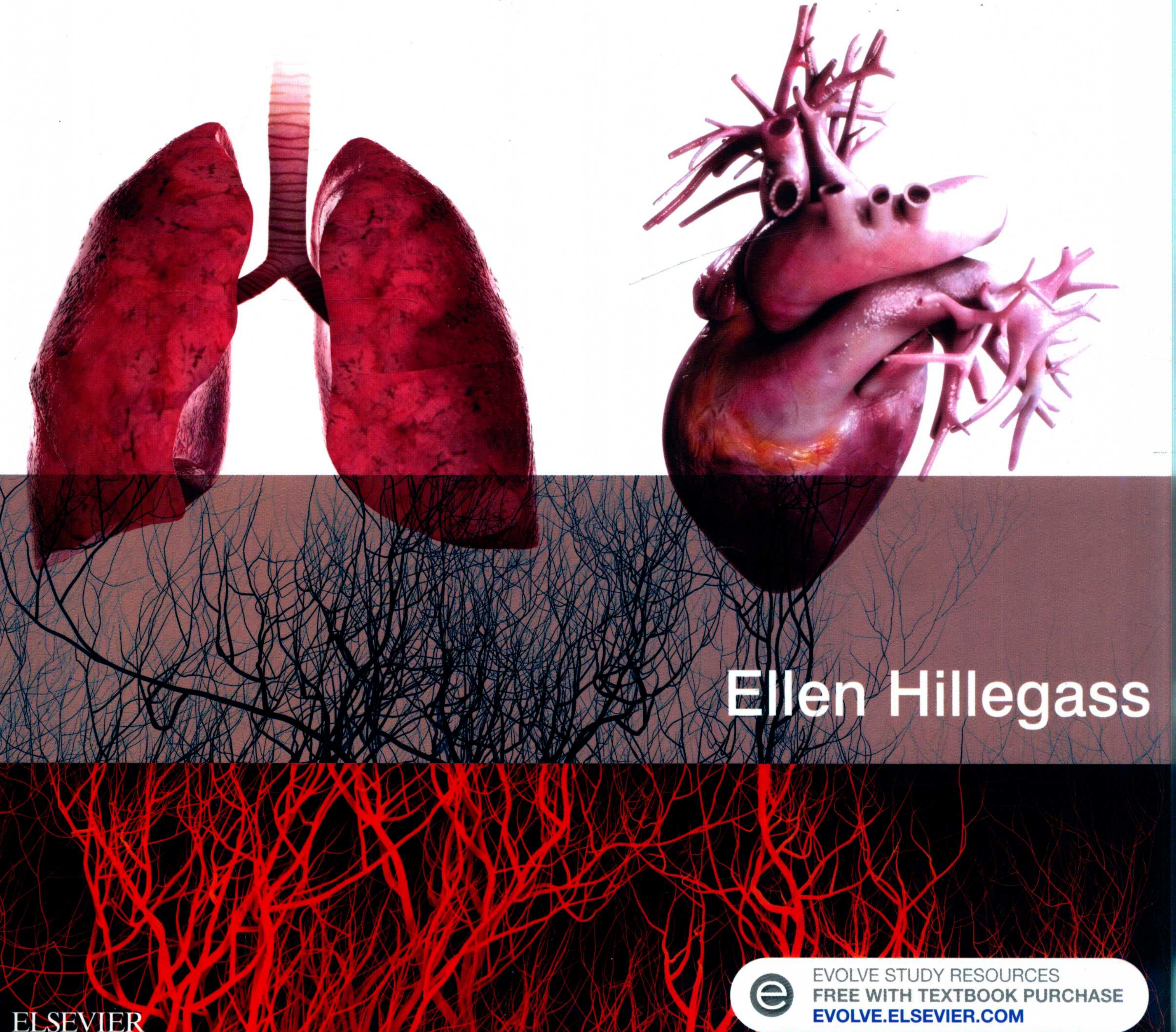
Essentials of
CARDIOPULMONARY PHYSICAL THERAPY
FOURTH EDITION



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Essentials of CARDIOPULMONARY PHYSICAL THERAPY

Fourth Edition

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ESSENTIALS OF CARDIOPULMONARY PHYSICAL THERAPY, FOURTH EDITION
ISBN: 978-0-323-43054-8

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Library of Congress Cataloging-in-Publication Data

Names: Hillegass, Ellen A., editor.
Title: Essentials of cardiopulmonary physical therapy / [edited by] Ellen Hillegass.
Other titles: Cardiopulmonary physical therapy
Description: Fourth edition. | St. Louis, Missouri : Elsevier, [2017] | Includes bibliographical references and index.
Identifiers: LCCN 2016002395 | ISBN 9780323430548 (hardcover : alk. paper)
Subjects: | MESH: Cardiovascular Diseases--physiopathology | Cardiovascular Diseases--rehabilitation | Lung Diseases--physiopathology | Lung Diseases--rehabilitation | Physical Therapy Modalities
Classification: LCC RC702 | NLM WG 166 | DDC 616.1/062--dc23 LC record available at http://lccn.loc.gov/2016002395

Executive Content Strategist: Kathy Falk
Content Development Manager: Jolynn Gower
Senior Content Development Specialist: Brian Loehr
Publishing Services Manager: Julie Eddy
Project Manager: Abigail Bradberry
Design Direction: Miles Hitchen

Printed in China

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Dedication

This book is dedicated to my beloved family for all their love and support as well as their understanding during my endless hours of working on this edition:

To my husband Dan, who is my rock and my constant support whom I could not live without;

To my three wonderful children: Patrick, Jamie, and Christi who give me moral support, make me laugh, and who constantly try to keep me up to date on all the modern technologies that have helped me communicate with them, communicate with my colleagues, and write this book. They keep me young with their ideas and assistance; they constantly have a "joie de vivre";

To my two dogs: Sparky and Bear who kept my feet warm while I sat for hours at the computer working on this edition but demanded daily play, and provided a wonderful mental break from writing;

To my brother-in-law George, who was an inspiration to everyone he knew and met with his positive attitude and fighting spirit that he had up until the day he died from pancreatic cancer.

And,

In loving memory of my parents, John and Norma, who kept me busy as their daughter and caregiver while they were alive, and were always proud of everything I did.

In addition, I dedicate this edition:

To my colleagues who keep me informed, give me moral and intellectual support, and who keep me inspired to maintain my passion for the field of cardiovascular and pulmonary physical therapy. I have enjoyed being a mentor to many rising cardiopulmonary specialists as well as all my students, and have especially enjoyed being a resident mentor to my first resident, Erica Colclough, and my current residents Tiffany Haney and Stephen Ramsey. I also especially rely on the support and inspiration of some very dear friends/colleagues including Dianne Jewell, Andrew Ries, Claire Rice, and Joanne Watchie.

And finally, I can never forget my very special friends/mentors to whom I am forever grateful and whose memories and teachings are with me always: Michael Pollock (1937–1998), Linda Crane (1951–1999), and Gary Dudley (1952–2006).

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Preface

Originally this text was developed to meet the needs of the physical therapy community, as cardiopulmonary was identified as one of the four clinical science components in a physical therapy education program as well as in clinical practice. Those aspects of physical therapy commonly referred to as "cardiovascular and pulmonary physical therapy" are recognized as fundamental components of the knowledge base and practice base of all entry-level physical therapists. Therefore this text was developed for entry-level physical therapists, as well as individuals in practice who need more in-depth knowledge of cardiopulmonary content. This text is also utilized by many clinicians studying for advanced practice board certification as well as those involved in residency programs. Although intended primarily for physical therapists, this text has been useful to practitioners in various disciplines who teach students or who work with patients who suffer from primary and secondary cardiopulmonary dysfunction. This fourth edition can also be used by all practitioners who teach entry-level clinicians, work with residents as well as to help in clinical practice of patients with cardiopulmonary dysfunction.

This fourth edition has gone through update and revision from the third edition to make the text more user friendly and provide more interactive learning. The same six sections exist: *Anatomy and Physiology; Pathophysiology; Diagnostic Tests and Procedures; Surgical Interventions, Monitoring and Support; Pharmacology;* and *Cardiopulmonary Assessment and Intervention.* The six sections were kept as they facilitate the progression of understanding of the material in order to be able to perform a thorough assessment and provide an optimal intervention as well as provide measurable outcomes to assess change.

The revisions you should notice include both major and minor changes. All chapters have been revised as well as supplemented with many figures and tables and some videos to help the learner visualize the written information. Additional figures, case studies, and resource material can also be found on the Evolve website that accompanies this text. The number of clinical notes was increased to help clinicians and students understand certain clinical findings and help them relate them to the pathophysiology of cardiovascular and pulmonary disease. All chapters were updated with new information, technology, and research.

Each chapter had specific revisions that should be highlighted. Chapters 1 and 2, which explain anatomy and physiology, increased the number of figures to help the learner relate the pathophysiology to the normal anatomy and physiology. In addition, the developmental and maturational anatomy was moved to the pediatrics chapter (Chapter 20) to help the learner compare the pathophysiology to the normal in this population. Chapter 3, *Ischemic Cardiovascular Conditions and Other Vascular Pathologies,* underwent revision particularly in areas that were lacking such as venous dysfunction including deep vein thrombosis. New material was added, so that you will now find hypertension, peripheral arterial disease, cerebrovascular disease, renal disease, and aortic aneurysm in this chapter, in addition to ischemic disease. Chapter 4, *Cardiac Muscle Dysfunction and Failure,* was restructured and revised to improve the flow and understanding of this important pathologic condition as well as all new figures and tables to help understand heart dysfunction and failure.

Due to the complexities and number of conditions of restrictive lung dysfunction many more tables were created in Chapter 5 to separate the material and assist the learner to identify key information quickly. Chapter 6, *Chronic Obstructive Pulmonary Diseases*, was updated and revised to emphasize the importance of this disease and the fact that COPD is the third leading cause of death. Revisions in Chapter 7, *Cardiopulmonary Implications of Specific Diseases*, emphasize information on obesity, diabetes, and metabolic syndrome, as well as cancer and neuromuscular diseases.

New technologies and advancements in diagnostic tests and surgical procedures were added to Chapters 8, 9, 10, and 11. Chapter 11, *Cardiovascular and Thoracic Interventions* underwent major overhaul with many new figures and text. The advances in transplantation were discussed in Chapter 12 and *Monitoring and Life Support* (Chapter 13) was revised to increase the depth of information on ventilators as well as other monitoring equipment found in intensive care units and used by PTs when mobilizing patients earlier.

As advances in health care and diagnostics occur, so do improvements and changes in medications, so both *Cardiovascular Medications* (Chapter 14) and *Pulmonary Medications* (Chapter 15) required updating. Chapter 16 (*Examination and Assessment Procedures*) was revised with addition of new tables to help organize assessments and improve the understanding of this material. Chapter 17, *Interventions for Acute Cardiopulmonary Conditions* added a greater emphasis on early mobility and Chapter 18, *Interventions and Prevention Measures for Individuals with Cardiovascular Disease, or Risk of Disease* had major updating and revision, new clinical notes and many new figures and tables. Chapter 19, *Pulmonary Rehabilitation* was revised to correspond with changes in the new pulmonary rehabilitation (PR) definition and in the changing practice since Medicare revised payment for PR. Chapter 20, *Pediatric Cardiopulmonary Physical Therapy* and Chapter 21, *The Lymphatic System* were two wonderful additions to the third edition of *Cardiopulmonary Physical Therapy* and were updated with some new figures. And, finally, the text ends with the outcomes chapter which was totally revamped and provides great information for measurement of improvement in the cardiopulmonary patient population.

Whenever possible, case studies are provided to exemplify the material being presented. Additional case studies are found on Evolve.

No matter how well you understand the material in this book, it will not make you a master clinician, skilled in the assessment and treatment of cardiovascular and pulmonary disorders. To become even a minimally competent clinician, you will have to practice physical therapy under the tutelage of an experienced clinician. *Essentials of Cardiopulmonary Physical Therapy* cannot provide you with everything there is to know about the assessment and treatment of cardiovascular and pulmonary disorders. It will provide the essentials as the title indicates. Learning is a continuous process, and technology and treatment are forever improving; therefore this text provides clinicians as well as educators with the most current information at the time of publication.

It is my true hope that you appreciate this edition and are able to learn from all the wealth of information provided by such wonderful contributors. Without heart and breath there is no therapy!

Acknowledgments

"Change is good and change equals opportunity!" This statement explains how I have approached each edition, but most especially this edition! Hopefully you will gain knowledge and insight from all the changes as there are many excellent contributions from my colleagues, who are THE experts in cardiovascular and pulmonary physical therapy and who poured their passion into their chapters. This edition is what I consider the "Mentoring" edition....many of the co-authors in the chapters are newly recognized cardiopulmonary specialists and past Residents of Cardiopulmonary Residency programs and new to writing. They were mentored along the way, and what they provided to this edition was amazing content, figures, videos, and updated material that makes this text stand out. We can all learn from these experts and you will as you dig into the material in the following pages.

Learning does not stop with this text. Continuing education is a vital component of lifelong learning so I would also encourage all of my readers to continue their lifelong learning in cardiopulmonary physical therapy by utilizing always updated webinars from www.ptcardiopulmonaryeducators.com.

During the publication phase of the first edition of the *Essentials of Cardiopulmonary Physical Therapy,* I was always worried about new developments in the field of Cardiovascular and Pulmonary diagnosis and treatment that were not going to be covered in the book. My very first editor, Margaret Biblis, kept saying "that's what the next edition is for" and that is how I approached the second edition and again the third and fourth edition. I have saved comments and suggestions along the way as well as attended conferences regularly to stay current with new developments in the field. And, with the age of the internet, you have access to the new Evolve site that accompanies this text. Instructional material including PowerPoint presentations and a test bank are available to instructors in the course, as well as updated information.

So, I would like to thank all the amazing experts who have helped with this fourth edition, including each of the wonderful contributors as well as all those clinicians, students, and faculty members who provided feedback on previous editions and who continue to use this book in their courses and their every day practice. I would like to especially thank the contributors for their ability to work under my constant nagging to achieve their deadlines and for providing great material including figures, tables, and clinical notes. I would also like to acknowledge and thank Angela Campbell and Meryl Cohen, who kept pressing me to get this edition going and make it interactive, as it was their comments that pushed me to finally initiate the fourth edition.

Of course my family and my dogs need to be acknowledged for all the time I spent at the computer working on this edition instead of spending time with them.

Lastly, this edition truly would not be published were it not for my wonderful editor, Brian Loehr, who called me weekly, joked with me about content and figures, and learned a lot of cardiopulmonary along the way while pushing this edition to a timely completion. He has become a friend and the best editor ever! Thanks, Brian!

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1

Anatomy of the cardiovascular and pulmonary systems

Konrad J. Dias

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This chapter describes the anatomy of the cardiovascular and pulmonary systems as it is relevant to the physical therapist. Knowledge of the anatomy of these systems provides clinicians with the foundation to perform the appropriate examination and provide optimal treatment interventions for individuals with cardiopulmonary dysfunction. An effective understanding of cardiovascular and pulmonary anatomy allows for comprehension of function and an appreciation of the central components of oxygen and nutrient transport to peripheral tissue. A fundamental assumption is made; namely, that the reader already possesses some knowledge of anatomic terms and cardiopulmonary anatomy.

Thorax

The bony thorax covers and protects the major organs of the cardiopulmonary system. Within the thoracic cavity exist the heart, housed within the mediastinum centrally, and laterally are two lungs. The bony thorax provides a skeletal framework for the attachment of the muscles of ventilation.

The thoracic cage (Fig. 1-1) is conical at both its superior and inferior aspects and somewhat kidney shaped in its transverse aspect. The skeletal boundaries of the thorax are the 12 thoracic vertebrae dorsally, the ribs laterally, and the sternum ventrally.

Sternum

The sternum, or breastbone, is a flat bone with three major parts: *manubrium, body,* and *xiphoid process* (see Fig. 1-1). Superiorly located within the sternum, the manubrium is the thickest component articulating with the clavicles and first and second ribs. A palpable jugular notch or suprasternal notch is found at the superior border of the manubrium of the sternum. Inferior to the manubrium lies the body of the sternum, articulating laterally with ribs three to seven. The sternal angle, or "angle of Louis," is the anterior angle formed by the junction of the manubrium and the body of the sternum. This easily palpated structure is in level with the second costal cartilage anteriorly and thoracic vertebrae T4 and T5 posteriorly. The most caudal aspect of the sternum is the xiphoid process, a plate of hyaline cartilage that ossifies later in life.

The sternal angle marks the level of bifurcation of the trachea into the right and left main stem bronchi and provides for the pump-handle action of the sternal body during inspiration.[1]

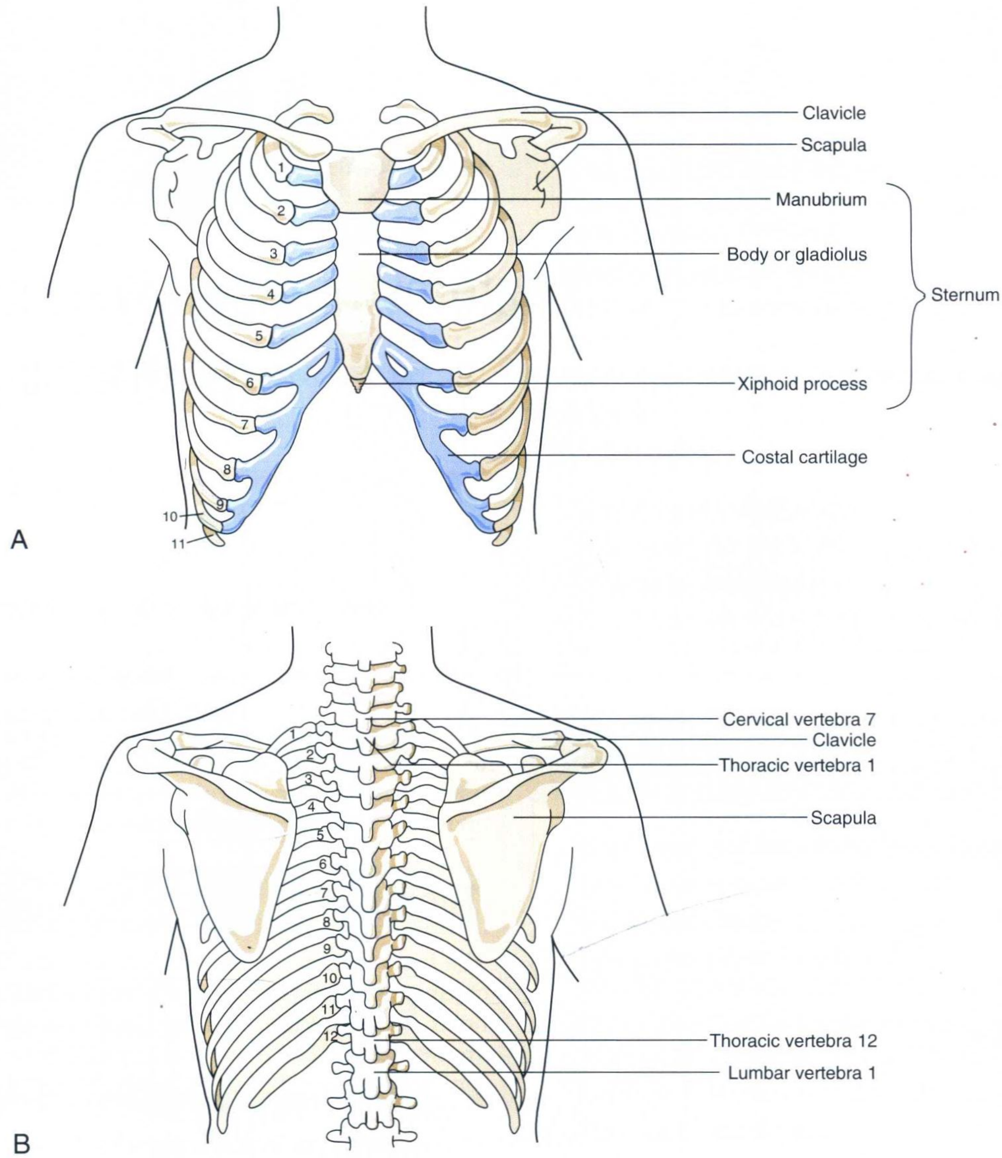

Figure 1-1 **A,** Anterior. **B,** Posterior views of the bones of the thorax. (From Hicks GH: *Cardiopulmonary Anatomy and Physiology,* Philadelphia, 2000, Saunders.)

Pectus excavatum is a common congenital deformity of the anterior wall of the chest in which several ribs and the sternum grow abnormally (see Fig. 5-25). This produces a caved-in or sunken appearance of the chest. It is present at birth, but rapidly progresses during the years of bone growth in the early teenage years. These patients have several pulmonary complications, including shortness of breath caused by altered mechanics of the inspiratory muscles on the caved-in sternum and ribs, and often have cardiac complications caused by the restriction (compression) of the heart.[2]

To gain access to the thoracic cavity for surgery, including coronary artery bypass grafting, the sternum is split in the median plane and retracted. This procedure is known as a *median sternotomy.* Flexibility of the ribs and cartilage allows for separation of the two ends of the sternum to expose the thoracic cavity.[3]

Ribs

The ribs, although considered "flat" bones, curve forward and downward from their posterior vertebral attachments toward their costal cartilages. The first seven ribs attach via their costal cartilages to the sternum and are called the *true ribs* (also known as the *vertebrosternal ribs*); the lower five ribs are termed the *false ribs*—the eighth, ninth, and tenth ribs attach to the rib above by their costal cartilages (the vertebrochondral ribs), and the eleventh and twelfth ribs end freely (the vertebral ribs; see Fig. 1-1). The true ribs increase in length from above downward, and the false ribs decrease in length from above downward.

Each rib typically has a vertebral end separated from a sternal end by the body or shaft of the rib. The head of the rib (at its vertebral end) is distinguished by a twin-faceted surface for articulation with the facets on the bodies of two adjacent thoracic vertebrae. The cranial facet is smaller than the caudal, and a crest between these permits attachment of the interarticular ligament.

Fig. 1-2 displays the components of typical ribs three to nine, each with common characteristics, including a head, neck, tubercle, and body. The neck is the 1-inch long portion of the rib extending laterally from the head; it provides attachment for the anterior costotransverse ligament along its cranial border. The tubercle at the junction of the neck and the

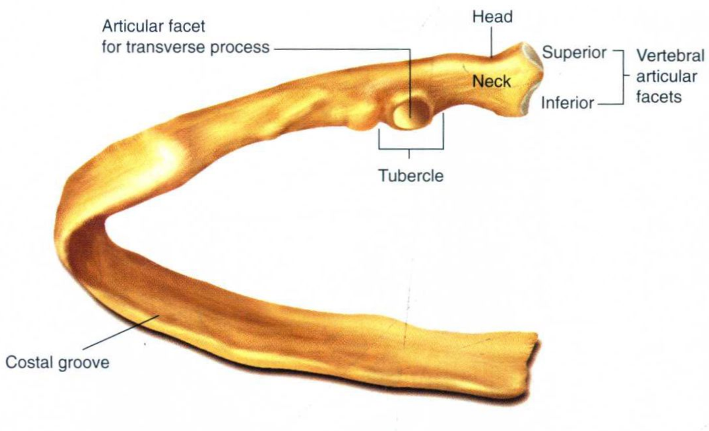

Figure 1-2 Typical middle rib as viewed from the posterior. The head end articulates with the vertebral bones, and the distal end is attached to the costal cartilage of the sternum. (From Wilkins RL: *Egan's Fundamentals of Respiratory Care,* ed 9, St. Louis, 2009, Mosby.)

body of the rib consists of an articular and a nonarticular portion. The articular part of the tubercle (the more medial and inferior of the two) has a facet for articulation with the transverse process of the inferior-most vertebra to which the head is connected. The nonarticular part of the tubercle provides attachment for the ligament of the tubercle.

The shaft, or body, of the rib is simultaneously bent in two directions and twisted about its long axis, presenting two surfaces (internal and external) and two borders (superior and inferior). A costal groove for the intercostal vessels and nerve extends along the inferior border dorsally but changes to the internal surface at the angle of the rib. The sternal end of the rib terminates in an oval depression into which the costal cartilage makes its attachment.

Although rib fractures may occur in various locations, they are more common in the weakest area where the shaft of the ribs bend—the area just anterior to its angle. The first rib does not usually fracture, as it is protected posteroinferiorly by the clavicle. When it is injured, the brachial plexus of nerves and subclavian vessel injury may occur.[4] Lower rib fractures may cause trauma to the diaphragm resulting in a diaphragmatic hernia. Rib fractures are extremely painful because of their profound nerve supply. It is important for all therapists to recommend breathing, splinting, and coughing strategies for patients with rib fractures. Paradoxical breathing patterns and a flail chest may also need to be evaluated in light of multiple rib fractures in adjacent ribs.[3]

Chest tubes are inserted above the ribs to avoid trauma to vessels and nerves found within the costal grove. A chest tube insertion involves the surgical placement of a hollow, flexible drainage tube into the chest. This tube is used to drain blood, air, or fluid around the lungs and effectively allow the lung to expand. The tube is placed between the ribs and into the space between the inner lining and the outer lining of the lung (pleural space).

The first, second, tenth, eleventh, and twelfth ribs are unlike the other, more typical ribs. The first rib is the shortest and most curved of all the ribs. Its head is small and rounded and has only one facet for articulation with the body of the first thoracic vertebra. The sternal end of the first rib is larger and thicker than it is in any of the other ribs. The second rib, although longer than the first, is similarly curved. The body is not twisted. There is a short costal groove on its internal surface posteriorly. The tenth through twelfth ribs each have only one articular facet on their heads. The eleventh and twelfth ribs (floating ribs) have no necks or tubercles and are narrowed at their free anterior ends. The twelfth rib sometimes is shorter than the first rib.

The Respiratory System

The respiratory system includes the bony thorax, the muscles of ventilation, the upper and the lower airways, and the pulmonary circulation. The many functions of the respiratory system include gas exchange, fluid exchange, maintenance of a relatively low-volume blood reservoir, filtration, and metabolism, and they necessitate an intimate and exquisite interaction of these various components. Because the thorax has already been discussed, this section deals with the muscles of ventilation, the upper and lower airways, and the pulmonary circulation.

Muscles of Ventilation

Ventilation, or breathing, involves the processes of inspiration and expiration. For air to enter the lungs during inspiration, muscles of the thoracic cage and abdomen must move the bony thorax to create changes in volume within the thorax and cause a concomitant reduction in the intrathoracic pressure. Inspiratory muscles increase the volume of the thoracic cavity by producing bucket-handle and pump-handle movements of the ribs and sternum, as depicted in Fig. 1-3. The resultant reduced intrathoracic pressure generated is below atmospheric pressure, forcing air into the lungs to help normalize pressure differences. The essential muscles to achieve the active process of inspiration at rest are the diaphragm and internal intercostals. To create a more forceful inspiration during exercise or cardiopulmonary distress, accessory muscles assist with the inspiration. The accessory muscles include the sternocleidomastoid, scalenes, serratus anterior, pectoralis major and minor, trapezius, and erector spinae muscles.

Diaphragm

The diaphragm is the major muscle of inspiration. It is a musculotendinous dome that forms the floor of the thorax and separates the thoracic and abdominal cavities (Fig. 1-4). The diaphragm is divided into right and left hemidiaphragms. Both hemidiaphragms are visible on radiographic studies from the front or back. The right hemidiaphragm is protected by the liver and is stronger than the left. The left hemidiaphragm is more often subject to rupture and hernia, usually because of weaknesses at the points of embryologic fusion. Each hemidiaphragm is composed of three musculoskeletal components, including the sternal, costal, and lumbar portions that converge into the central tendon. The central tendon of the diaphragm is a thin but strong layer of tendons (aponeurosis) situated anteriorly and immediately below the pericardium. There are three major openings to enable various vessels to traverse the diaphragm. These include the vena caval opening for the inferior vena cava; the esophageal opening for the esophagus and gastric vessels; and the aortic opening containing the aorta, thoracic duct, and azygos veins. The phrenic nerve arises from the third, fourth, and fifth cervical spinal nerves (C3 to C5) and is involved in contraction of the diaphragm.

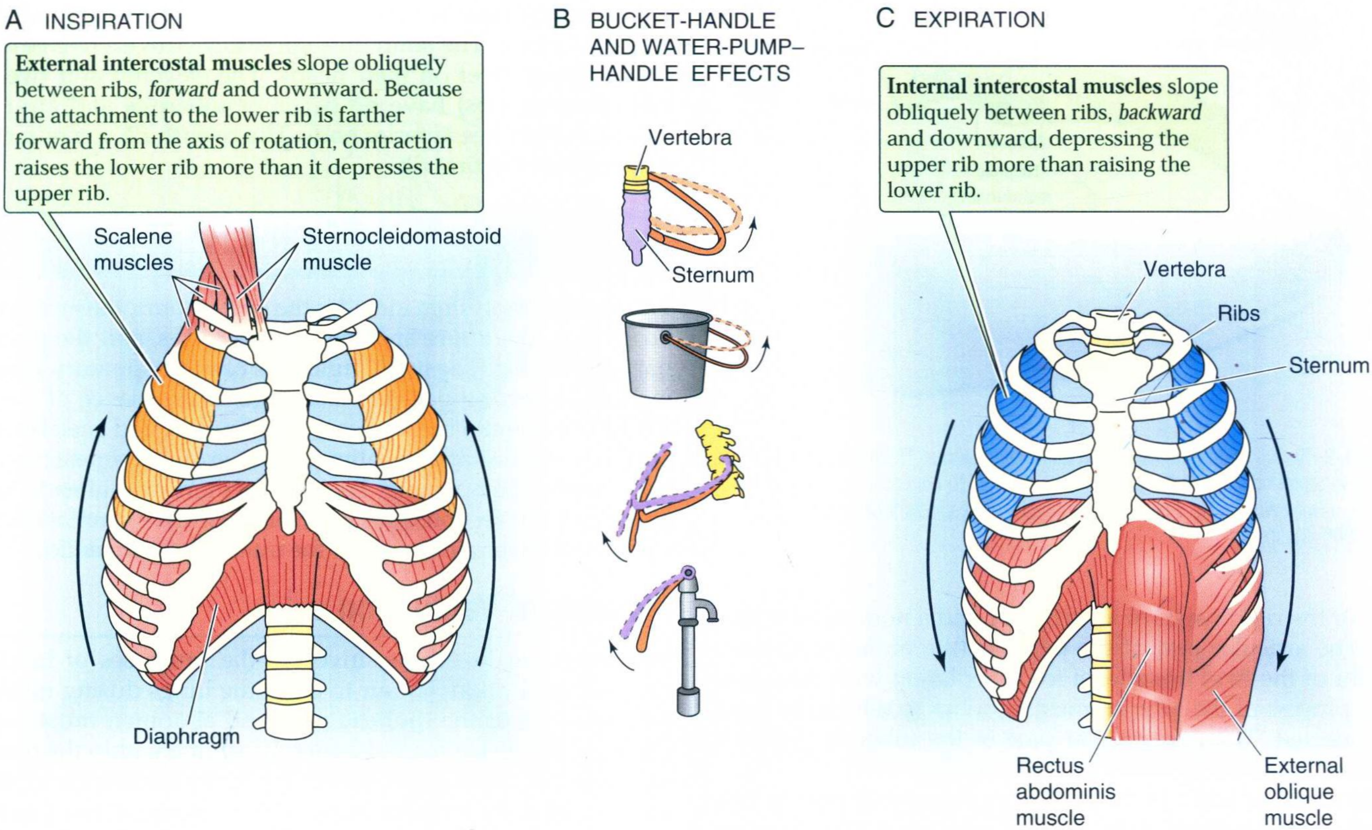

Figure 1-3 A-C, Actions of major respiratory muscles. (From Boron WF: *Medical Physiology,* updated ed, St. Louis, 2005, Saunders.)

The resting position of the diaphragm is an arched position high in the thorax. The level of the diaphragm and the amount of movement during inspiration vary as a result of factors such as body position, obesity, and size of various gastrointestinal organs present below the diaphragm. During normal ventilation or breathing, the diaphragm contracts to pull the central tendon down and forward. In doing so, the resting dome shape of the diaphragm is reversed to a flattening of the diaphragm. Contraction of this muscle increases the dimensions of the thorax in a cephalocaudal, anterior posterior, and lateral direction.[1] The increase in volume decreases pressure in the thoracic cavity and simultaneously causes a decrease in volume and an increase in pressure within the abdominal cavity. The domed shape of the diaphragm is largely maintained until the abdominal muscles end their extensibility, halting the downward displacement of the abdominal viscera, essentially forming a fixed platform beneath the central tendon. The central tendon then becomes a fixed point against which the muscular fibers of the diaphragm contract to elevate the lower ribs and thereby push the sternum and upper ribs forward. The right hemidiaphragm meets more resistance than the left during its descent, because the liver underlies the right hemidiaphragm and the stomach underlies the left; it is therefore more substantial than the left.

In patients with chronic obstructive pulmonary disease (COPD), there is compromised ability to expire. This results in a flattening of the diaphragm as a result of the presence of hyperinflated lungs.[1,5] It is essential for therapists to reverse hyperinflation and restore the normal resting arched position of the diaphragm using any exercise aimed at strengthening the diaphragm muscle. A flat and rigid diaphragm cannot be strengthened and will cause an automatic firing of the accessory muscles to trigger inspiration.

Body position in supine, upright, or side lying alters the resting position of the diaphragm, resulting in concomitant changes in lung volumes.[6] In the supine position, without the effects of gravity, the level of the diaphragm in the thoracic cavity rises. This allows for a relatively greater excursion of the diaphragm. Despite a greater range of movement of the diaphragm, lung volumes are low as a consequence of the elevated position of the abdominal organs within the thoracic cavity. In an upright position, the dome of the diaphragm is pulled down because of the effects of gravity. The respiratory excursion is less in this position; however, the lung volumes are larger. In the side-lying position, the hemidiaphragms are unequal in their positions: the uppermost side drops to a lower level and has less excursion than that in the sitting position; the lowermost side rises higher in the thorax and has a greater excursion than in the sitting position. In quiet breathing, the diaphragm normally moves about two-thirds of an inch; with maximal ventilatory effort, the diaphragm may move from 2.5 to 4 inches.[5]

Clinical tip

Stomach fullness, obesity with presence of a large pannus, ascites with increased fluid in the peritoneal space from liver disease, and pregnancy are additional factors affecting the normal excursion of the diaphragm during inspiration.

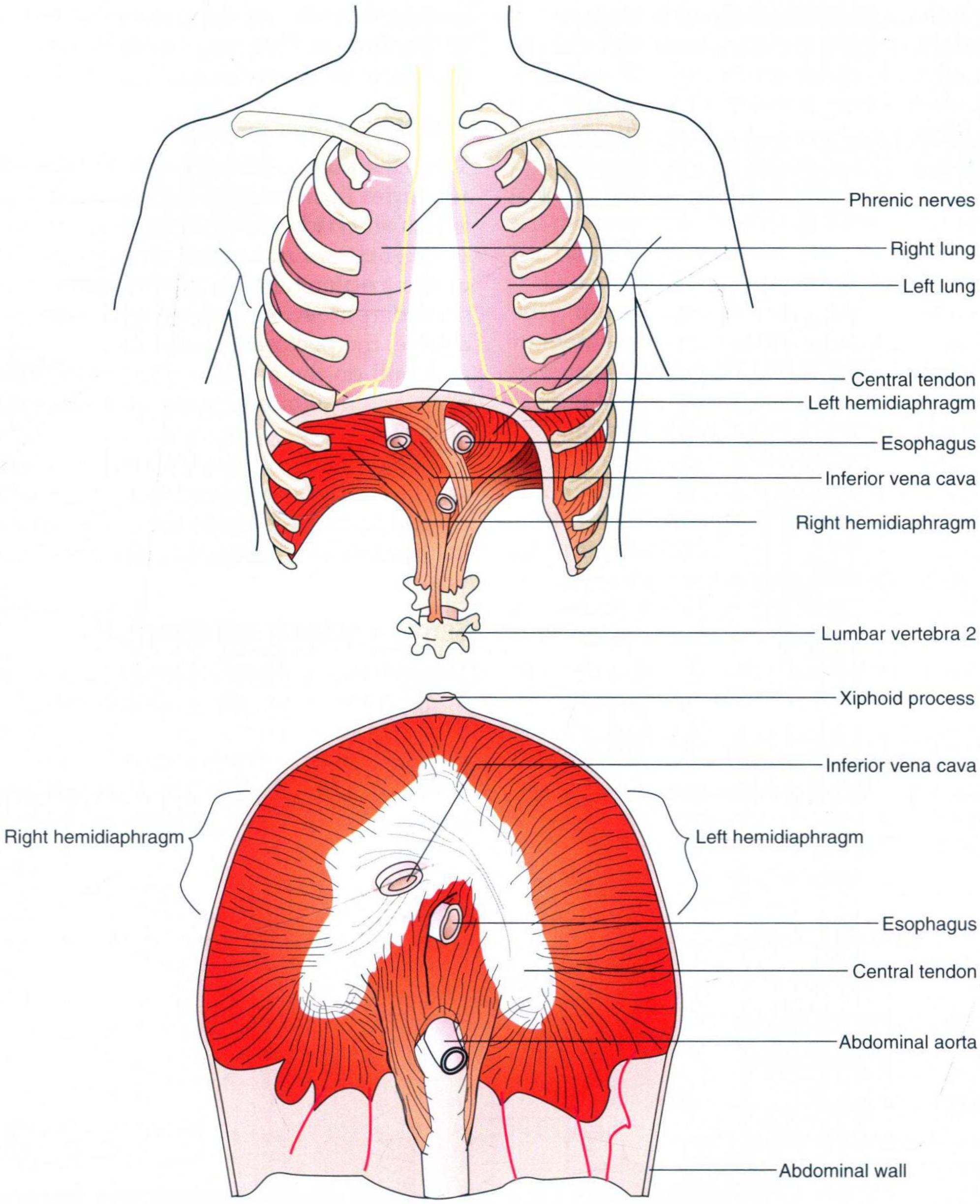

Figure 1-4 The diaphragm originates from the lumbar vertebra, lower ribs, xiphoid process, and abdominal wall and converges in a central tendon. Note the locations of the phrenic nerves and openings for the inferior vena cava, esophagus, and abdominal aorta. (From Hicks GH: *Cardiopulmonary Anatomy and Physiology,* Philadelphia, 2000, Saunders.)

External Intercostal Muscles

The external intercostal muscles originate from the lower borders of the ribs and attach to the upper border of the ribs below (Fig. 1-5). There are 11 external intercostal muscles on each side of the sternum. Contraction of these muscles pull the lower rib up and out toward the upper rib, thereby elevating the ribs and expanding the chest.

Accessory Muscles

Fig. 1-6 explains the anatomy of the accessory muscles.

Sternocleidomastoid Muscle

The sternocleidomastoid arises by two heads (sternal and clavicular from the medial part of the clavicle), which unite to extend obliquely upward and laterally across the neck to the mastoid process. For this muscle to facilitate inspiration, the head and neck must be held stable by the neck flexors and extensors. This muscle is a primary accessory muscle and elevates the sternum, increasing the anteroposterior diameter of the chest.

Scalene Muscle

The scalene muscles lie deep to the sternocleidomastoid, but may be palpated in the posterior triangle of the neck. These muscles function as a unit to elevate and fix the first and second ribs:

- The *anterior* scalene muscle passes from the anterior tubercles of the transverse processes of the third or fourth to the sixth cervical vertebrae, attaching by tendinous insertion into the first rib.
- The *middle* scalene muscle arises from the transverse processes of all the cervical vertebrae to insert onto the first rib (posteromedially to the anterior scalene, the brachial plexus and subclavian artery pass between the anterior scalene and middle scalene).
- The *posterior* scalene muscle arises from the posterior tubercles of the transverse processes of the fifth and sixth

cervical vertebrae, passing between the middle scalene and levator scapulae, to attach onto the second or third rib.

Upper Trapezius

The trapezius (upper fibers) muscle arises from the medial part of the superior nuchal line on the occiput and the ligamentum nuchae (from the vertebral spinous processes between the skull and the seventh cervical vertebra) to insert onto the distal third of the clavicle. This muscle assists with ventilation by helping to elevate the thoracic cage.

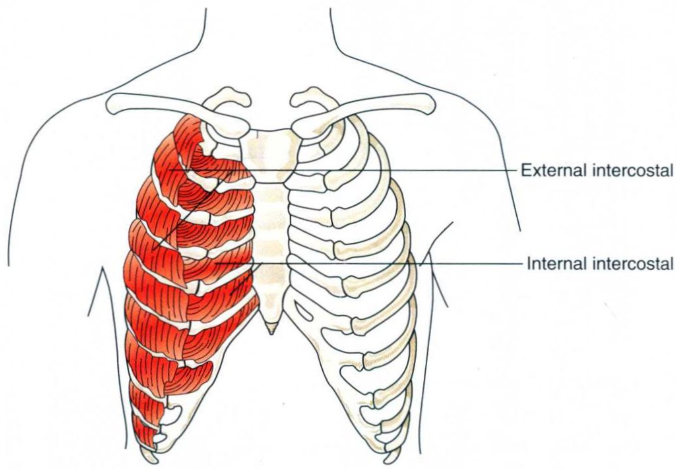

Figure 1-5 The external intercostal muscles lift the inferior ribs and enlarge the thoracic cavity. The internal intercostal muscles compress the thoracic cavity by pulling together the ribs. (From Hicks GH: *Cardiopulmonary Anatomy and Physiology*, Philadelphia, 2000, Saunders.)

Pectoralis Major and Minor

The pectoralis major arises from the medial third of the clavicle, from the lateral part of the anterior surface of the manubrium and body of the sternum, and from the costal cartilages of the first six ribs to insert upon the lateral lip of the crest of the greater tubercle of the humerus. When the arms and shoulders are fixed, by leaning on the elbows or grasping onto a table, the pectoralis major can use its insertion as its origin and pull on the anterior chest wall, lifting the ribs and sternum, and facilitate an increase in the anteroposterior diameter of the thorax.

The pectoralis minor arises from the second to fifth or the third to sixth ribs upward to insert into the medial side of the coracoid process close to the tip. This muscle assists in forced inspiration by raising the ribs and increasing intrathoracic volume.

Serratus Anterior and Rhomboids

The serratus anterior arises from the outer surfaces of the upper eight or nine ribs to attach along the costal aspect of the medial border of the scapula. The primary action of the serratus is to abduct, rotate the scapula, and hold the medial border firmly over the rib cage. The serratus can only be utilized as an accessory muscle in ventilation, when the rhomboids stabilize

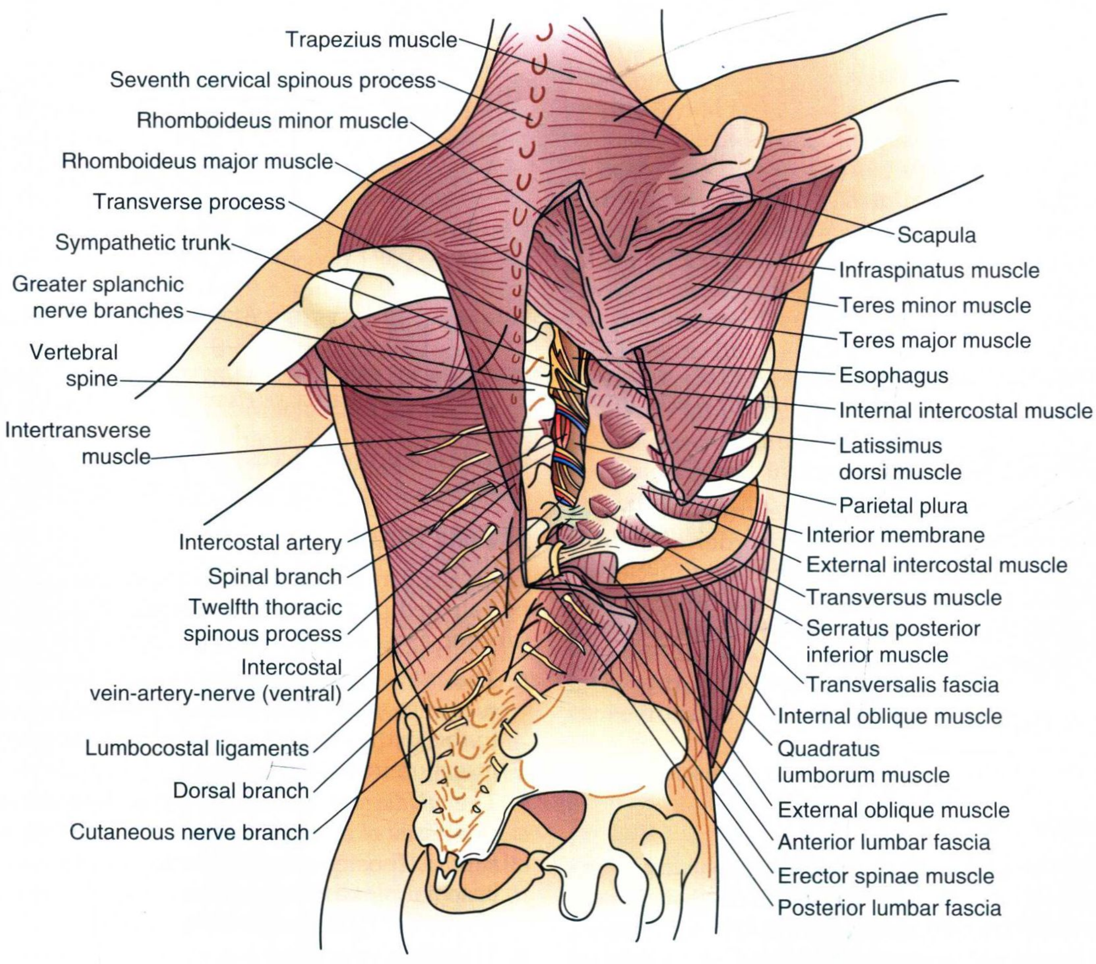

Figure 1-6 Musculature of the chest wall. (From Ravitch MM, Steichen FM: *Atlas of General Thoracic Surgery*, Philadelphia, 1988, Saunders.)

the scapula in adduction.[7] The action of the rhomboids fixes the insertion, allowing the serratus to expand the rib cage by pulling the origin toward the insertion.

Latissimus Dorsi

The latissimus dorsi arises from the spinous processes of the lower six thoracic, the lumbar, and the upper sacral vertebrae, from the posterior aspect of the iliac crest, and slips from the lower three or four ribs to attach to the intertubercular groove of the humerus.[7] The posterior fibers of this muscle assist in inspiration as they pull the trunk into extension.

Serratus Posterior Superior

The serratus posterior superior passes from the lower part of the ligamentum nuchae and the spinous processes of the seventh cervical and first two or three thoracic vertebrae downward into the upper borders of the second to fourth or fifth ribs. This muscle assists in inspiration by raising the ribs to which it is attached and expanding the chest.

Thoracic Erector Spinae Muscles

The erector spinae is a large muscle group extending from the sacrum to the skull. The thoracic erector spinae muscles extend the thoracic spine and raise the rib cage to allow greater expansion of the thorax.

Muscles of Expiration

Abdominal Muscles

The abdominal muscles include the rectus abdominis, transversus abdominis, and internal and external obliques. These muscles work to raise intraabdominal pressure when a sudden expulsion of air is required in maneuvers such as huffing and coughing. Pressure generated within the abdominal cavity is transmitted to the thoracic cage to assist in emptying the lungs.

Internal Intercostal Muscles

Eleven internal intercostal muscles exist on each side of the sternum. These muscles arise on the inner surfaces of the ribs and costal cartilages and insert on the upper borders of the adjacent ribs below (see Fig. 1-5). The posterior aspect on the internal intercostal muscles is termed the *interosseus portion* and depresses the ribs to aid in a forceful expiration. The intercartilaginous portion of the internal intercostals elevates the ribs and assists in inspiration.

Pulmonary Ventilation

Pulmonary ventilation, commonly referred to as *breathing*, is the process in which air is moved in and out of the lungs. Inspiration, an active process at rest and during exercise, involves contraction of the diaphragm and external intercostal muscles. The muscle that contracts first is the diaphragm, with a caudal movement and resultant increase within the volume of the thoracic cavity. The diaphragm eventually meets resistance against the abdominal viscera, causing the costal fibers of the diaphragm to contract and pull the lower ribs up and out—*the bucket-handle movement*. The outward movement is also facilitated by the external intercostal muscles. In addition, a pump-handle movement of the upper ribs is achieved through contraction of the external intercostals and the intercartilaginous portion of the internal intercostal muscles. The actions of the inspiratory muscles expand the dimensions of the thoracic cavity and concomitantly reduce the pressure in the lungs (intrathoracic pressure) below the air pressure outside the body. With the respiratory tract being open to the atmosphere, air rushes into the lungs to normalize the pressure difference, allowing inspiration to occur and the lungs to fill with air.

During forced or labored breathing, additional accessory muscles need to be used to increase the inspiratory maneuver. The accessory muscles raise the ribs to a greater extent and promote extension of the thoracic spine. These changes facilitate a further increase in the volume within the thoracic cavity and a subsequent drop in the intrathoracic pressure beyond that caused by the contraction of the diaphragm and external intercostals. This relatively lower intrathoracic pressure will promote a larger volume of air entering the lung.

At rest, expiration is a passive process and achieved through the elastic recoil of the lung and relaxation of the external intercostal and diaphragm muscle. As the external intercostals relax, the rib drops to its preinspiratory position and the diaphragm returns to its elevated dome position high in the thorax. To achieve a forceful expiration, additional muscles can be used, including the abdominals and internal intercostal muscles. The internal intercostals actively pull the ribs down to help expel air out of the lungs. The abdominals contract to force the viscera upward against the diaphragm, accelerating its return to the dome position.

> **Clinical tip**
>
> The changes in intraabdominal and intrathoracic pressure that occur with forced breathing assist with venous return of blood back to the heart. The drop in pressure allows for a filling of the veins, and the changing pressure within the abdomen and thorax cause a milking effect to help return blood back to the heart.

Pleurae

Two serous membranes, or pleurae, exist that cover each lung (Fig. 1-7). The pleura covering the outer surface of each lung is the visceral pleura and is inseparable from the tissue of the lung. The pleura covering the inner surface of the chest wall, diaphragm, and mediastinum is called the *parietal pleura*. The parietal pleura is frequently described with reference to the anatomic surfaces it covers: the portion lining the ribs and vertebrae is named the *costovertebral pleura;* the portion over the diaphragm is the *diaphragmatic pleura;* the portion covering the uppermost aspect of the lung in the neck is the *cervical pleura;* and that overlying the mediastinum is called the *mediastinal pleura*.[8] Parietal and visceral pleurae blend with one another where they come together to enclose the root of the lung. Normally, the pleurae are in intimate contact during all phases of the ventilatory cycle, being separated only by a thin serous film. There exists a potential space between the pleurae called the *pleural space* or *pleural cavity*. A constant negative pressure within this space maintains lung inflation.

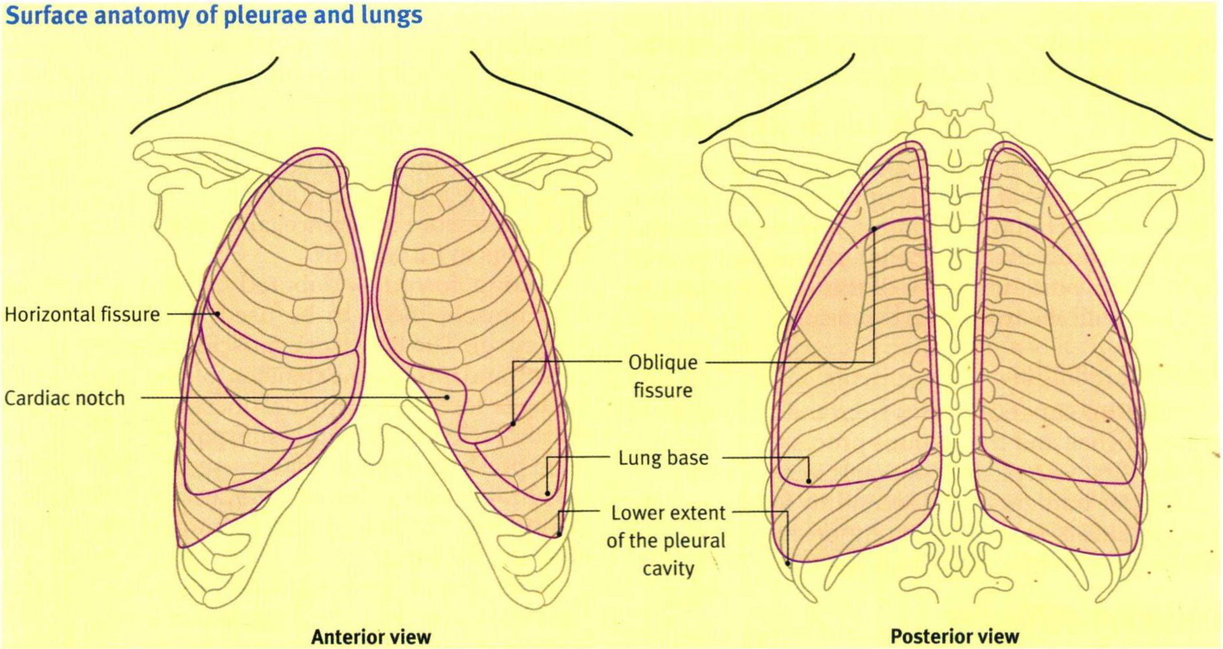

Figure 1-7 Pleurae of the lungs. (From Craven J: The lungs and their relations. *Anaesth Intensive Care Med*, 9(11):459-512, 2008.)

The serous fluid within the pleural space serves to hold the pleural layers together during ventilation and reduce friction between the lungs and the thoracic wall.[6,8]

The parietal pleura receives its vascular supply from the intercostal, internal thoracic, and musculophrenic arteries. Venous drainage is accomplished by way of the systemic veins in the adjacent parts of the chest wall. The bronchial vessels supply the visceral pleura. There exists no innervation to the visceral pleura and therefore no sensation.[5] The phrenic nerve innervates the parietal pleura of the mediastinum and central diaphragm, whereas the intercostal nerves innervate the parietal pleura of the costal region and peripheral diaphragm.

Irritation of the intercostally innervated pleura may result in the referral of pain to the thoracic or abdominal walls, and irritation of the phrenic-supplied pleura can result in referred pain in the lower neck and shoulder.[9]

Several complications can affect pleural integrity. Infection with resultant inflammatory response within the pleura is termed *pleuritis* or *pleurisy* and is best appreciated through the presence of pleural chest pain and an abnormal pleural friction rub on auscultation.[9] A pleural effusion refers to a buildup of fluid in the pleural space commonly seen after cardiothoracic surgery or with cancer. This is evidenced by diminished or absent breath sounds in the area of the effusion, is more likely to be in gravity-dependent areas, and is accompanied by reduced lung volumes. Blood in the pleural space is termed a *hemothorax*, whereas air in the pleural space from a collapsed lung is termed a *pneumothorax*. Finally, a bacterial infection with resultant pus in the pleural space is referred to as *empyema*.

Management for several of these complications of the pleural space is achieved through insertion of a chest tube into the pleural space to drain pleural secretions or to restore a negative pressure within the space and allow for lung inflation. A needle aspiration of fluid from the space, a thoracocentesis, may be performed for patients with large pleural effusions.

Lungs

The lungs are located on either side of the thoracic cavity, separated by the mediastinum. Each lung lies freely within its corresponding pleural cavity, except where it is attached to the heart and trachea by the root and pulmonary ligament. The substance of the lung—the parenchyma—is normally porous and spongy in nature. The surfaces of the lungs are marked by numerous intersecting lines that indicate the polyhedral (secondary) lobules of the lung. The lungs are basically cone shaped and are described as having an apex, a base, three borders (anterior, inferior, and posterior), and three surfaces (costal, medial, and diaphragmatic).

The apex of each lung is situated in the root of the neck, its highest point being approximately 1 inch above the middle third of each clavicle. The base of each lung is concave, resting on the convex surface of the diaphragm. The inferior border of the lung separates the base of the lung from its costal surface; the posterior border separates the costal surface from the vertebral aspect of the mediastinal surface; the anterior border of each lung is thin and overlaps the front of the pericardium. Additionally, the anterior border of the left lung presents a cardiac notch. The costal surface of each lung conforms to the shape of the overlying chest wall. The medial surface of each lung may be divided into vertebral and mediastinal aspects. The vertebral aspect contacts the respective sides of the thoracic vertebrae and their intervertebral disks, the posterior intercostal vessels, and nerves. The mediastinal aspect is notable for the cardiac impression; this concavity is larger on the left than on the right lung to accommodate the projection of the apex of the heart toward the left. Just posterior to the cardiac impression is the hilus, where the structures forming the root of the lung enter and exit the parenchyma. The extension of the pleural covering below and behind the hilus from the root of the lung forms the pulmonary ligament.