard evidence that can be analyzed, data based, studied, and modeled. Not all aspects of physiology can be seen. And, while technology is racing forward in the field of laryngeal imaging, subsystem processes that create, for example, the air pressure and airflow for voice are often equally important to examine. At the same time, over collection of data is not a wise way to spend time with a patient. Most of you have probably heard the saying “if it walks like a duck, quacks like a duck—it’s a duck.” Bottom line, if the collection of more data is not going to alter the treatment plan, then do not subject the patient to unnecessary procedures.

Since 1998, there have been significant advances in the following areas of medicine, all of which have impact on the care of the voice:

- pharmacogenomics
- brain damage and spinal cord injury
- cancer therapy and viruses
- antibiotics and resistant infections
- autoimmune disease
- slowing of the aging process

Within our discipline, technological advances include functional magnetic resonance imaging, high-speed video image analysis, computer assisted biofeedback techniques, advanced animal modeling techniques, enhanced surgical procedures, and many others. It wasn’t long ago that we witnessed the first laryngeal transplant performed at the Cleveland Clinic in 1999 by Dr. Marshall Strome and his team of physicians.

In order to appreciate such groundbreaking events, we need to acknowledge the fact that advances in the core science of our discipline are being made nationally and internationally at facilities dedicated to the advancement of science and medical practice. Recall one area of voice research that began in Groningen at the Institute of Physiology of

the Faculty of Medicine by van den Berg in the late 1940's. His fundamental article on the *Myoelastic-Aerodynamic Theory of Voice Production* in 1958 forever shaped our perceptions on the function of the vocal folds. There are historical lists of contributors to voice, voice care and voice science. Included in that list are the contributors referenced in this book, as well as all of our contemporary colleagues dedicated to the study of voice.

We hope this book serves you well in your graduate coursework in voice disorder. We believe it provides the core information needed for your training. For those practicing in the area of voice and its disorders, we currently expect the following academic preparation: understanding of the normal and physiologic process of voice production; understanding of the etiological bases of voice disorders; the ability to examine and interpret laryngeal structure and function; understanding of the instrumentation used to examine laryngeal structure and

function; understanding of the principles of diagnosis; understanding of the structural and functional differences across the life span; the ability to assist in differentially diagnosing the disorder and classifying it as structural, functional, idiopathic or neurological; the ability to develop a treatment plan that considers the patient's functional outcome goals; and others. Included on the *PluralPlus* companion website is a comprehensive workbook that should allow you to reflect on the reading and help you practice your knowledge and skills through test questions and problem solving assignments.

Additional courses we recommend include: issues surrounding continuum of care; interdisciplinary approaches; pharmacology; medical terminology; patient advocacy and accreditations; among others. This is not an inclusive list but one that suggests that our literature, as well as academic course work, must accommodate our needs more fully.

Acknowledgments

To my colleagues at Jacksonville University, my entire family and dear friends who continually support my research and career in the field of speech-language pathology. To the talented graphic arts of Cindy McMillen and anatomical drawings of Dave Forrestel—true artists. Thank you to all of the students who have read our book, course instructors who have adopted it, critiqued it and made it better.

“Do not follow where the path may lead. Go, instead,
where there is no path and leave a trail.”

—Ralph Waldo Emerson

Dr. Christine Sapienza

My sincere appreciation to all physicians at The Ear Nose Throat and Plastic Surgery Associates for providing the ideal collaborative, medical environment. My deepest gratitude to Jeffrey Lehman, MD, for his mentorship, collaboration, and participation in this project. Thank you to my University of Central Florida colleagues for their ongoing support and to my students who inspire me in my teaching and training. Finally, my eternal gratitude to my family and friends, daughters Danielle and Alexandra for surrounding me with their love and support.

Dr. Bari Hoffman Ruddy

Drs. Sapienza and Ruddy wish to sincerely thank:

- The Ear, Nose and Throat Surgical Associates, Orlando, Florida, for providing all endoscopic images and laryngostroboscopic samples;
- Dr. Jeffrey J. Lehman, The Ear, Nose and Throat Surgical Associates, Orlando, Florida, for the surgical videos and images;
- Dr. Bernard Rousseau for his contributions to Chapter 2 on content related to vocal fold biology and histology;
- Dr. Rahul Shrivastav and Dr. Judy Wingate for their contribution on the Acoustic section within Chapter 4;
- Dr. Jeffrey J. Lehman for his writing Chapter 8;
- Vicki Lewis, MA, for her contributions to Chapter 9;
- Adam T. Lloyd, MM, MA, and Dr. Judy Wingate for his contributions to Chapter 10;
- Dr. Kiran Tipernini, Monica Tipernini, and Jeffrey Fichera for their contributions for Chapter 11;
- Dr. Suzanne N. King for the writing of Chapter 12.
- Dr. Teresa Pitts and Ms. Alyssa Huff for the writing of Chapter 13.
- PENTAX, InHealth Technologies, and Glottal Enterprises for their provision of images.

Contributors

Bari Hoffman Ruddy, PhD, CCC-SLP

Associate Professor
Department of Communication Sciences
and Disorders
University of Central Florida
Research Partner
Florida Hospital Cancer Institute
Director, Center for Voice Care and
Swallowing Disorders
Ear, Nose, Throat and Plastic Surgery
Associates
Orlando, Florida
Chapters 1–11

Alyssa Huff, BS

Graduate Student
Department of Physiology
Department of Neurological Surgery
Kentucky Spinal Cord Injury Research Center
University of Louisville
Louisville, Kentucky
Chapter 13

Suzanne N. King, PhD, CCC-SLP

Assistant Professor
Department of Otolaryngology-Head
and Neck Surgery and Communicative
Disorders
Kentucky Spinal Cord Injury Research Center
University of Louisville
Louisville, Kentucky
Chapter 12

Jeffrey J. Lehman, MD, FACS

Medical Staff President
Florida Hospital
Medical Director
Center for Voice Care and Swallowing
Disorders

Ear, Nose, Throat and Plastic Surgery
Associates
Orlando, Florida
Chapter 8

Vicki Lewis, MA, CCC-SLP

Speech Pathologist
The Center for Voice Care and Swallowing
Disorders
The Ear, Nose, Throat and Plastic Surgery
Associates
Orlando, Florida
Chapter 9

Adam T. Lloyd, MM, MA, CCC-SLP

Voice Pathologist and Singing Health
Specialist
University of Miami Miller School of
Medicine
Department of Otolaryngology
Miami, Florida
Chapter 10

Teresa Pitts, PhD, CCC-SLP

Assistant Professor
Department of Neurological Surgery
Kentucky Spinal Cord Injury Research
Center
University of Louisville
Louisville, Kentucky
Chapter 13

Christine Sapienza, PhD, CCC-SLP

Dean
Brooks Rehabilitation College of Healthcare
Sciences
Jacksonville University
Jacksonville, Florida
Chapters 1–11

Judith Wingate, PhD, CCC-SLP

Associate Professor

Communication Sciences and Disorders

Brooks Rehabilitation College of Healthcare

Sciences

Jacksonville University

Jacksonville Florida

Chapter 10

Companion Website

Purchase of *Voice Disorders, Third Edition* comes with complimentary access to supplementary student and instructor materials on a PluralPlus companion website. To access the materials, log in to the website using the URL and instructions located inside the front cover of your copy of *Voice Disorders, Third Edition*.

Student Website

Included on the student website is a comprehensive workbook. The workbook will allow you to reflect on the reading and help you practice your knowledge and skills through test questions and problem solving assignments. Throughout the textbook you will find this icon that directs you to the workbook exercises.



Look for the multimedia icon that directs you to laryngoscopic examinations, many of which include audio of the voice quality, surgical video, surgical still images, and a number of comprehensive case studies.



Also included on the student website are all of the still images printed in the text and where applicable, available in color. Use of the combined textbook and these ancillary resources will enhance your overall learning proficiency.

Instructor Website

Included on the instructor website are PowerPoint slides to aid instructors in the delivery of content.

To Dr. G. Paul Moore and Dr. Janina Casper, who in their greatness paved the pathways that we traveled on to our professional endeavors, shadowing us with guidance and mentorship.

To Dr. Dave Ingram for creating opportunity through his continuous mentorship and excellence in teaching students about voice and patient care. Dr. Ingram, your integrity and excitement for student learning is unmatched. You will always be remembered and never forgotten.

To our clinical partners in otolaryngology and our medical center affiliates, who have taught us excellence in care and have kept us progressive in thoughts and actions.

To our students and colleagues for their energy, enthusiasm, and passion for patient care. Your open-mindedness and continuous thirst for information motivates us to write new editions and impart information for teaching.

To our patients for inspiring us to provide excellence in the evaluation and treatment of laryngeal function disorders. Thank you for the opportunity to train our students and be involved with your voice care.

Respiratory Anatomy and Physiology



This chapter describes intricacies of the human anatomy of the respiratory system and explains how it functions to produce voice. Anatomy is the study of structure(s) and physiology is the study of how structures function to produce a particular action. In the case of voice production, respiratory structures play a very important role by providing the necessary driving force to initiate and sustain vocal fold vibration.

Breathing appears to be a relatively simple process—seemingly automatic, and unconscious. Yet, it is highly controlled and complex. And, breathing for voice production is a unique process, different from the act of ventilation or circulation for the life purpose of exchanging O_2 and CO_2 . Anatomically, the most basic elements of the respiratory system are the lungs, rib cage, and diaphragm/abdominal unit.

After reading this chapter, you will:

- Understand the basic components of respiratory anatomy
- Understand the passive and active forces involved in breathing
- Understand the role of the respiratory system for producing voice

- Understand how disordered respiratory function may affect voice production

Ventilation means bringing oxygen into the lungs. Circulation is the transporting of oxygen all over the body, to where it is needed.

The Lungs



The lungs are elastic tissue that inflate and deflate and, as a result of the inflation and deflation, move air. Anatomically, there are three lobes on the right lung and two lobes on the left lung. The right lung is larger than the left lung to make room for the heart (Figure 1–1).

Inspiration is the act of taking air into the lungs and expiration is the act of expelling air out of the lungs. By bringing air into the lungs during inspiration, oxygen can be circulated into the bloodstream to the cells in the body. Expiration allows for the release of CO_2 .

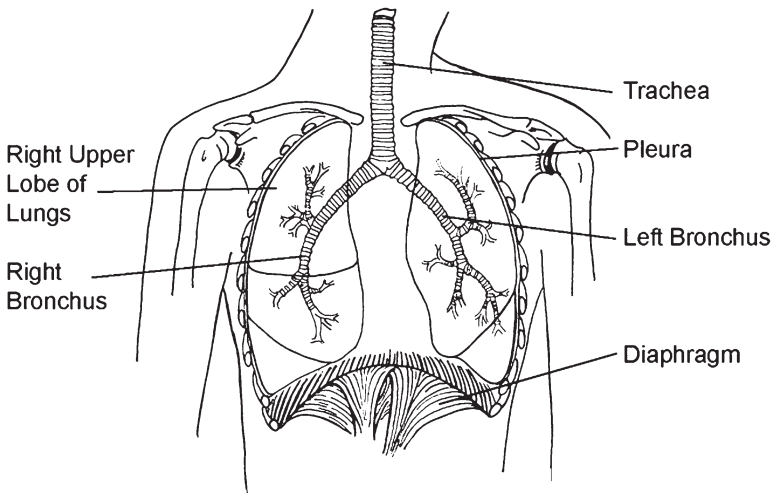


Figure 1–1. Lower airway and right and left lungs.



For airflow to increase, a greater pressure differential must be created.

In a clinical report you may see the term, Hypercapnia, which is when excessive carbon dioxide in the bloodstream occurs, typically caused by inadequate respiration.

The Trachea

The trachea is a cartilaginous structure that allows air to pass from the nose and mouth into the lungs. It is made up of 16 cartilaginous rings. The larynx sits on top of the uppermost tracheal ring. The trachea, if damaged, is potentially life threatening. In the event the trachea is damaged, a tube is placed into the airway to allow air to flow into the lungs. This is called intubation. Intubation may be necessary due to injury, illness or dur-

ing a surgical procedure where the muscles of respiration are paralyzed and ventilation requires support.

The Bronchi

There are two main bronchi that branch off the trachea, one going to each lung. Smaller branches from the bronchi continue to divide, known as secondary bronchi. There are three secondary bronchi supplying the right lung and two secondary bronchi supplying the left lung. Bronchioles are the smallest branches stemming from the secondary bronchi and lead to the alveoli, where gas exchange occurs, allowing air to enter into the blood. The cartilage and mucous membrane of the primary bronchi are similar to that in the trachea. The amount of hyaline cartilage in the bronchial walls decreases as the branching continues throughout the bronchial tree. Hyaline cartilage is absent in the smallest bronchioles (Figure 1–2).

Hyaline cartilage forms most of the fetal skeleton and is found in the trachea, larynx (see Chapter 2), and joint surfaces of the adult.

respiratory structures, such as the bronchial tree. Made up of the ribs and muscles, the most inferior aspect of the thorax is the diaphragm.



The Thorax

The thorax is the chest cavity that surrounds and protects the lungs, as well as the heart and other

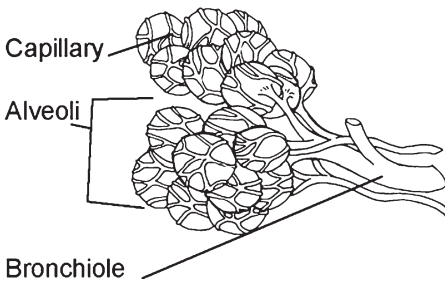


Figure 1–2. Final branches of the respiratory tree where primary gas exchange occurs.

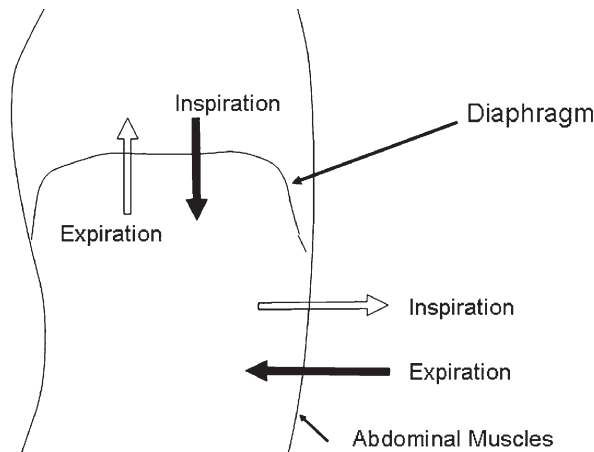
The Ribs

There are 12 pairs of ribs. Ribs 1 to 7 are called the true ribs and ribs 8 to 10 are called the false ribs. Ribs 11 and 12 are called floating ribs because they do not attach to the sternum like ribs 1 to 10.

The Diaphragm



The diaphragm anatomically separates the chest from the abdomen. It is the major muscle of inspiration (Figures 1–3 and 1–4). At rest, the diaphragm sits in a dome-shaped



— Passive Movement
 — Active Contraction



Figure 1–3. Direction of thoracic cavity movement with inspiration and expiration.

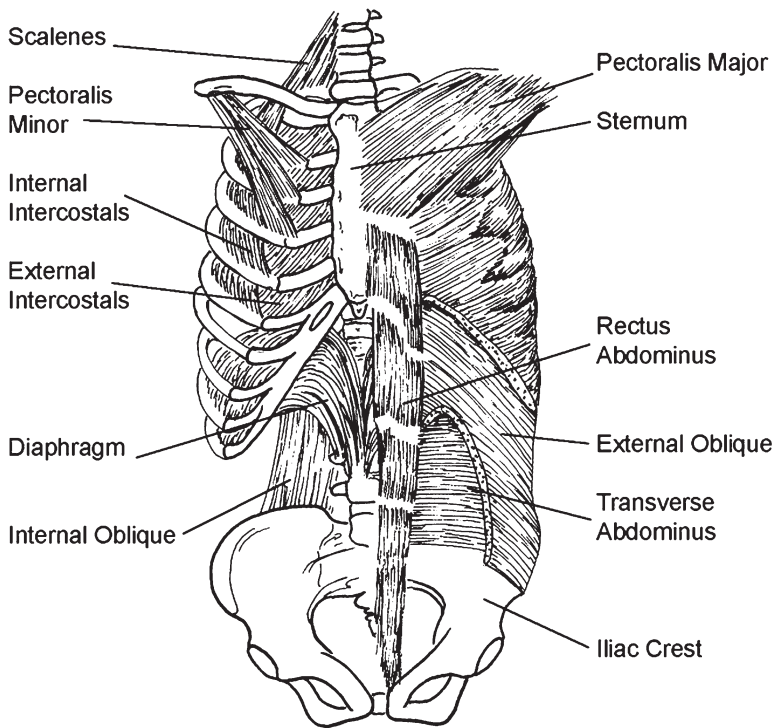


Figure 1–4. The diaphragm muscle and the supporting abdominal muscle structures.



position, and when it contracts during inspiration, it moves downward and flattens, enlarging the chest cavity. As the diaphragm moves downward, the force is transferred to the lower ribs moving them outward. As the diaphragm contracts, it is opposed by the passive properties of the abdominal wall, the tone of its muscles, and the inertia of the abdominal contents. When this occurs, the intra-abdominal pressure rises and the lower rib cage expands (Goldman, Rose, Morgan, & Denison, 1986). This, in turn, enlarges the thoracic dimension, creating an inspiratory maneuver.

When the diaphragm contracts, during normal breathing, it moves down about 1 to 2 cm and, interestingly, can move as much as 10 cm during deep inspiration.

The Abdominal Wall

The abdominal wall is a layered structure with external, internal, and innermost regions. Made up of central and lateral muscles that arise from the ribs and the pelvic girdle, the abdominal wall has passive and active properties that are described in more detail below. During passive expiration, the abdominal wall draws in, and during effortful tasks like coughing, sneezing, and certain voicing tasks, the abdominal muscles contract to compress the abdominal contents. This in turn, increases the intra-abdominal pressures. This compression is also important for other functions like defecation and childbirth. The next section describes other important anatomical structures to the respiratory system.

Sternum

The sternum has three processes that serve as attachments for respiratory muscles like the diaphragm and intercostal muscles. The three processes include the manubrium, body, and xiphoid process.

The first seven ribs are attached to the sternum. The manubrium appears as a handle and serves as an attachment for ribs 1 and 2, the corpus is the body of the sternum and serves as the attachment for ribs 2 to 7, and the xiphoid process is the smallest of the three parts and serves as a partial attachment for many muscles including some of the abdominal wall muscles.

When giving CPR, pressure on the xiphoid process should be avoided as it can cause a piece of the xiphoid process to break off, creating potential damage to the heart lining and muscle and/or resulting in punctures or lacerations of the diaphragm.

Clavicle

The clavicle is known as the collarbone, and the two bones of the clavicle extend from the manubrium. The clavicle serves for attachment of certain respiratory muscles like the trapezius, pectoralis major, and sternocleidomastoid.

Driving Forces of the Respiratory System

The process of moving air requires a driving force. The force comes from a pressure gradient or difference between the alveolar pressure and the atmospheric pressure (Figures 1–5 and 1–6). Alveolar pressure is the pressure within the alveoli.

Alveolar pressure is the smallest gas exchange unit of the lung and is about 105 mm Hg or 142.8 cm H₂O.

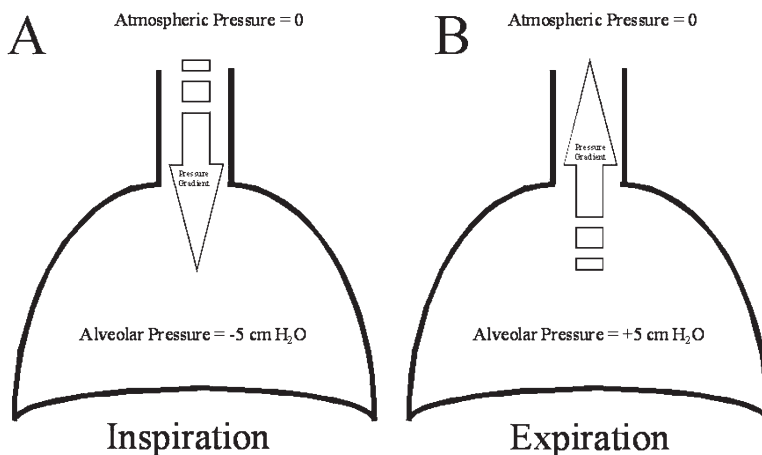


Figure 1–5. Schematic depicting pressure relationships for inspiration and expiration. The arrow indicates the direction of the driving force.

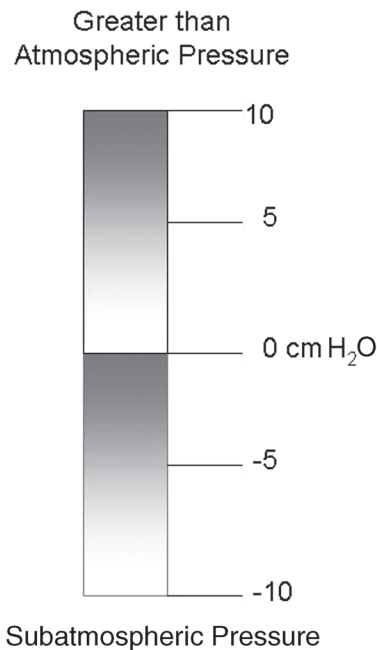


Figure 1-6. Schematic depicting positive pressure and negative pressure generation relative to atmospheric pressure (0 cm H₂O).

Alveolar pressure is typically referenced with respect to atmospheric pressure, which is always set to zero. When alveolar pressure is above atmospheric pressure, it is positive; when alveolar pressure is below atmospheric pressure it is negative.

For the lungs to inflate, the inward driving force must be an alveolar pressure less than atmospheric pressure. This creates a pressure gradient that causes air to flow into the lung (inspiration). On the other hand, for air to flow out of the lung (expiration), the driving force must be an alveolar pressure greater than atmospheric pressure. The pressure of a gas equals the perpendicular force exerted by the gas divided by the surface area on which the force is exerted.

In order to produce voice, air moves from the alveolar spaces through the conducting

airways, including the trachea, through the glottis, or the space between the vocal folds, vibrating the medial edges of the vocal folds. Sound from the vocal folds is then transferred to the pharynx and oral cavity, where it is shaped by the articulators into speech sounds. Discussion of how the voice is produced by vocal fold vibration is discussed in Chapter 2.

How Does the Human Body Generate These Respiratory Forces?



The alveolar pressure is changed by two forces. The first, a passive force, is due to the elastic properties of the respiratory system. The second force, an active force, is developed by the contraction of the respiratory muscles. One example that is often used to illustrate and explain the passive and active forces of the respiratory system is a balloon, as it helps explain the concepts of respiratory forces (Figure 1-7). Inflation of a balloon requires an active stretching of the balloon. This illustration shows how inspiratory muscles contract to expand the chest wall. It takes active muscle force to overcome the balloon stiffness and force air into the balloon. This increases the balloon's volume, just as the lungs increase in volume, creating a pressure gradient that allows air to flow into the balloon/lungs. With the balloon inflated and the opening to the balloon closed, the balloon retracts toward its rest position and produces a pressure inside the balloon causing the air inside the balloon to compress. This is an elastic force, which is an inherent property of the balloon, just like the lungs (see Figure 1-7). The strength of the elastic force is a *passive* property of the balloon/lungs and is directly proportional to the stretch of the balloon/lungs. The greater the balloon/lung volume, (i.e., the greater the stretch of the balloon/lung wall) the greater the elastic recoil of the balloon/lung and the greater the

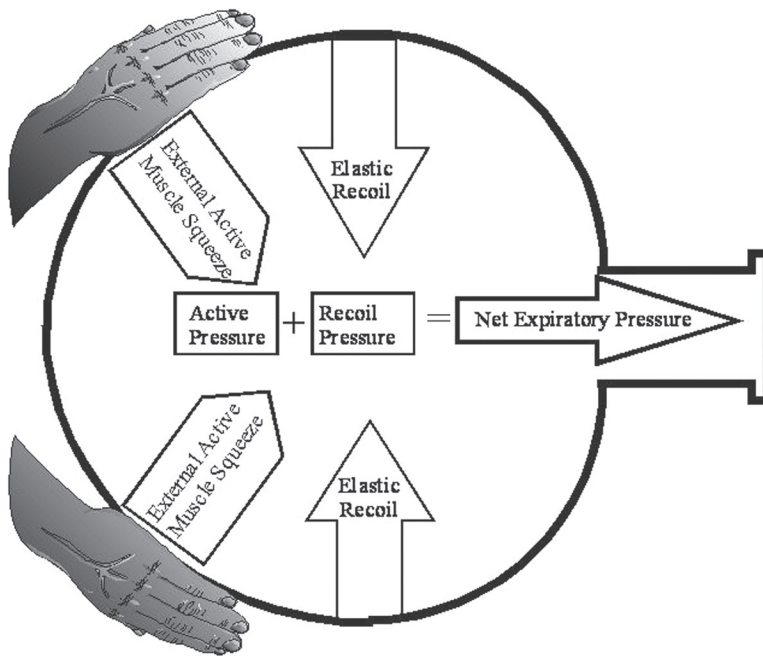


Figure 1–7. Schematic of a balloon depicting active and passive mechanisms during expiration. The hands squeezing the balloon illustrate the addition of an active expiratory force.

pressure inside the balloon/lung. The pressure inside the balloon/lung can be further increased if the outside of the balloon/lung is squeezed (see Figure 1–7). This “squeeze” is the result of the *active* contraction of expiratory muscles and is referred to as an active pressure. The total pressure within the balloon/lung is then the sum of the passive elastic pressure and the active “squeeze” pressure.

When the respiratory system is at rest, the lung is partially inflated to approximately 40% of the total lung capacity (TLC). This is important to remember because the lungs are actually not deflated at “rest” but rather are partially inflated. This rest position is called the Functional Residual Capacity or FRC (Figure 1–8). At FRC, neither the lung nor the thorax is really at its respective rest position. With age, the lungs may lose some of their elasticity.

The lungs are apposed (or connected) to the thorax by pleural linkage. In fact, three-quarters of the lung’s surface contacts the thoracic wall by pleural linkage. With a pneumothorax, a lung immediately collapses *but* the thorax expands. A pneumothorax occurs when the pleural space is disrupted.

A pneumothorax can happen with a blast injury, as a result of a fractured rib, and sometimes with diseases like cystic fibrosis and chronic obstructive pulmonary disease.

When a pneumothorax occurs, the lungs and thorax achieve a natural position, which is the natural preference if they were anatomically independent from one another. The lungs natural position is a volume much

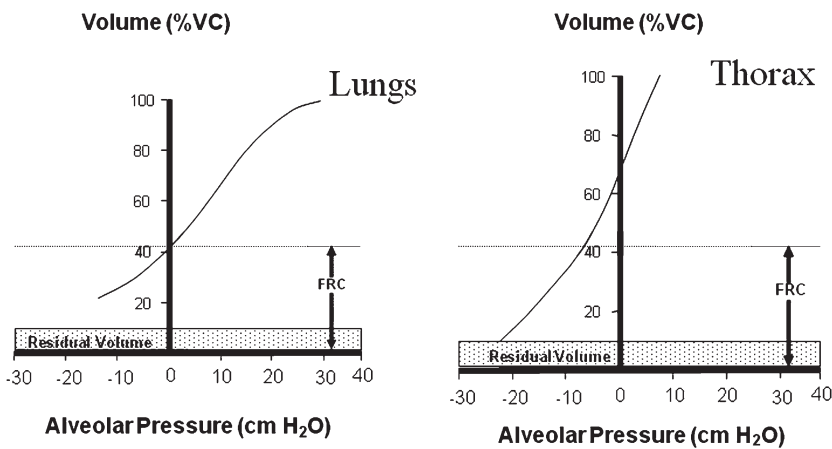


Figure 1–8. Pressure-volume curves for lungs and thorax.

smaller than FRC. That is why the lung(s) has a natural tendency to collapse. The thorax's natural position is a volume much greater than FRC, approximately 70% of TLC, which means the thorax has a natural tendency to expand at FRC (see Figure 1–8).

When the lung is placed in the thorax, the outer surface of the lung is apposed to the inner surface of the thorax by the pleural linkage mentioned above. The pleural linkage is actually a hydrostatic force. A membrane called the visceral pleura covers the lung. A similar membrane called the parietal pleura covers the thorax. A small amount of fluid, the pleural fluid, separates these membranes. If you were to place two smooth surfaces against each other with fluid between them, like two microscope slides with water between them, you would see how easily they move back and forth but how very hard they are to pull apart. This is the hydrostatic force “holding” the two smooth surfaces together yet allowing free movement between the surfaces. In the respiratory system, the pleural fluid between the visceral and parietal pleurae holds the lung against the thoracic wall while allowing the lung to slide freely during volume changes. However, mechanically linking the lung and

thorax means that the combined systems' elastic behavior is a result of the interaction of the lung and thoracic elastic forces. As stated above, this causes the lung to be at a volume that is above its elastic natural position, yielding a collapsing force. The thorax is at a volume smaller than its elastic natural position yielding an expanding force. At FRC, the expanding elastic force of the thorax balances the collapsing elastic force of the lung.

Passive and Active Forces of the Respiratory System

Active inspiration is a muscle action that increases the dimensions of the chest wall. A portion of the inspiratory muscle energy used to expand the thorax is recaptured by the passive collapsing force of the elastic recoil pressure that is volume dependent. This is the passive property of expiration. *Remember*, the act of inspiration is *always* active. This means that in order for inspiration to occur, muscle contraction must happen. Mentioned briefly above, and of such importance to remember, is that the diaphragm is the main muscle of inspira-

tion. The diaphragm is a large sheet of muscle and tendons. It attaches to the lumbar vertebrae of the spinal column, the lower ribs (ribs 7–12) and the xiphoid process of the sternum. The cervical nerves of the spinal cord called C3, C4, and C5, also known as the phrenic nerves, supply innervation to the diaphragm.

A saying goes “C3, C4, C5, keeps you alive” . . . but there is now evidence that bilateral loss of the phrenic nerve might not necessarily result in death.

Did you know that a hiccup is caused by a spasmodic, involuntary contraction of the diaphragm?

The external intercostal muscles are the other primary muscles of inspiration and are found between the ribs. The external intercostal muscles slant downward and outward and their diagonal position allows them to do more work upon their contraction. Due to their hinged anatomical relationship at the spine and sternum, when they contract they lift the ribs up and outward (Figure 1–9). Other secondary inspiratory muscles are listed in Table 1–1. Accessory muscles of inspiration are only most active with high ventilatory tasks (e.g., deep inspiration) and are not used during quiet inspiration.

Active expiratory pressure can be added to the passive elastic expiratory driving force by generating muscle contraction that decreases the chest wall dimension. The decrease in

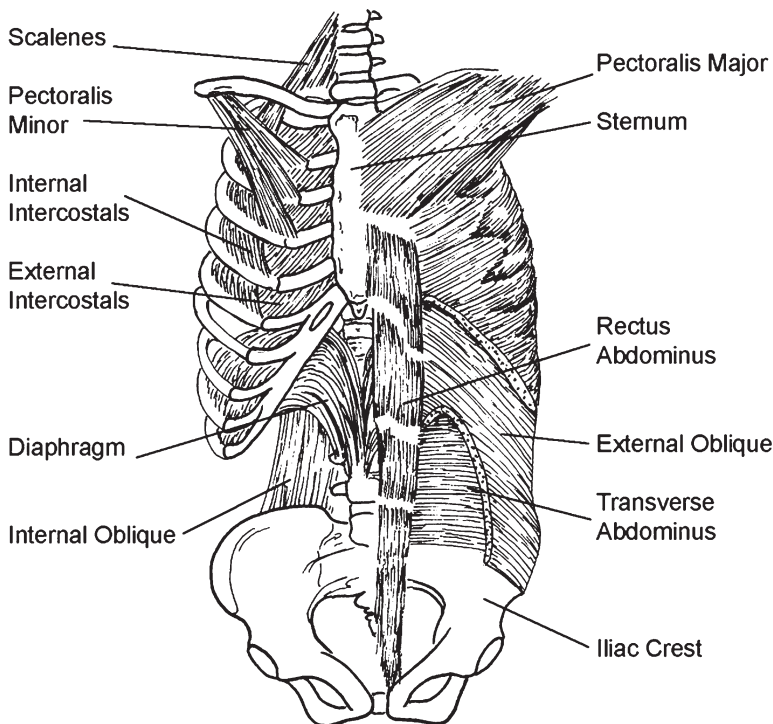


Figure 1–9. External and internal intercostal muscles, and abdominal wall muscles.

Table 1–1. Accessory Inspiratory Muscles and Their Origins and Insertions and Major Expiratory Muscles and Their Origins and Insertions

| Muscle | Function | Origin | Insertion |
|------------------------------------|-----------------------|--|--|
| Levatores costarum | Accessory Inspiratory | Transverse processes of C7 to T12 vertebrae | Superior surfaces of the ribs immediately inferior to the preceding vertebrae |
| Serratus posterior superior | Accessory Inspiratory | The spinous processes of C7 through T3 | The upper borders of the 2nd through 5th ribs |
| Sternocleidomastoid | Accessory Inspiratory | Manubrium and medial portion of the clavicle | Mastoid process of the temporal bone |
| Scalenus | Accessory Inspiratory | C2–C7 vertebrae | The first and second ribs |
| Trapezius | Accessory Inspiratory | The spinous processes of the vertebrae C7–T12 | At the shoulders, into the <i>lateral</i> third of the clavicle, and into the spine of the scapula |
| Pectoralis major | Accessory Inspiratory | The anterior surface of the clavicle; the anterior surface of the sternum, as low down as the attachment of the cartilage of the 6th or 7th rib | The crest of the greater tubercle of the humerus |
| Pectoralis minor | Accessory Inspiratory | 3rd to 5th ribs, near their costal cartilages | The medial border and upper surface of the scapula |
| Serratus anterior | Accessory Inspiratory | The surface of the upper eight ribs | The entire anterior length of the medial border of the scapula |
| Subclavius | Accessory Inspiratory | Arises by a short, thick tendon from the first rib and its cartilage at their junction, in front of the costoclavicular ligament | The groove on the under surface of the clavicle |
| Levator scapulae | Accessory Inspiratory | Arises by tendinous slips from the transverse processes of the atlas and axis and from the posterior tubercles of the transverse processes of the 3rd and 4th cervical vertebrae | The vertebral border of the scapula |
| Rhomboides major | Accessory Inspiratory | The spinous processes of T2 to T5 | The medial border of the scapula |
| Rhomboides minor | Accessory Inspiratory | The spinous processes of C7 and T1 | The vertebral border near the point that it meets the spine of the scapula |