

The Respiratory System Outline

PART 1: FUNCTIONAL ANATOMY

22.1 The upper respiratory system warms, humidifies, and filters air (pp. 808–813; Figs. 22.1–22.4; Table 22.1)

A. The respiratory system includes the nose, nasal cavity, and paranasal sinuses; pharynx, larynx, trachea, and bronchi; and the lungs, which contain tiny air sacs, the alveoli. (p. 808; Fig. 22.1)

1. The upper respiratory system consists of structures from the nose to the larynx: The lower respiratory system includes the larynx, airways, and alveoli.

B. The Nose and Paranasal Sinuses (pp. 809–812; Figs. 22.2–22.3; Table 22.1)

1. The nose provides an airway for respiration; moistens, warms, filters, and cleans incoming air; provides a resonance chamber for speech; and houses olfactory receptors.

2. The external nose extends from the root between the eyebrows to the apex, and has two openings, the external nares.

3. The nasal cavity is divided along the midline by the nasal septum, and ends at the pharynx, exiting through two openings, the posterior nasal apertures, or choanae.

4. The roof of the nasal cavity is formed by bones of the skull; the floor consists of the hard and soft palate.

5. The anterior nasal cavity is lined with skin containing sebaceous sweat glands, and hairs; the remainder is lined with two types of mucous membranes:

a. The olfactory mucosa contains receptors for smell.

b. The respiratory mucosa has scattered goblet cells, for mucus production

6. Nasal conchae protrude into the nasal cavity from each lateral wall, increasing the mucosal surface exposure in order to filter, heat, and moisten air.

7. The nasal cavity is surrounded by paranasal sinuses within the frontal, maxillary, sphenoid, and ethmoid bones that serve to lighten the skull, warm and moisten air, and produce mucus.

C. The Pharynx (pp. 812–813; Fig. 22.4; Table 22.1)

1. The pharynx connects the nasal cavity and mouth superiorly to the larynx and esophagus inferiorly.

a. The nasopharynx serves as only an air passageway and contains the pharyngeal tonsil, which traps and destroys airborne pathogens.

b. The oropharynx is an air and food passageway that extends inferiorly from the level of the soft palate to the epiglottis and houses the palatine and lingual tonsils.

c. The laryngopharynx is an air and food passageway that lies directly posterior to the epiglottis, extends to the larynx, and is continuous inferiorly with the esophagus.

22.2 The lower respiratory system consists of conducting and respiratory zone structures (pp. 813–821; Figs. 22.4–22.12; Table 22.2)

A. The Larynx (pp. 814–816; Figs. 22.4–22.6; Table 22.2)

1. The larynx attaches superiorly to the hyoid bone, opening into the laryngopharynx, and attaches inferiorly to the trachea.
2. The larynx provides an open airway, routes food and air into the proper passageways, and produces sound through the vocal cords.
3. The larynx consists of hyaline cartilages: thyroid, cricoid, paired arytenoid, corniculate, and cuneiform; and the epiglottis, which is elastic cartilage.
 - a. The epiglottis is designed to close off the larynx during swallowing to prevent food or liquids from entering the airways.
 - b. The larynx houses vocal ligaments that form the true vocal cords, which vibrate as air passes over them to produce sound.
 - c. The vocal folds and the medial space between them are called the glottis.
4. Voice production involves the intermittent release of expired air and the opening and closing of the glottis.
 - a. As length and tension of the vocal folds change, pitch of the voice varies; generally, as tension increases, pitch becomes higher.
 - b. Loudness of the voice is determined by the force of the air forced over the vocal folds.
5. The larynx can act as a sphincter preventing air passage; Valsalva's maneuver is a behavior in which the glottis closes to prevent exhalation and the abdominal muscles contract, causing intra-abdominal pressure to rise.

B. The trachea, or windpipe, descends from the larynx through the neck into the mediastinum, where it terminates at the primary bronchi. (pp. 816–817; Figs. 22.7–22.8; Table 22.2)

1. The tracheal wall is similar to other tubular body structures, consisting of a mucosa, submucosa, and adventitia.
2. The trachea is lined with ciliated pseudostratified epithelium, designed to propel mucus upward toward the pharynx.
3. C-shaped cartilaginous rings associated with the connective tissue submucosa support the trachea, preventing collapse, while allowing the esophagus to expand normally during swallowing.
4. The trachealis is smooth muscle that decreases the trachea's diameter during contraction, increasing the force of air out of the lungs.

C. The Bronchi and Subdivisions (pp. 817–821; Figs. 22.8–22.11; Table 22.2)

1. The conducting zone consists of right and left primary bronchi that enter each lung and diverge into secondary bronchi that serve each lobe of the lungs.
2. Secondary bronchi branch into several orders of tertiary bronchi, which ultimately branch into bronchioles.
3. As the conducting airways become smaller, structural changes occur:
 - a. The supportive cartilage changes in character until it is no longer present in the bronchioles.
 - b. The mucosal epithelium transitions from pseudostratified columnar, to columnar, and finally, to cuboidal in the terminal bronchioles.

- c. The relative amount of smooth muscle in the walls increases, allowing significant changes in resistance to airflow in the smaller airways.
 - 4. The respiratory zone begins as the terminal bronchioles feed into respiratory bronchioles that terminate in alveolar ducts within clusters of alveolar sacs, which consist of alveoli.
 - a. The respiratory membrane consists of a single layer of squamous epithelium, type I alveolar cells, surrounded by a basal lamina.
 - b. The external surface of the alveoli are densely covered by a web of pulmonary capillaries; the capillary endothelium and the alveolar epithelium together form the respiratory membrane, across which gas exchange occurs.
 - c. Interspersed among the type I alveolar cells are cuboidal type II alveolar cells that secrete surfactant.
 - d. Alveoli are surrounded by elastic fibers, contain open alveolar pores, and have alveolar macrophages.
- 22.3 Each multi-lobed lung occupies its own pleural cavity (pp. 821–822; Fig. 21.12; Table 22.2)**
- A. The lungs occupy all of the thoracic cavity except for the mediastinum; each lung is suspended within its own pleural cavity and connected to the mediastinum by vascular and bronchial attachments called the lung root. (821–822; Fig 21.12; Table 22.2)
 - 1. The left lung is smaller than the right because the position of the heart is shifted slightly to the left; each lung is divided into lobes, separated from each other by fissures.
 - 2. Each lobe contains a number of bronchopulmonary segments, each served by its own artery, vein, and tertiary bronchus.
 - 3. Lung tissue consists largely of air spaces, with the balance of lung tissue, its stroma, composed mostly of elastic connective tissue.
 - B. Blood Supply and Innervation of the Lungs (p. 822)
 - 1. There are two circulations that serve the lungs: the pulmonary network carries systemic blood to the lungs for oxygenation, and the bronchial arteries provide systemic blood to the lung tissue.
 - 2. The lungs are innervated by parasympathetic and sympathetic motor fibers that constrict or dilate the airways, as well as visceral sensory fibers.
 - C. The pleurae form a thin, double-layered serosa. (p. 822; Table 22.2)
 - 1. The parietal pleura covers the thoracic wall, superior face of the diaphragm, and continues around the heart between the lungs.
 - 2. The visceral pleura covers the external lung surface, following its contours and fissures.
 - 3. Pleural fluid lubricates the space between the pleurae to allow friction-free movement during breathing.
 - 4. The pleurae divide the thoracic cavity into three discrete chambers, preventing one organ's movement from interfering with another's, as well as limiting the spread of infection.

PART 2: RESPIRATORY PHYSIOLOGY

- 22.4 Volume changes cause pressure changes, which cause air to move (pp. 823–828; Figs. 22.13–22.17; Table 22.2)**

- A. Respiratory pressures are described relative to atmospheric pressures: a negative pressure indicates that the respiratory pressure is lower than atmospheric pressure. (pp. 823–824; Figs. 22.13–22.14)
1. Intrapulmonary pressure is the pressure in the alveoli, which rises and falls during respiration, but always eventually equalizes with atmospheric pressure.
 2. Intrapleural pressure is the pressure in the pleural cavity. It also rises and falls during respiration, but is always about 4 mm Hg less than intrapulmonary pressure.
 - a. The negative intrapleural pressure is due to the opposition of two forces: the recoil force and surface tension of alveolar fluid in the lungs versus the natural tendency of the chest wall to pull outward.
 - b. Neither force overcomes the other due to the fluid adhesion between the pleural membranes created by the presence of pleural fluid.
 3. Transpulmonary pressure is the difference between intrapulmonary and intrapleural pressure: the greater the transpulmonary pressure, the larger the lung volume.
- B. Pulmonary Ventilation (pp. 824–826; Figs. 22.15–22.16)
1. Pulmonary ventilation is a mechanical process causing gas flow into and out of the lungs according to volume changes in the thoracic cavity.
 - a. Boyle's law states that at a constant temperature, the pressure of a gas varies inversely with its volume: Pressure changes lead to gas flow.
 2. During quiet inspiration, the diaphragm and intercostals contract, resulting in an increase in thoracic volume, which causes intrapulmonary pressure to drop below atmospheric pressure, and air flows into the lungs.
 3. During forced inspiration, accessory muscles of the neck and thorax contract, increasing thoracic volume beyond the increase in volume during quiet inspiration.
 4. Quiet expiration is a passive process that relies mostly on elastic recoil of the lungs as the thoracic muscles relax.
 5. Forced expiration is an active process relying on contraction of abdominal muscles to increase intra-abdominal pressure and depress the rib cage.
 6. Nonrespiratory air movements cause movement of air into or out of the lungs, but are not related to breathing (coughing, sneezing, crying, laughing, hiccups, and yawning).
- C. Physical Factors Influencing Pulmonary Ventilation (pp. 826–828; Fig. 22.17)
1. Airway resistance is the friction encountered by air in the airways; gas flow is reduced as airway resistance increases.
 - a. Airway resistance is mostly insignificant for two reasons: upper airways are very large diameter, and lower airways, while smaller, are very numerous.
 2. Alveolar surface tension due to water in the alveoli acts to draw the walls of the alveoli together, presenting a force that must be overcome in order to expand the lungs.
 - a. Surfactant, produced by type II alveolar cells, reduces alveolar surface tension to an optimal amount.

3. Lung compliance is determined by distensibility of lung tissue and the surrounding thoracic cage and alveolar surface tension.
 - a. Any decrease in resilience reduces compliance; factors such as chronic inflammation, the presence of nonelastic scar tissue, or decreased surfactant can reduce resilience of the lungs.

22.5 Measuring respiratory volumes, capacities, and flow rates helps us assess ventilation (pp. 828–830; Fig. 22.18; Table 20.3)

A. Respiratory Volumes (p. 828; Fig. 22.18)

1. Tidal volume (TV) is the amount of air that moves in and out of the lungs with each breath during quiet breathing and averages 500 ml per breath.
2. The inspiratory reserve volume (IRV) is the amount of air that can be forcibly inspired beyond the tidal volume (2100–3200 ml).
3. The expiratory reserve volume (ERV) is the amount of air that can be evacuated from the lungs after tidal expiration (1000–1200 ml).
4. Residual volume (RV) is the amount of air that remains in the lungs after maximal forced expiration (about 1200 ml).

B. Respiratory capacities are sums of multiple respiratory volumes. (p. 828; Fig. 22.18)

1. Inspiratory capacity (IC) is the sum of tidal volume and inspiratory reserve volume and represents the total amount of air that can be inspired after a tidal expiration.
2. Functional residual capacity (FRC) is the combined residual volume and expiratory reserve volume and represents the amount of air that remains in the lungs after a tidal expiration.
3. Vital capacity (VC) is the sum of tidal volume, inspiratory reserve, and expiratory reserve volumes and is the total amount of exchangeable air.
4. Total lung capacity (TLC) is the sum of all lung volumes.

C. The anatomical dead space is the volume of the conducting zone conduits, roughly 150 ml, a volume that never contributes to gas exchange in the lungs. (pp. 828–829; Fig. 22.18)

D. Pulmonary function tests evaluate losses in respiratory function using a spirometer to distinguish between obstructive and restrictive pulmonary disorders. (pp. 829–830)

1. Obstructive pulmonary diseases involve hyperinflation of the lungs and are characterized by increased TLC, FRC, and RV, due to hyperinflation of the lungs.
2. Restrictive pulmonary disorders, in which expansion of the lungs is limited, display low VC, TLC, FRC, and RV, due to reduced expansion of the lungs.
3. Forced vital capacity (FVC) and forced expiratory volume (FEV) are values that indicate the rate that air moves into and out of the lungs: obstructive and restrictive disorders differ in the rate of FEV and amount of FVC.

E. Alveolar ventilation is the volume of air flowing into or out of the respiratory tract per minute, and averages 6 L/min in healthy adults. (p. 830; Table 22.3)

22.6 Gases exchange by diffusion among the blood, lungs, and tissues (pp. 830–834; Figs. 22.19–22.21; Table 22.4)

- A. Gases have basic properties, as defined by Dalton's law of partial pressures and Henry's law. (pp. 831-831)
1. Dalton's law of partial pressures reveals how a gas behaves in a mixture of gases, and states that the total pressure exerted by a mixture of gases is the sum of the pressures exerted by each gas in the mixture.
 2. Henry's law describes how gases move into and out of solution, and states that when a mixture of gases is in contact with a liquid, each gas will dissolve in the liquid in proportion to its partial pressure.
- B. The composition of alveolar gas differs significantly from atmospheric gas due to gas exchange occurring in the lungs, humidification of air by conducting passages, and mixing of alveolar gas that occurs with each breath. (p. 831; Table 22.4)
- C. External Respiration (pp. 831-834; Figs. 22.19-22.20)
1. External respiration involves O_2 uptake and CO_2 unloading from hemoglobin in red blood cells, and is influenced by three factors: gas partial pressure gradients and solubilities, thickness and surface area of the respiratory membrane, and ventilation-perfusion coupling.
 - a. A steep partial pressure gradient exists between blood in the pulmonary arteries and alveoli, and O_2 diffuses rapidly from the alveoli into the blood, until it reaches equilibrium at P_{O_2} of 104 mm Hg: Carbon dioxide moves in the opposite direction along a partial pressure gradient that is much less steep, reaching equilibrium at 40 mm Hg.
 2. The respiratory membrane is normally very thin and presents a huge surface area for efficient gas exchange.
 3. Ventilation-perfusion coupling ensures a close match between the amount of gas reaching the alveoli and the blood flow in the pulmonary capillaries.
 - a. In order to optimize perfusion and maximize oxygen uptake into the blood, arterioles feeding areas with low P_{O_2} constrict, while arterioles serving well ventilated areas dilate.
 - b. To increase ventilation so that there can be more rapid elimination of CO_2 from the body, bronchioles serving areas with high alveolar CO_2 dilate, but in areas with low CO_2 , bronchioles constrict.
 - c. Ventilation and perfusion are balanced so that they work together to make O_2 and CO_2 levels match physiological demands.
- D. Internal Respiration (p. 834; Fig. 22.21)
1. While the diffusion gradients for oxygen and carbon dioxide are reversed from those for external respiration and pulmonary gas exchange, the factors promoting gas exchange are identical.
 - a. The partial pressure of oxygen in the tissues is always lower than the blood, so oxygen diffuses readily into the tissues, while a similar but less dramatic gradient exists in the reverse direction for carbon dioxide.
- 22.7 Oxygen is transported by hemoglobin, and carbon dioxide is transported in three different ways (pp. 834-840; Figs. 22.22-22.23; Focus Figure 22.1)

- A. Oxygen Transport (pp. 834–838; Fig. 22.22; Focus Figure 22.1)
1. Because molecular oxygen is poorly soluble in the blood, only 1.5% is dissolved in plasma, while the remaining 98.5% must be carried on hemoglobin.
 - a. Up to four oxygen molecules can be reversibly bound to a molecule of hemoglobin—one oxygen on each iron.
 - b. The affinity of hemoglobin for oxygen changes with each successive oxygen that is bound or released, making oxygen loading and unloading very efficient.
 2. At higher plasma partial pressures of oxygen, hemoglobin unloads little oxygen, but if plasma partial pressure falls dramatically, such as during vigorous exercise, much more oxygen can be unloaded to the tissues.
 3. Other factors—temperature, blood pH, P_{CO_2} , and the amount of BPG in the blood—influence hemoglobin saturation at a given partial pressure.
- B. Carbon Dioxide Transport (pp. 838–840; Fig. 22.23)
1. Carbon dioxide is transported in the blood in three ways: 7–10% is dissolved in plasma, 20% is carried on hemoglobin bound to globins, and 70% exists as bicarbonate, an important buffer of blood pH.
 2. The Haldane effect encourages CO_2 exchange in the lungs and tissues: the drop in P_{O_2} at the tissues allows Hb to carry more CO_2 , while the rise in P_{O_2} in the lungs encourages Hb to release CO_2 .
 3. The carbonic acid–bicarbonate buffer system of the blood is formed when CO_2 combines with water and dissociates, producing carbonic acid and bicarbonate ions that can release or absorb hydrogen ions.

22.8 Respiratory centers in the brain stem control breathing with input from chemoreceptors and higher brain centers (pp. 840–845; Figs. 22.24–22.27)

- A. Neural Mechanisms (pp. 840–841; Fig. 22.24)
1. Two areas of the medulla oblongata are critically important to respiration: the ventral respiratory group (VRG), and the dorsal respiratory group (DRG).
 - a. The ventral respiratory group (VRG) is a rhythm-generating and integration center containing separate groups of neurons, some that fire during inhalation and others that fire during exhalation, that control contraction of the diaphragm and external intercostals.
 - b. The dorsal respiratory group (DRG) integrates input from peripheral stretch and chemoreceptors, and communicates information to the ventral respiratory group (VRG).
 2. The pontine respiratory group within the pons modifies the breathing rhythm and prevents overinflation of the lungs through an inhibitory action on the medullary respiration centers.
 3. It is likely that reciprocal inhibition on the part of the different respiratory centers is responsible for the rhythm of breathing.
- B. Factors Influencing Breathing Rate and Depth (pp. 841–845; Figs. 22.25–22.27)

1. The most important factors influencing breathing rate and depth are changing levels of CO_2 , O_2 , and H^+ in arterial blood.
 - a. The receptors monitoring fluctuations in these parameters are the central chemoreceptors in the medulla oblongata and the peripheral chemoreceptors in the aortic arch and carotid arteries.
 - b. Rising plasma P_{CO_2} results in an increase in free H^+ , exciting the central chemoreceptors, which, in turn, stimulate regulatory respiratory centers to cause an increase in breathing rate and depth.
 - c. Peripheral chemoreceptors are sensitive to arterial PO_2 but, arterial PO_2 must drop substantially before oxygen levels become a major stimulus for increased ventilation, due to the large reserves of O_2 carried on the hemoglobin.
 - d. Changes in arterial pH due to metabolic causes, detected through peripheral chemoreceptors, can result in changed breathing rate and depth, in order to return blood pH to normal.
2. Higher brain centers alter rate and depth of respiration.
 - a. The hypothalamus and the rest of the limbic system, in response to strong emotions and pain, signal respiratory centers to modify respiratory rate and depth.
 - b. The cerebral cortex can exert conscious control over ventilation behavior by bypassing the medullary centers and directly stimulating the respiratory muscles.
3. Pulmonary irritant reflexes respond to inhaled irritants in the nasal passages or trachea by causing reflexive bronchoconstriction in the respiratory airways.
4. The inflation, or Hering-Breuer, reflex is activated by stretch receptors in the visceral pleurae and conducting airways, protecting the lungs from overexpansion by inhibiting inspiration.

22.9 Exercise and high altitude bring about respiratory adjustments (pp. 845–846)

A. Exercise (pp. 845–846)

1. During vigorous exercise, deeper and more vigorous respirations, called hyperpnea, ensure that tissue demands for oxygen are met.
2. Three neural factors contribute to the change in respiration: psychological stimuli, cortical stimulation of skeletal muscles and respiratory centers, and excitatory impulses to the respiratory areas from active muscles, tendons, and joints.

B. High Altitude (p. 846)

1. Acute mountain sickness (AMS) may result from a rapid transition from sea level to altitudes above 8000 feet.
2. A long-term change from sea level to high altitudes results in acclimatization of the body, including an increase in ventilation rate, lower than normal hemoglobin saturation, and increased production of erythropoietin.

22.10 Lung diseases are major causes of disability and death (pp. 846–848; Fig. 22.28)

- A. Chronic obstructive pulmonary diseases (COPD) are seen in patients that have a history of smoking and result in progressive dyspnea, coughing and frequent pulmonary infections, and respiratory failure. (pp. 846–847; Fig. 22.28)
 - 1. Obstructive emphysema is characterized by permanently enlarged alveoli and deterioration of alveolar walls.
 - 2. Chronic bronchitis results in excessive mucus production, as well as inflammation and fibrosis of the lower respiratory mucosa.
- B. Asthma is characterized by coughing, dyspnea, wheezing, and chest tightness brought on by active inflammation of the airways. (p. 847)
- C. Tuberculosis (TB) is an infectious disease caused by the bacterium *Mycobacterium tuberculosis* and is spread by coughing and inhalation. (pp. 847–848)
- D. Lung Cancer (p. 848)
 - 1. In both sexes, lung cancer is the most common type of malignancy and is strongly correlated with smoking.
 - 2. Adenocarcinoma originates in peripheral lung areas as nodules that develop from bronchial glands and alveolar cells.
 - 3. Squamous cell carcinoma arises in the epithelium of the bronchi and tends to form masses that hollow out and bleed.
 - 4. Small cell carcinoma contains lymphocyte-like cells that form clusters within the mediastinum and rapidly metastasize.

Developmental Aspects of the Respiratory System (pp. 848–849; Fig. 22.29)

- A. By the fourth week of development, the olfactory placodes are present and give rise to olfactory pits that form the nasal cavities, which extend posteriorly to join the developing pharynx. (p. 848; Fig. 22.29)
- B. The lower respiratory organs develop from the endoderm of the foregut, which gives rise to an outpocketing called the laryngotracheal bud: This outpocketing forms the tracheal lining, and mucosae of the bronchi and alveoli. (p. 848; Fig. 22.29)
- C. As a fetus, the lungs are filled with fluid, and vascular shunts are present that divert blood away from the lungs; at birth, the fluid drains away, and rising plasma P_{CO_2} stimulates respiratory centers. (p. 848)
- D. Respiratory rate is highest in newborns, and gradually declines in adulthood; in old age, respiratory rate increases again. (p. 849)
- E. As we age, the thoracic wall becomes more rigid, the lungs lose elasticity, and the amount of oxygen we can use during aerobic respiration decreases. (p. 849)
- F. The number of mucus glands and blood flow in the nasal mucosa decline with age, as do ciliary action of the mucosa and macrophage activity. (p. 849)