CHAPTER 4

Pulmonary System

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CHAPTER OUTLINE

CHAPTER OBJECTIVES

The objectives of this chapter are the following:

1. Provide a brief review of the structure and function of the pulmonary system
2. Present an overview of pulmonary evaluation, including physical examination and diagnostic testing
3. Describe pulmonary diseases and disorders, including clinical findings, medical-surgical management, and physical therapy intervention

Introduction

To safely and effectively provide physical therapy interventions of exercise, airway clearance program(s), or both to patients with pulmonary system dysfunction, physical therapists require an understanding of the pulmonary system and of the principles of ventilation and gas exchange. *Ventilation* is defined as gas (oxygen [O_2] and carbon dioxide [CO_2]) transport into and out of lungs, and *respiration* is defined as gas exchange across the alveolar-capillary and capillary-tissue interfaces. The term *pulmonary* primarily refers to the lungs, their airways, and their vascular system.[1]

Body Structure and Function

Structure

The primary organs and muscles of the pulmonary system are outlined in Tables 4.1 and 4.2, respectively. A schematic of the lungs within the thorax is presented in Fig. 4.1.

Function

To accomplish ventilation and respiration, the pulmonary system is regulated by many neural, chemical, and nonchemical mechanisms, which are discussed in the sections that follow.

Neural Control

Ventilation is regulated by two separate neural mechanisms: one controls automatic ventilation, and the other controls voluntary ventilation. The medullary respiratory center in the brainstem, is responsible for the rhythmicity of breathing and controls automatic ventilation. The pneumotaxic center, located in the pons, controls the rate and depth of ventilation. The cerebral cortex, which sends impulses directly to the motor neurons of ventilatory muscles, mediates voluntary ventilation.[2]

Chemical Control

Arterial levels of CO_2 (PCO_2), hydrogen ions (H^+), and O_2 (PO_2) can modify the rate and depth of respiration. To maintain homeostasis in the body, specialized chemoreceptors on the carotid arteries and aortic arch (carotid and aortic bodies, respectively) respond to either a rise in PCO_2 and H^+ or a fall in PO_2. Stimulation of these chemoreceptors results in transmission of impulses to the respiratory centers to increase or decrease the rate, depth, or both, of respiration. The respiratory center found in the medulla primarily responds to a rise in PCO_2 and H^+.[3,4] For example, an increase in PCO_2 would increase the ventilation rate to help increase the amount of CO_2 exhaled and ultimately lower the PCO_2 levels in arterial blood.

[a]The authors acknowledge Paul Ricard for prior contributions to this chapter.

TABLE 4.1 Structure and Function of Primary Organs of the Pulmonary System

Structure	Description	Function
Nose	Paired mucosal-lined nasal cavities supported by bone and cartilage	Conduit that filters, warms, and humidifies air entering lungs
Pharynx	Passageway that connects nasal and oral cavities to larynx, and oral cavity to esophagus Subdivisions naso-, oro-, and laryngopharynx	Conduit for air and food Facilitates exposure of immune system to inhaled antigens
Larynx	Passageway that connects pharynx to trachea Opening (glottis) covered by vocal folds or by the epiglottis during swallowing	Prevents food from entering the lower pulmonary tract Voice production
Trachea	Flexible tube composed of C-shaped cartilaginous rings connected posteriorly to the trachealis muscle Divides into the left and right main stem bronchi at the carina	Cleans, warms, and moistens incoming air
Bronchial tree	Right and left main stem bronchi subdivide within each lung into secondary bronchi, tertiary bronchi, and bronchioles, which contain smooth muscle	Warms and moistens incoming air from trachea to alveoli Smooth muscle constriction alters airflow
Lungs	Paired organs located within pleural cavities of the thorax The right lung has three lobes, and the left lung has two lobes	Contains air passageways distal to main stem bronchi, alveoli, and respiratory membranes
Alveoli	Microscopic sacs at end of bronchial tree immediately adjacent to pulmonary capillaries Functional unit of the lung	Primary gas exchange site Surfactant lines the alveoli to decrease surface tension and prevent complete closure during exhalation
Pleurae	Double-layered, continuous serous membrane lining the inside of the thoracic cavity Divided into parietal (outer) pleura and visceral (inner) pleura	Produces lubricating fluid that allows smooth gliding of lungs within the thorax Potential space between parietal and visceral pleura

Data from Marieb E. *Human Anatomy and Physiology*. 3rd ed. Redwood City, CA: Benjamin-Cummings; 1995; Moldover JR, Stein J, Krug PG. Cardiopulmonary physiology. In: Gonzalez EG, Myers SJ, Edelstein JE, et al. *Downey & Darling's Physiological Basis of Rehabilitation Medicine*. 3rd ed. Philadelphia: Butterworth-Heinemann; 2001.

Nonchemical Influences

The lungs have protective reflexes of coughing, bronchoconstriction, and mucus secretion and react to irritants, such as smoke or dust. Additional factors that can influence the rate and depth of ventilation include emotions, stressors, pain, and visceral reflexes from the lung tissue and other organ systems.[3,5]

Mechanics of Ventilation

Ventilation occurs as a result of changes in the potential space (volume) and subsequent pressures within the thoracic cavity created by the muscles of ventilation. The largest primary muscle of inhalation, the diaphragm, compresses the contents of the abdominal cavity as it contracts and descends, increasing the volume of the thoracic cavity.

> **CLINICAL TIP**
>
> The compression of the abdominal contents can be observed with the protrusion of the abdomen. Clinicians use the term "belly breathing" to denote diaphragmatic breathing.

The contraction of the intercostal muscles results in two motions simultaneously: bucket and pump handle. These motions are outlined schematically in Fig. 4.2. The combined motions further increase the volume of the thorax. The overall increase in the volume of the thoracic cavity creates a negative intrathoracic pressure compared with the pressure outside the body. As a result, air is pulled into the body and lungs via the pulmonary tree, stretching the lung parenchyma, to equalize the pressures within the thorax with those outside the body.

Accessory muscles of inspiration, noted in Table 4.2, are generally not active at rest. Although not the primary actions of the individual muscles, contractions of the accessory muscles can increase the depth and rate of ventilation during progressive activity by increasing the expansion of the thorax. Increased expansion results in greater negative pressures being generated and subsequent larger volumes of air entering the lungs.

> **CLINICAL TIP**
>
> In healthy lungs, depth of breath or tidal volume (VT) generally occurs before increases in respiratory rate.

Although inhalation is an active process, exhalation is generally passive. The muscles relax, causing a decrease in the thoracic volume while the lungs deflate to their natural resting state. The combined effects of these actions result in an increase of intrathoracic pressure and flow of air out of the lungs. Contraction of the primary and accessory muscles of exhalation (see Table 4.2) results in an increase in intrathoracic pressure and a faster rate of decrease in thoracic size, forcing air out of the lungs.[6]

In persons with primary or secondary chronic pulmonary health conditions, changes in tissue and mechanical properties of the pulmonary system can result in accessory muscle use being observed earlier in activity or even being present at rest. Determination of the impairment(s) resulting in the observed activity limitation can help a clinician determine a plan of care. In addition, clinicians should consider the reversibility, or the degree to which the impairment can be improved, when determining a patient's prognosis for improvement with physical therapy.

TABLE 4.2 Primary and Accessory Ventilatory Muscles With Associated Innervation

	Pulmonary Muscles	Innervation
Primary inspiratory muscles	Diaphragm	Phrenic nerve (C3–C5)
	External intercostals	Spinal segments T1–T9
Accessory inspiratory muscles	Trapezius	Cervical nerve (C1–C4), spinal part of cranial nerve XI
	Sternocleidomastoid	Spinal part of cranial nerve XI
	Scalenes	Cervical/brachial plexus branches (C3–C8, T1)
	Pectorals	Medial/lateral pectoral nerve (C5–C8, T1)
	Serratus anterior	Long thoracic nerve (C5–C7)
	Latissimus dorsi	Thoracodorsal nerve (C5–C8)
Primary expiratory muscles	Rectus abdominis	Spinal segments T5–T12
	External obliques	Spinal segments T7–T12
	Internal obliques	Spinal segments T8–T12
	Internal intercostals	Spinal segments T1–T9
Accessory expiratory muscles	Latissimus dorsi	Thoracodorsal nerve (C5–C8)

Data from Kendall FP, McCreary EK, eds. *Muscles: Testing and Function*. 3rd ed. Baltimore, MD: Lippincott, Williams, and Wilkins; 1983; Rothstein JM, Roy SH, Wolf SL. The *Rehabilitation Specialist's Handbook*. 2nd ed. Philadelphia: FA Davis; 1998; DeTurk WE, Cahalin LP. *Cardiovascular and Pulmonary Physical Therapy: An Evidence-Based Approach*. New York: McGraw-Hill Medical Publishing Division; 2004.

If reversing a patient's ventilatory impairments is unlikely, facilitation of accessory muscle use can be promoted during functional activities and strengthening of these accessory muscles (e.g., use of a four-wheeled rolling walker with a seat and accompanying arm exercises).[7]

CLINICAL TIP

Patients with advanced pulmonary conditions may automatically assume positions to optimize accessory muscle use, such as forward leaning on their forearms (i.e., tripod posturing).

Gas Exchange

Once air has reached the alveolar spaces, respiration or gas exchange can occur at the alveolar-capillary membrane. Diffusion of gases through the membrane is affected by the following[8]:

- A concentration gradient (partial pressure difference) in which gases will diffuse from areas of high concentration to areas of low concentration:

$$\text{Alveolar } O_2 = 100 \text{ mmHg} \rightarrow \text{Capillary } O_2 = 40 \text{ mmHg}$$

- Surface area, or the total amount of alveolar-capillary interface available for gas exchange (e.g., the breakdown of alveolar membranes that occurs in emphysema will reduce the amount of surface area available for gas exchange)
- The thickness of the barrier (membrane) between the two areas involved (e.g., retained secretions in the alveolar spaces will impede gas exchange through the membrane)
- Diffusion coefficient of gas through a membrane, which is dependent on the solubility of a particular gas in the membrane

Ventilation-to-Perfusion Ratio

Gas exchange is optimized when the ratio of air flow (ventilation $\dot{V}$) to blood flow (perfusion $\dot{Q}$) approaches a 1 : 1 relationship. However, the actual $\dot{V}/\dot{Q}$ ratio is 0.8 because alveolar ventilation is approximately equal to 4 μL per minute and pulmonary blood flow is approximately equal to 5 L per minute.[9–11]

Gravity, body position, and cardiopulmonary dysfunction can influence this ratio. Ventilation is optimized in areas of least resistance. For example, when a person is in the sitting position, the upper lobes initially receive more ventilation than the lower lobes; however, the lower lobes have the largest net change in ventilation.[12]

Perfusion is greatest in gravity-dependent areas. For example, when a person is in the sitting position, perfusion is the greatest at the base of the lungs; when a person is in the left side-lying position, the left lung receives the most blood.[12]

A $\dot{V}/\dot{Q}$ mismatch (inequality in the relationship between ventilation and perfusion) can occur in certain situations. Two terms associated with $\dot{V}/\dot{Q}$ mismatch are *dead space* and *shunt*. Dead space occurs when ventilation is in excess of perfusion, as with a pulmonary embolus. A shunt occurs when perfusion is in excess of ventilation, as in alveolar collapse from secretion retention.[12] These conditions are shown in Fig. 4.3.

Gas Transport

O_2 is transported away from the lungs to the tissues in two forms: dissolved in plasma (PO_2) or chemically bound to hemoglobin on a red blood cell (oxyhemoglobin). As a by-product of cellular metabolism, CO_2 is transported away from the tissues to the lungs in three forms: dissolved in plasma (PCO_2), chemically bound to hemoglobin (carboxyhemoglobin), and as bicarbonate.[13]

Approximately 97% of O_2 transported from the lungs is carried in chemical combination with hemoglobin. The majority of CO_2 transport (93%) occurs in the combined forms of carbaminohemoglobin and bicarbonate. A smaller percentage (3%) of O_2 and 7% of CO_2 are transported in dissolved forms.[13] Dissolved O_2 and CO_2 exert partial pressure within the plasma and can be measured by sampling arterial, venous, or mixed venous blood.[14] (See the Arterial Blood Gas section for further description of this process.)

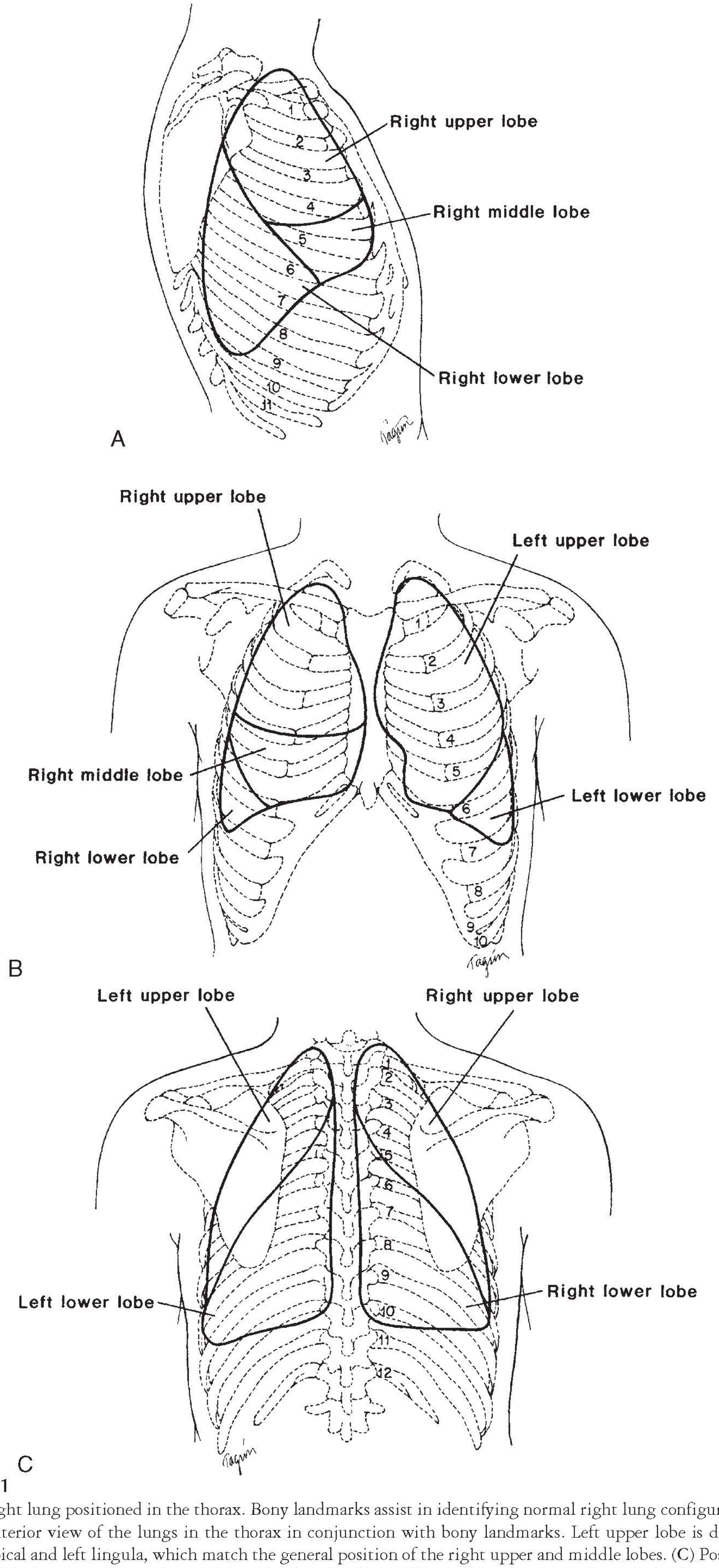

FIG. 4.1

(A) Right lung positioned in the thorax. Bony landmarks assist in identifying normal right lung configuration. (B) Anterior view of the lungs in the thorax in conjunction with bony landmarks. Left upper lobe is divided into apical and left lingula, which match the general position of the right upper and middle lobes. (C) Posterior view of the lungs in conjunction with bony landmarks. (From Ellis E, Alison J, eds. *Key Issues in Cardiorespiratory Physiotherapy.* Oxford, UK: Butterworth-Heinemann; 1992:12.)

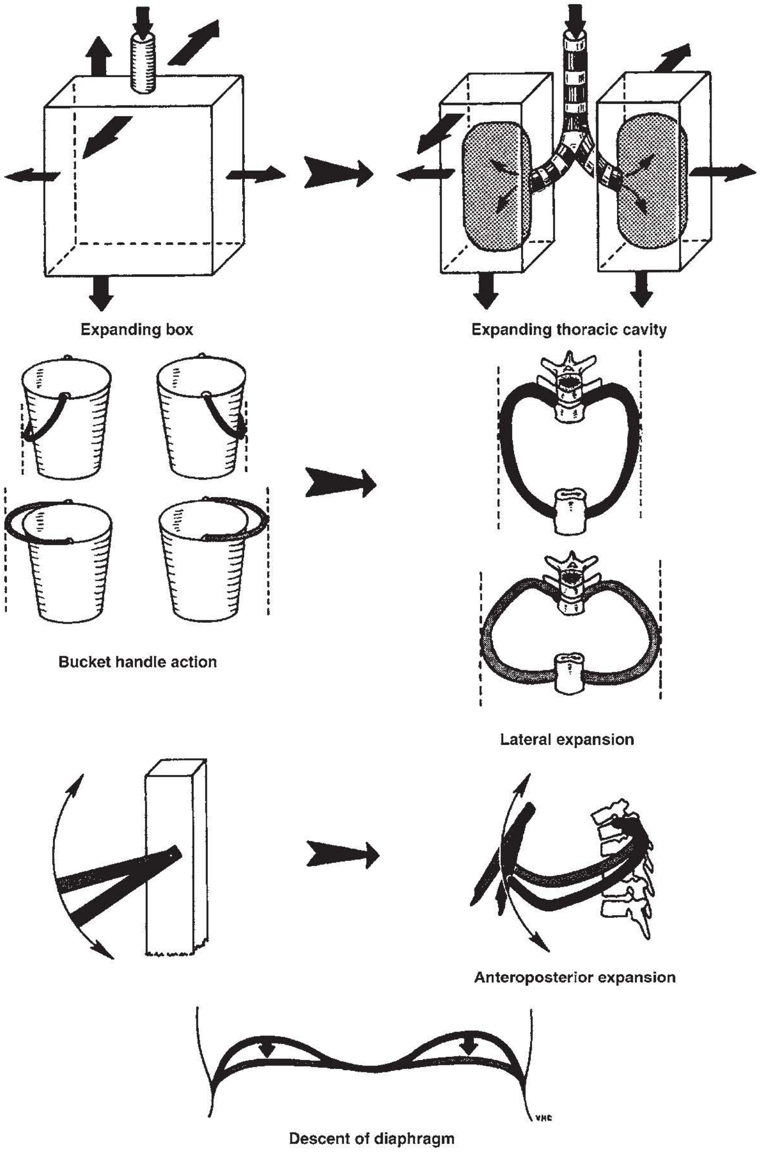

FIG. 4.2
Respiratory mechanics (bucket and pump handle motions). (From Snell RS, ed. *Clinical Anatomy by Regions.* 9th ed. Baltimore, MD: Lippincott, Williams & Wilkins; 2012.)

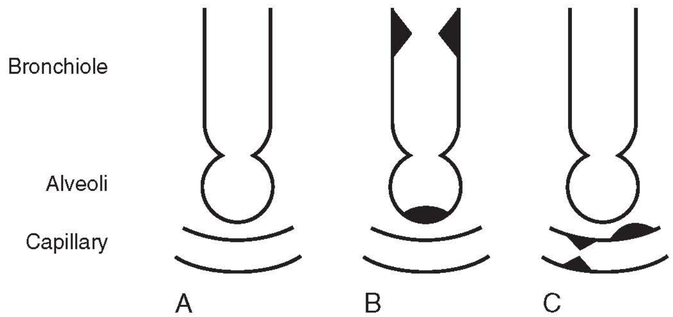

FIG. 4.3
Ventilation and perfusion mismatch. (A) Normal alveolar ventilation. (B) Capillary shunt. (C) Alveolar dead space.

Examination

Pulmonary examination is composed of patient history, physical examination, and interpretation of diagnostic test results.

Patient History

In addition to the general chart review presented in Chapter 2, other relevant information regarding pulmonary dysfunction that should be ascertained from the chart review or patient interview is as follows[14–16]:

- History of smoking, including packs per day or pack-years (packs per day × number of years smoked) and the amount of time that smoking has been discontinued (if applicable). Current or past exposure to secondhand smoke may also be determined along with type of smoking the patient had been performing (e.g., cigarette, cigar, pipe, vaporizing device).
- Presence, history, and amount of supplemental O_2 therapy at rest, with activity and at night. The choice of delivery methods of supplemental O_2 therapy, such as intermittent versus continuous flow or nasal cannula, versus an oxymizer is also clinically important to determine.
- Exposure to environmental or occupational toxins (e.g., asbestos or occupational dusts).
- History of thoracic procedures, or surgery.
- History and frequency of pneumonia and other lung infections.
- History or current use of assisted ventilation or intubation with mechanical ventilation.
- History or current reports of dyspnea either at rest or with exertion. Dyspnea is the subjective complaint of difficulty with respiration, also known as shortness of breath. Measurement tools are available to assess the multidimensional aspects of dyspnea. Categories of these scales include sensory-perceptual scales that measure ratings of intensity, such as the Modified Borg Scale and visual analog scales; affective distress scales that measure how distressing breathing feels to the patient, such as single or multi-item ratings of distress or emotional responses, and lastly symptom or impact burden scales measuring how dyspnea affects function and quality of life, such as the Medical Research Council (MRC) scale (Table 4.3).[17,18] At this time, the American Thoracic Society does not recognize a single standard measure.
- Prior level of activity, exercise and function.
- History of baseline sputum production, including color (e.g., yellow, green), consistency (e.g., thick, thin), and amount. Familiar or broad terms can be applied as units of measure for sputum (e.g., quarter-sized, tablespoon, or copious).
- Airway clearance techniques used currently and in the past, along with their perceived effectiveness.
- Breathing treatments (e.g., metered-dose inhalers [MDIs] and nebulized medications).
- Sleeping position and number of pillows used.

> **✎ CLINICAL TIP**
>
> Dyspnea may also be measured by counting the number of syllables a person can utter per breath. For example, a patient with one- to two-word dyspnea noticeably has more dyspnea compared with a person who can speak a full sentence per breath.

TABLE 4.3 Medical Research Council Breathlessness Scale

Grade	Degree
1	Is the patient's breath as good as that of other men of his age and build at work, on walking, and on climbing hills or stairs?
2	Is the patient able to walk with normal men of own age and build on the level but unable to keep up on hills or stairs?
3	Is the patient unable to keep up with normal men on the level, but able to walk about a mile or more at his own speed?
4	Is the patient unable to walk more than about 100 yards on the level without a rest?
5	Is the patient breathless on talking or undressing, or unable to leave his house because of breathlessness?

From Brooks SM. Surveillance for respiratory hazards. *ATS News*. 1982;8:12-16. Used with the permission of the Medical Research Council.

> **✎ CLINICAL TIP**
>
> Dyspnea can be measured to further quantify functional activities or exercise, either as a primary or secondary measurement of intensity. This is also especially useful in goal writing (e.g., "Patient will ascend/descend 10 stairs using one rail with reported dyspnea < 2/10.")

Physical Examination

The physical examination of the patient with pulmonary impairments consists of inspection, auscultation, palpation, mediate percussion, cough examination, postural assessment and musculoskeletal testing. Suggested guidelines for physical therapy intervention(s) that are based on examination findings and diagnostic test results are found at the end of this chapter.

Inspection

A wealth of information can be gathered by simple observation of the patient at rest and with activity. Physical observation should proceed in a systematic fashion and include the following[14–16]:

- General appearance and level of alertness
- Ease of phonation
- Skin color
- Posture and chest shape
- Ventilatory or breathing pattern
- Presence of digital clubbing
- Presence of supplemental O_2 and other medical equipment (refer to Chapter 18)
- Presence and location of surgical incisions

Observation of Breathing Patterns

Breathing patterns vary among individuals and may be influenced by pain, emotion, body temperature, sleep, body position, activity level, and the presence of pulmonary, cardiac, metabolic, or nervous system disease (Table 4.4).

TABLE 4.4 Description of Breathing Patterns and Their Associated Conditions

Breathing Pattern	Description	Associated Conditions
Apnea	Lack of airflow to the lungs for >15 seconds	Airway obstruction, cardiopulmonary arrest, alterations of the respiratory center, narcotic overdose
Biot's respirations	Constant increased rate and depth of respiration followed by periods of apnea of varying lengths	Elevated intracranial pressure, meningitis
Bradypnea	Ventilation rate <12 breaths per minute	Use of sedatives, narcotics, or alcohol; neurologic or metabolic disorders; excessive fatigue
Cheyne-Stokes respirations	Increasing depth of ventilation followed by a period of apnea	Elevated intracranial pressure, CHF, narcotic overdose
Hyperpnea	Increased depth of ventilation	Activity, pulmonary infections, CHF
Hyperventilation	Increased rate and depth of ventilation resulting in decreased PCO_2	Anxiety, nervousness, metabolic acidosis
Hypoventilation	Decreased rate and depth of ventilation resulting in increased PCO_2	Sedation or somnolence, neurologic depression of respiratory centers, overmedication, metabolic alkalosis
Kussmaul respirations	Increased regular rate and depth of ventilation	Diabetic ketoacidosis, renal failure
Orthopnea	Dyspnea that occurs in a flat supine position. Relief occurs with more upright sitting or standing	Chronic lung disease, CHF
Paradoxical ventilation	Inward abdominal or chest wall movement with inspiration and outward movement with expiration	Diaphragm paralysis, ventilation muscle fatigue, chest wall trauma
Sighing respirations	The presence of a sigh >2–3 times per minute	Angina, anxiety, dyspnea
Tachypnea	Ventilation rate >20 breaths per minute	Acute respiratory distress, fever, pain, emotions, anemia
Hoover's sign[a]	The inward motion of the lower rib cage during inhalation	Flattened diaphragm often related to decompensated or irreversible hyperinflation of the lungs

[a]Hoover's sign has been reported to have a sensitivity of 58% and specificity of 86% for detection of airway obstruction. Hoover's sign is associated with a patient's body mass index, severity of dyspnea, and frequency of exacerbations and is seen in up to 70% of patients with severe obstruction.
CHF, Congestive heart failure; *PCO_2,* partial pressure of carbon dioxide.
Data from Johnson CR, Krishnaswamy N, Krishnaswamy G. The Hoover's sign of pulmonary disease: molecular basis and clinical relevance. *Clin Mol Allergy*. 2008;6:8; Kersten LD. *Comprehensive Respiratory Nursing: A Decision-Making Approach*. Philadelphia: Saunders; 1989; DesJardins T, Burton GG. *Clinical Manifestations and Assessment of Respiratory Disease*. 3rd ed. St. Louis: Mosby; 1995.

Observation of breathing pattern should include an assessment of rate (12–20 breaths per minute is normal), depth, ratio of inspiration to expiration (one to two is normal), sequence of chest wall movement during inspiration and expiration, comfort, presence accessory muscle use, and symmetry.[14–16]

CLINICAL TIP

If possible, examine the patient's breathing pattern when he or she is unaware of the inspection, because knowledge of the physical examination can influence the patient's respiratory pattern and/or rate. Objective observations of ventilation rate may not always be consistent with a patient's subjective complaints of dyspnea. For example, a patient may complain of shortness of breath but have a ventilation rate or pattern that is within normal limits. Therefore the patient's subjective complaints, rather than the objective observations, may be a more accurate measure of treatment intensity.

Auscultation

Auscultation is the process of listening to the sounds of air passing through the tracheobronchial tree and the alveolar spaces. The sounds of airflow normally dissipate from proximal to distal airways, making the sounds less audible in the periphery than in the central airways. Alterations in airflow and ventilation effort result in distinctive sounds within the thoracic cavity that may indicate pulmonary disease or dysfunction.

Auscultation proceeds in a systematic, side-to-side, and cephalocaudal fashion. Breath sounds on the left and right sides are compared in the anterior, lateral, and posterior segments of the chest wall, as shown in Fig. 4.4. The diaphragm (flat side) of the stethoscope should be used for auscultation. The patient should be seated or lying comfortably in a position that allows access to all lung fields. Full inspirations and expirations are performed by the patient through the mouth as the clinician listens to the entire cycle of respiration before moving the stethoscope to another lung segment.[14–16]

All of the following ensure accurate auscultation:

- Make sure stethoscope earpieces are pointing up and inward (toward your patient) before placing them in your ears.
- Long stethoscope tubing may dampen sound transmission. Length of tubing should be approximately 30 cm (12 in) to 55 cm (21–22 in).[15]
- Double tubing stethoscopes may cause the false appearance of adventitious breath sounds when the two tubes touch during auscultation.

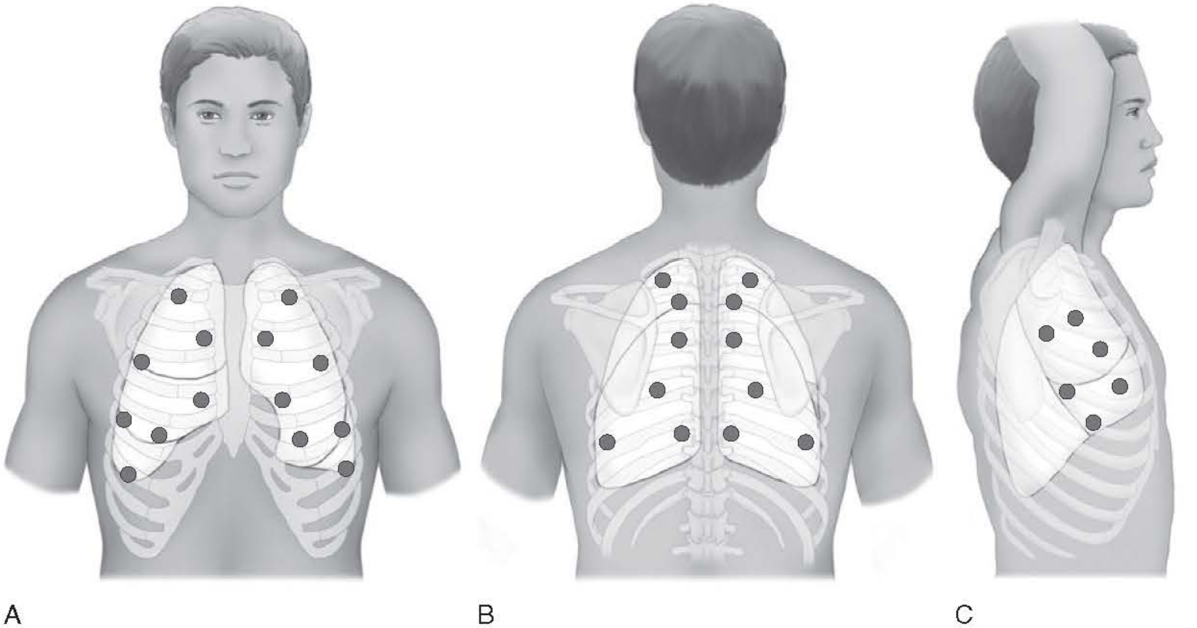

FIG. 4.4
Landmarks for lung auscultation on (A) anterior, (B) posterior, and (C) lateral aspects of the chest wall. (Courtesy Peter P. Wu.)

- Always check proper function of the stethoscope before auscultating by listening to finger tapping on the diaphragm while the earpieces are in place.
- Apply the stethoscope diaphragm firmly against the patient's bare skin so that the diaphragm lays flat. Never auscultate over clothes if it can be avoided.
- Observe chest wall expansion and breathing pattern while auscultating to confirm the palpatory findings of breathing pattern (e.g., sequence and symmetry). For example, decreased chest wall motion, detected during palpation in the left lower lung field, may present with decreased breath sounds in that same area.

Breath sounds may be normal or abnormal (adventitious or added) breath sounds; all breath sounds should be documented according to the location and the phase of respiration (i.e., inspiration, expiration, or both) and in comparison with the opposite lung. Several strategies can be used to reduce the chance of false-positive adventitious breath sound findings, including the following:

- Ensure full, deep inspirations (decreased effort can be misinterpreted as decreased breath sounds).
- Ask the patient to breath in and out through the mouth instead of the nose.
- Be aware of the stethoscope tubing touching other objects (especially ventilator tubing) or chest hair.
- Periodically lift the stethoscope off the chest wall to help differentiate extraneous sounds (e.g., chest or nasogastric tubes, patient snoring) that may appear to originate from the thorax.
- Auscultate side to side to compare the sounds of a similar region in the other lung.

> **CLINICAL TIP**
>
> To maximize patient comfort, allow periodic rest periods between deep breaths to prevent hyperventilation and dizziness. Instructing the patient to "Please stop if you get lightheaded or dizzy" is also helpful to prevent these symptoms with auscultation.

Normal Breath Sounds

Clinically, tracheal, bronchial, and vesicular breath sounds generally are documented in the medical record as "normal" or "clear" breath sounds; however, the use of tracheal or vesicular breath sounds as descriptors is more accurate.

Tracheal, Bronchial, or Bronchovesicular Sounds. Normal tracheal or bronchial breath sounds are loud tubular sounds heard over the proximal airways, such as the trachea and main stem bronchi. A pause is heard between inspiration and expiration; the expiratory phase is longer than the inspiratory phase. Normal bronchovesicular sounds are similar to bronchial breath sounds; however, no pause occurs between inspiration and expiration.[14,15]

Vesicular Sounds. Vesicular sounds are soft rustling sounds heard over the more distal airways and lung parenchyma. Inspiration is longer and more pronounced than expiration because a decrease in airway lumen during expiration limits transmission of airflow sounds.[14,15]

> **CLINICAL TIP**
>
> The abbreviation CTA stands for "clear to auscultation."

TABLE 4.5 Possible Sources of Abnormal Breath Sounds

Sound	Possible Etiology
Bronchial (abnormal if heard in areas where vesicular sounds should be present)	Fluid or secretion consolidation (airlessness) that could occur with pneumonia
Decreased or diminished (less audible)	Hypoventilation, severe congestion, or emphysema
Absent	Pneumothorax or lung collapse

Abnormal Breath Sounds

Breath sounds are abnormal if they are heard outside their usual location in the chest or if they are qualitatively different from normal breath sounds.[19] Despite efforts to make the terminology of breath sounds more consistent, terminology may still vary from clinician to clinician and facility to facility. Always clarify the intended meaning of the breath sound description if your findings differ significantly from what has been documented or reported. Abnormal breath sounds with possible sources are outlined in Table 4.5.

Adventitious Breath Sounds

Adventitious breath sounds occur from alterations or turbulence in airflow through the tracheobronchial tree and lung parenchyma. These sounds can be divided into continuous (wheezes and rhonchi) or discontinuous (crackles) sounds.[15,19]

The American Thoracic Society and the American College of Chest Physicians have discouraged the use of the term *rhonchi,* recommending instead that the term *wheezes* be used for all continuous adventitious breath sounds.[20] Many health care providers in hospitals and clinics continue to use the term *rhonchi;* therefore it is mentioned in this section.

Continuous Sounds

Wheeze. Wheezes occur most commonly with airway obstruction from bronchoconstriction or retained secretions and commonly are heard on expiration. Wheezes also may be present during inspiration if the obstruction is significant enough. Wheezes can be high pitched (usually from bronchospasm or constriction, as in asthma) or low pitched (usually from secretions, as in pneumonia).[15]

Stridor. Stridor is an extremely high-pitched wheeze that occurs with significant upper airway obstruction and is present during inspiration and expiration. The presence of stridor indicates a medical emergency. Stridor is also audible without a stethoscope.[16]

> ✎ **CLINICAL TIP**
>
> Acute onset of stridor during an intervention session warrants immediate notification of the nursing and medical staff.

Rhonchi. Low-pitched or "snoring" sounds that are continuous characterize rhonchi. These sounds generally are associated with large airway obstruction, typically from secretions lining the airways.[15]

Discontinuous Sounds

Crackles. Crackles are bubbling or popping sounds that represent the presence of fluid, secretions, or the sudden opening of closed airways. Crackles that result from fluid (pulmonary edema) or secretions (pneumonia or hypersecretion of mucus) are described as "wet" or "coarse," whereas crackles that occur from the sudden opening of closed airways (atelectasis) are referred to as "dry" or "fine."[15]

> ✎ **CLINICAL TIP**
>
> Wet crackles also can be referred to as ***rales;*** however, the American Thoracic Society and the American College of Chest Physicians have moved to eliminate this terminology for purposes of standardization.[20]

Extrapulmonary Sounds

These sounds are generated from dysfunction outside of the lung tissue. The most common sound is the pleural friction rub. This sound is heard as a loud grating sound, generally throughout both phases of respiration, and almost always is associated with pleuritis (inflamed pleurae rubbing on one another).[15,19] The sound is often described as that caused by two pieces of leather rubbing together. The presence of a chest tube inserted into the pleural space also may cause a sound similar to a pleural rub.[15]

> ✎ **CLINICAL TIP**
>
> Auscultation should be used to guide selection of interventions, assess for changes in patient status and determine the effectiveness of treatment (i.e., high-pitched wheezes could justify interventions to promote opening airways, and location and degree of wet crackles can help assess effectiveness of airway clearance techniques).

Voice Sounds

Normal phonation is audible during auscultation, with the intensity and clarity of speech also dissipating from proximal to distal airways. Voice sounds that are more or less pronounced in distal lung regions, where vesicular breath sounds should occur, may indicate areas of consolidation or hyperinflation, respectively. The same areas of auscultation should be used when assessing voice sounds. The following three types of voice sound tests can be used to help confirm breath sound findings[15,16]:

1. Whispered pectoriloquy. The patient whispers "one, two, three." The test is positive for consolidation if phrases are clearly audible in distal lung fields. This test is positive for hyperinflation if the phrases are less audible in distal lung fields.
2. Bronchophony. The patient repeats the phrase "ninety-nine." The results are similar to whispered pectoriloquy.
3. Egophony. The patient repeats the letter *e.* If the auscultation in the distal lung fields sound like *a,* then fluid in the air spaces or lung parenchyma is suspected.

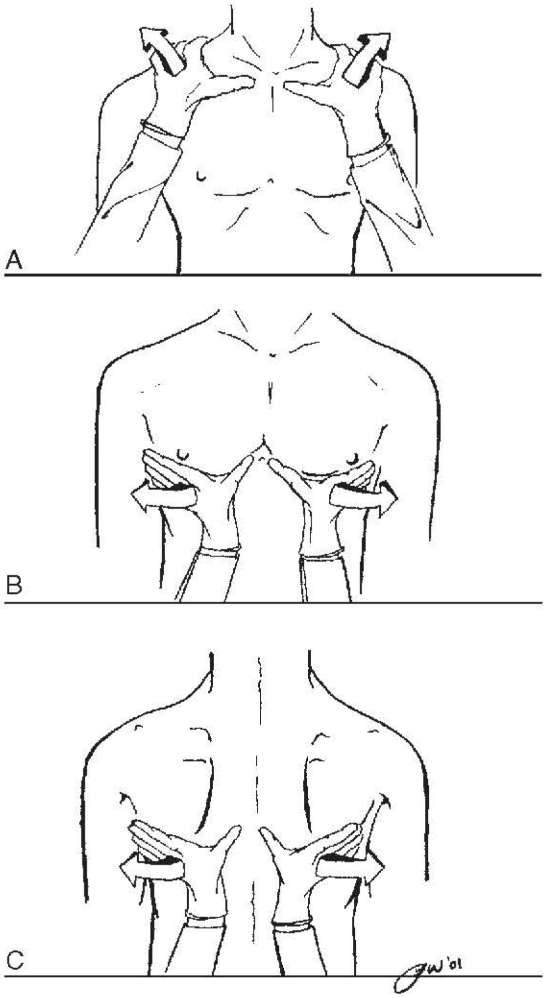

FIG. 4.5
Palpation of (A) upper, (B) middle, and (C) lower chest wall motion. (Courtesy Peter P. Wu.)

Palpation

The third component of the physical examination is palpation of the chest wall, which is performed in a cephalocaudal direction. Fig. 4.5 demonstrates hand placement for chest wall palpation of the upper, middle, and lower lung fields. Palpation is performed to examine the following:

- Presence of fremitus (a vibration caused by the presence of secretions or voice production, which is felt through the chest wall) during respirations[14]
- Presence, location, and reproducibility of pain, tenderness, or both
- Skin temperature
- Presence of bony abnormalities, rib fractures, or both
- Chest expansion and symmetry
- Presence of subcutaneous emphysema (palpated as bubbles popping under the skin from the presence of air in the subcutaneous tissue). This finding is abnormal and represents air that has escaped or is escaping from the lungs. Subcutaneous emphysema can occur from a pneumothorax (PTX), a complication from central line placement, after thoracic surgery, or laparoscopic abdominal surgery.[1]

> **CLINICAL TIP**
>
> To decrease patient fatigue while palpating each of the chest wall segments for motion, all of the items listed above can be examined simultaneously.

Chest Wall and Abdominal Excursion

Direct measurement of chest wall expansion can be used for objective data collection, intervention, or goal setting. Begin by placing a tape measure snugly around the circumference of the patient's chest wall at three levels:

1. Angle of Louis
2. Xyphoid process
3. Umbilicus

Measure the change in circumference in each of these areas with normal breathing and then deep breathing. The resulting values can be used to describe breathing patterns or identify ventilation impairments. Changes in these values after an intervention may indicate improvements in breathing patterns and can be used to evaluate treatment efficacy. Normal changes in breathing patterns exist in the supine, sitting, and standing positions.[21]

> **CLINICAL TIP**
>
> By placing your thumb tips together on the spinous processes or xyphoid process, you can estimate the distance of separation between your thumb tips to qualitatively measure chest wall motion.

Posture and Musculoskeletal Examination

Difficulty breathing can lead to trunk muscles shifting more support to respiration while decreasing their ability to function as posture muscles. In addition to abnormal thoracic pressures this change in function can lead to postural impairments. These impairments and poor alignment, in turn, do not allow for proper respiration mechanics. Particular attention should be paid to the examination of alignment, range of motion (ROM), flexibility, muscle balance and motor control of the shoulders, scapulae, spine, rib cage and pelvis.[22]

> **CLINICAL TIP**
>
> Writing goals that address pain and breathing mechanics can help justify musculoskeletal interventions for patients with high functional mobility.

Mediate Percussion

Mediate percussion can evaluate tissue densities within the thoracic cage and indirectly measure diaphragmatic excursion during respirations. Mediate percussion also can be used to confirm other findings in the physical examination. The procedure is shown in Fig. 4.6 and is performed by placing the palmar surface of the index finger, middle finger, or both from one hand

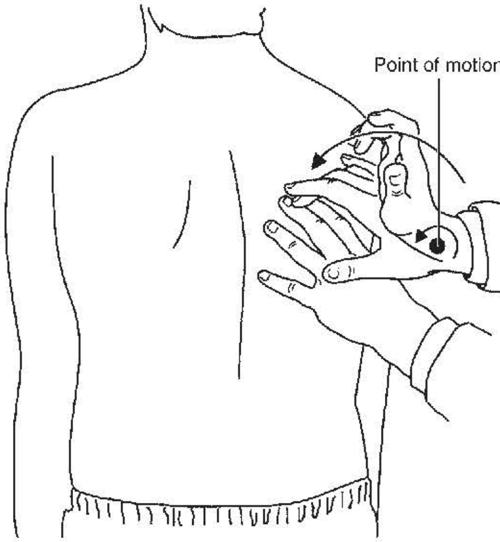

FIG. 4.6
Demonstration of mediate percussion technique. (From Hillegass EA, Sadowsky HS. *Essentials of Cardiopulmonary Physical Therapy.* 2nd ed. Philadelphia: Saunders; 2001.)

flatly against the surface of the chest wall within the intercostal spaces. The tip of the other index finger, middle finger, or a combination of both then strike the distal third of the fingers resting against the chest wall. The clinician proceeds from side to side in a cephalocaudal fashion, within the intercostal spaces, for anterior and posterior aspects of the chest wall. Mediate percussion is a difficult skill and is performed most proficiently by experienced clinicians; mediate percussion also can be performed over the abdominal cavity to assess tissue densities, which is described further in Chapter 8.

Sounds produced from mediate percussion can be characterized as one of the following:

- Resonant (over normal lung tissue)
- Hyperresonant (over emphysematous lungs or PTX)
- Tympanic (over gas bubbles in abdomen)
- Dull (from increased tissue density or lungs with decreased air)
- Flat (extreme dullness over very dense tissues, such as the thigh muscles)[15]

To evaluate diaphragmatic excursion with mediate percussion, the clinician first delineates the resting position of the diaphragm by percussing down the posterior aspect of one side of the chest wall until a change from resonant to dull (flat) sounds occurs. The clinician then asks the patient to inspire deeply and repeats the process, noting the difference in landmarks when sound changes occur. The difference is the amount of diaphragmatic excursion. The other side is also examined, and a comparison then can be made of the hemidiaphragms.[15,16]

Cough Examination

An essential component of airway clearance is cough effectiveness. The cough mechanism can be divided into four phases: (1) full inspiration, (2) closure of the glottis with an increase of intrathoracic pressure, (3) abdominal contraction, and (4) rapid expulsion of air. The inability to perform one or more portions of the cough mechanism can lead to impaired secretion clearance. Cough examination includes the following components[14,15]:

- Effectiveness (ability to clear secretions)
- Control (ability to start and stop coughs)
- Quality (wet, dry, bronchospastic)
- Frequency (how often during the day and night cough occurs)
- Sputum production (color, quantity, odor, and consistency)

The effectiveness of the patient's cough can be examined directly by simply asking the patient to cough or indirectly by observing the above components when the patient coughs spontaneously.

Hemoptysis

Hemoptysis, the expectoration of blood during coughing, may occur for many reasons. Hemoptysis is usually benign postoperatively if it is not sustained with successive coughs. The therapist should note whether the blood is dark red or brownish in color (old blood) or bright red (new or frank blood). The presence of new blood in sputum should be documented and the nurse or the physician notified.[23]

Patients with cystic fibrosis may have periodic episodes of hemoptysis with streaking or larger quantities of new blood. During these episodes airway clearance techniques (ACTs) may need to be modified. Current recommendations for patients who have scant hemoptysis (<5 mL) are to continue with all ACT, and those with massive hemoptysis (>240 mL) should discontinue all ACTs. For persons with mild to moderate hemoptysis (≥5 mL), no clear recommendations exist for continuing or discontinuing ACTs. However, expert consensus is that autogenic drainage and active cycle of breathing techniques are least likely to exacerbate hemoptysis while maintaining the needs of assisted sputum clearance.[23]

Diagnostic Testing

Oximetry

Pulse oximetry is a noninvasive method of determining arterial oxyhemoglobin saturation (SaO_2) through the measurement of the saturation of peripheral oxygen (SpO_2). It also indirectly examines the partial pressure of O_2. Finger or ear sensors generally are applied to the patient on a continuous or intermittent basis. O_2 saturation readings can be affected by poor circulation (cool digits), movement of sensor cord, cleanliness of the sensors, nail polish, intense light, increased levels of carboxyhemoglobin ($HbCO_2$), jaundice, skin pigmentation, shock states, cardiac dysrhythmias (e.g., atrial fibrillation), and severe hypoxia.[24,25]

CLINICAL TIP

To ensure accurate oxygen (O_2) saturation readings, (1) check for proper waveform or pulsations, which indicate proper signal reception, and (2) compare pulse readings on an O_2 saturation monitor with the patient's peripheral pulses or electrocardiography (ECG) readings (if available).