Welcome to

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Faculty of Health Sciences
Health Science Courses

Respiratory System

- Consists of the respiratory and conducting zones
- Respiratory zone
  - Site of gas exchange
  - Consists of bronchioles, alveolar ducts, and alveoli
- Conducting zone
  - Provides rigid conduits for air to reach the sites of gas exchange
  - Includes all other respiratory structures (e.g., nose, nasal cavity, pharynx, trachea)
- Respiratory muscles – diaphragm and other muscles that promote ventilation

Respiratory System

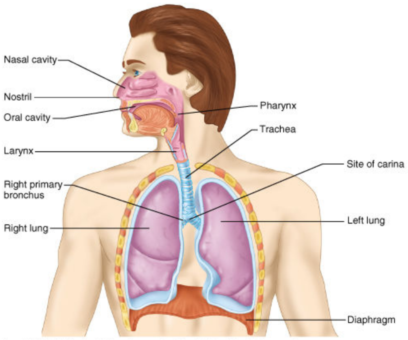


Figure 21.1

Major Functions of the Respiratory System

- To supply the body with oxygen and dispose of carbon dioxide
- Respiration – four distinct processes must happen
  - Pulmonary ventilation – moving air into and out of the lungs
  - External respiration – gas exchange between the lungs and the blood
  - Transport – transport of oxygen and carbon dioxide between the lungs and tissues
  - Internal respiration – gas exchange between systemic blood vessels and tissues

Conducting Zone: Bronchi

- The carina of the last tracheal cartilage marks the end of the trachea and the beginning of the right and left bronchi
- Air reaching the bronchi is:
  - Warm and cleansed of impurities
  - Saturated with water vapor
- Bronchi subdivide into secondary bronchi, each supplying a lobe of the lungs
- Air passages undergo 23 orders of branching in the lungs

Conducting Zone: Bronchial Tree

- Tissue walls of bronchi mimic that of the trachea
- As conducting tubes become smaller, structural changes occur
  - Cartilage support structures change
  - Epithelium types change
  - Amount of smooth muscle increases
- Bronchioles:
  - Consist of cuboidal epithelium
  - Have a complete layer of circular smooth muscle
  - Lack cartilage support and mucus-producing cells

Respiratory Zone

- Defined by the presence of alveoli; begins as terminal bronchioles feed into respiratory bronchioles
- Respiratory bronchioles lead to alveolar ducts, then to terminal clusters of alveolar sacs composed of alveoli
- Approximately 300 million alveoli:
  - Account for most of the lungs' volume
  - Provide tremendous surface area for gas exchange

Respiratory Zone

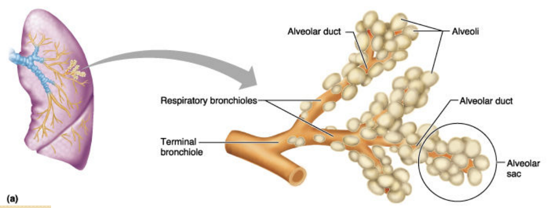


Figure 21.8

Respiratory Membrane

- This air-blood barrier is composed of:
  - Alveolar and capillary walls
  - Their fused basal laminas
- Alveolar walls:
  - Are a single layer of type I epithelial cells
  - Permit gas exchange by simple diffusion
  - Secrete *angiotensin converting enzyme* (ACE)
- Type II cells secrete surfactant

Respiratory Membrane

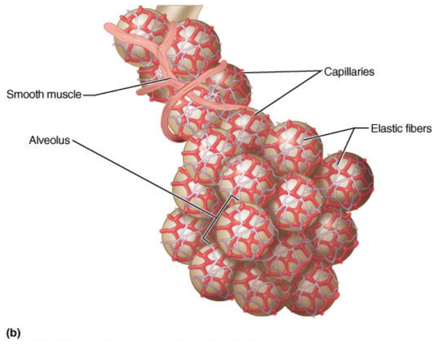


Figure 21.9b

Respiratory Membrane

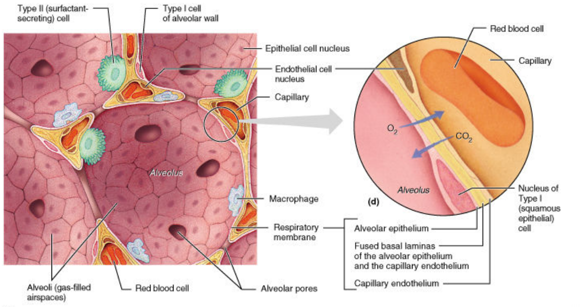


Figure 21.9c, d

Alveoli

- Surrounded by fine elastic fibers
- Contain open pores that:
  - Connect adjacent alveoli
  - Allow air pressure throughout the lung to be equalized
- House macrophages that keep alveolar surfaces sterile

Alveoli

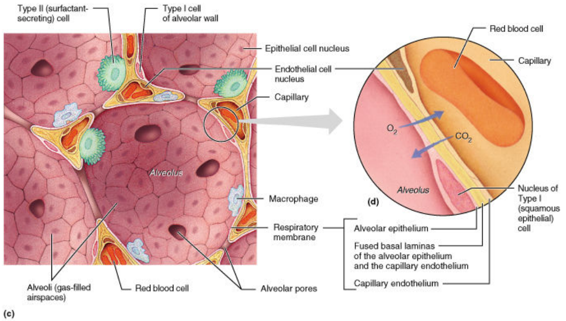


Figure 21.9c, d

Gross Anatomy of the Lungs

- Lungs occupy all of the thoracic cavity except the mediastinum
  - Root – site of vascular and bronchial attachments
  - Costal surface – anterior, lateral, and posterior surfaces in contact with the ribs
  - Apex – narrow superior tip
  - Base – inferior surface that rests on the diaphragm
  - Hilus – indentation that contains pulmonary and systemic blood vessels

Lungs

- Cardiac notch (impression) – cavity that accommodates the heart
- Left lung – separated into upper and lower lobes by the oblique fissure
- Right lung – separated into three lobes by the oblique and horizontal fissures
- There are 10 bronchopulmonary segments in each lung

Blood Supply to Lungs

- Lungs are perfused by two circulations: pulmonary and bronchial
- Pulmonary arteries – supply systemic venous blood to be oxygenated
  - Branch profusely, along with bronchi
  - Ultimately feed into the pulmonary capillary network surrounding the alveoli
- Pulmonary veins – carry oxygenated blood from respiratory zones to the heart

Bronchial Circulation

- Bronchial arteries – provide systemic blood to the lung tissue
  - Arise from aorta and enter the lungs at the hilus
  - Supply all lung tissue except the alveoli
- Bronchial veins anastomose with pulmonary veins
- Pulmonary veins carry most venous blood back to the heart

Pleurae

- Thin, double-layered serosa
- Parietal pleura
  - Covers the thoracic wall and superior face of the diaphragm
  - Continues around heart and between lungs
- Visceral, or pulmonary, pleura
  - Covers the external lung surface
  - Divides the thoracic cavity into three chambers
    - The central mediastinum
    - Two lateral compartments, each containing a lung

Breathing

- Breathing, or pulmonary ventilation, consists of two phases
  - Inspiration – air flows into the lungs
  - Expiration – gases exit the lungs

Pressure Relationships in the Thoracic Cavity

- Respiratory pressure is always described relative to atmospheric pressure
- Atmospheric pressure (P_{atm})
  - Pressure exerted by the air surrounding the body
  - Negative respiratory pressure is less than P_{atm}
  - Positive respiratory pressure is greater than P_{atm}
- Intrapulmonary pressure (P_{alv}) – pressure within the alveoli
- Intrapleural pressure (P_{ip}) – pressure within the pleural cavity

Pressure Relationships

- Intrapulmonary pressure and intrapleural pressure fluctuate with the phases of breathing
- Intrapulmonary pressure always eventually equalizes itself with atmospheric pressure
- Intrapleural pressure is always less than intrapulmonary pressure and atmospheric pressure

Pressure Relationships

- Two forces act to pull the lungs away from the thoracic wall, promoting lung collapse
  - Elasticity of lungs causes them to assume smallest possible size
  - Surface tension of alveolar fluid draws alveoli to their smallest possible size
- Opposing force – elasticity of the chest wall pulls the thorax outward to enlarge the lungs

Pressure Relationships

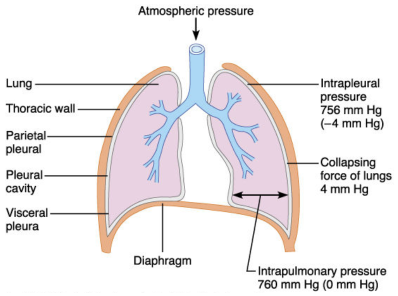


Figure 21.12

Lung Collapse

- Caused by equalization of the intrapleural pressure with the intrapulmonary pressure
- Transpulmonary pressure keeps the airways open
  - Transpulmonary pressure – difference between the intrapulmonary and intrapleural pressures ($P_{alv} – P_{ip}$)

Pulmonary Ventilation

- A mechanical process that depends on volume changes in the thoracic cavity
- Volume changes lead to pressure changes, which lead to the flow of gases to equalize pressure

$\Delta V \rightarrow \Delta P \rightarrow$ F (flow of gases)

Boyle's Law

- Boyle's law – the relationship between the pressure and volume of gases

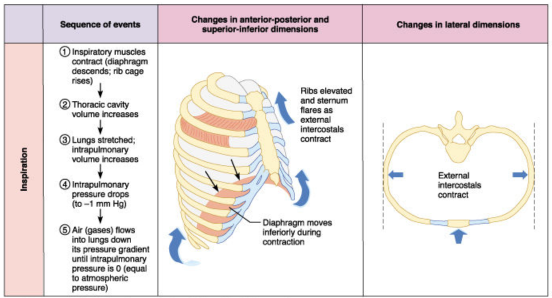
$$P_1V_1 = P_2V_2$$

  - P = pressure of a gas in mm Hg
  - V = volume in cubic millimeters
  - Subscripts 1 and 2 represent the initial and resulting conditions, respectively

Inspiration

- The diaphragm and external intercostal muscles (inspiratory muscles) contract and the rib cage rises
- The lungs are stretched and intrapulmonary volume increases
- Intrapulmonary pressure drops below atmospheric pressure (−1 mm Hg)
- Air flows into the lungs, down its pressure gradient, until intrapleural pressure = atmospheric pressure

Inspiration



① Inspiratory muscles contract (diaphragm descends; rib cage rises)

② Thoracic cavity volume increases

③ Lungs stretched; intrapulmonary volume increases

④ Intrapulmonary pressure drops (to −1 mm Hg)

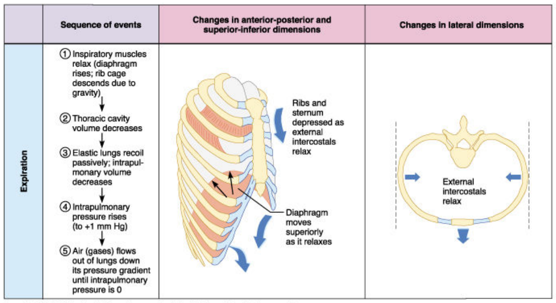
⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure)

Figure 21.13.1

Expiration

- Inspiratory muscles relax and the rib cage descends due to gravity
- Thoracic cavity volume decreases
- Elastic lungs recoil passively and intrapulmonary volume decreases
- Intrapulmonary pressure rises above atmospheric pressure (+1 mm Hg)
- Gases flow out of the lungs down the pressure gradient until intrapulmonary pressure is 0

Expiration



① Inspiratory muscles relax (diaphragm rises; rib cage descends due to gravity)

② Thoracic cavity volume decreases

③ Elastic lungs recoil passively; intrapulmonary volume decreases

④ Intrapulmonary pressure rises (to +1 mm Hg)

⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0

Figure 21.13.2

Physical Factors Influencing Ventilation: Airway Resistance

- Friction is the major nonelastic source of resistance to airflow
- The relationship between flow (F), pressure (P), and resistance (R) is:

$$F = \frac{\Delta P}{R}$$

Physical Factors Influencing Ventilation: Airway Resistance

- The amount of gas flowing into and out of the alveoli is directly proportional to ΔP, the pressure gradient between the atmosphere and the alveoli

$$\Delta P = \Delta\ (P_{atm} - P_{alv})$$

- Gas flow is inversely proportional to resistance with the greatest resistance being in the medium-sized bronchi

Physical Factors Influencing Ventilation: Airway Resistance

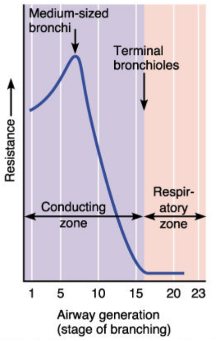


Figure 21.15

Airway Resistance

- As airway resistance rises, breathing movements become more strenuous
- Severely constricted or obstructed bronchioles:
  - Can prevent life-sustaining ventilation
  - Can occur during acute asthma attacks, which stops ventilation
- Epinephrine release via the sympathetic nervous system dilates bronchioles and reduces air resistance

Alveolar Surface Tension

- Surface tension – the attraction of liquid molecules for one another at a liquid-gas interface
- The liquid coating the alveolar surface is always acting to reduce the alveoli to the smallest possible size
- Surfactant, a detergent-like complex, reduces surface tension and helps keep the alveoli from collapsing

Lung Compliance

- The ease with which lungs can be expanded
- Specifically, the measure of the change in lung volume that occurs with a given change in transpulmonary pressure
- Determined by two main factors
  - Distensibility of the lung tissue and surrounding thoracic cage
  - Surface tension of the alveoli

Factors That Diminish Lung Compliance

- Scar tissue or fibrosis that reduces the natural resilience of the lungs
- Blockage of the smaller respiratory passages with mucus or fluid
- Reduced production of surfactant
- Decreased flexibility of the thoracic cage or its decreased ability to expand
- Examples include:
  - Deformities of thorax
  - Ossification of the costal cartilage
  - Paralysis of intercostal muscles

Respiratory Volumes

- Tidal volume (TV) – air that moves into and out of the lungs with each breath (approximately 500 ml)
- Inspiratory reserve volume (IRV) – air that can be inspired forcibly beyond the tidal volume (2100–3200 ml)
- Expiratory reserve volume (ERV) – air that can be evacuated from the lungs after a tidal expiration (1000–1200 ml)
- Residual volume (RV) – air left in the lungs after strenuous expiration (1200 ml)

Respiratory Capacities

- Inspiratory capacity (IC) – total amount of air that can be inspired after a tidal expiration (IRV + TV)
- Functional residual capacity (FRC) – amount of air remaining in the lungs after a tidal expiration (RV + ERV)
- Vital capacity (VC) – the total amount of exchangeable air (TV + IRV + ERV)
- Total lung capacity (TLC) – sum of all lung volumes (approximately 6000 ml in males)

Dead Space

- Anatomical dead space – volume of the conducting respiratory passages (150 ml)
- Alveolar dead space – alveoli that cease to act in gas exchange due to collapse or obstruction
- Total dead space – sum of alveolar and anatomical dead spaces

Pulmonary Function Tests

- Spirometer – an instrument consisting of a hollow bell inverted over water, used to evaluate respiratory function
- Spirometry can distinguish between:
  - Obstructive pulmonary disease – increased airway resistance
  - Restrictive disorders – reduction in total lung capacity from structural or functional lung changes

Pulmonary Function Tests

- Total ventilation – total amount of gas flow into or out of the respiratory tract in one minute
- Forced vital capacity (FVC) – gas forcibly expelled after taking a deep breath
- Forced expiratory volume (FEV) – the amount of gas expelled during specific time intervals of the FVC
- Increases in TLC, FRC, and RV may occur as a result of obstructive disease
- Reduction in VC, TLC, FRC, and RV result from restrictive disease

Alveolar Ventilation

- Alveolar ventilation rate (AVR) – measures the flow of fresh gases into and out of the alveoli during a particular time

AVR	=	frequency	X	(TV – dead space)
(ml/min)		(breaths/min)		(ml/breath)

- Slow, deep breathing increases AVR and rapid, shallow breathing decreases AVR

Nonrespiratory Air Movements

- Most result from reflex action
- Examples include: coughing, sneezing, crying, laughing, hiccuping, and yawning

Basic Properties of Gases: Dalton's Law of Partial Pressures

- Total pressure exerted by a mixture of gases is the sum of the pressures exerted independently by each gas in the mixture
- The partial pressure of each gas is directly proportional to its percentage in the mixture

Basic Properties of Gases: Henry's Law

- When a mixture of gases is in contact with a liquid, each gas will dissolve in the liquid in proportion to its partial pressure
- The amount of gas that will dissolve in a liquid also depends upon its solubility
- Various gases in air have different solubilities
  - Carbon dioxide is the most soluble
  - Oxygen is 1/20th as soluble as carbon dioxide
  - Nitrogen is practically insoluble in plasma

Composition of Alveolar Gas

- The atmosphere is mostly oxygen and nitrogen, while alveoli contain more carbon dioxide and water vapor
- These differences result from:
  - Gas exchanges in the lungs – oxygen diffuses from the alveoli and carbon dioxide diffuses into the alveoli
  - Humidification of air by the conducting pathways
  - The mixing of alveolar gas that occurs with each breath

External Respiration: Pulmonary Gas Exchange

- Factors influencing the movement of oxygen and carbon dioxide across the respiratory membrane
  - Partial pressure gradients and gas solubilities
  - Matching of alveolar ventilation and pulmonary blood perfusion
  - Structural characteristics of the respiratory membrane

Partial Pressure Gradients and Gas Solubilities

- The partial pressure oxygen (PO_2) of venous blood is 40 mm Hg; the partial pressure in the alveoli is
  104 mm Hg
  - This steep gradient allows oxygen partial pressures to rapidly reach equilibrium (in 0.25 seconds), and thus blood can move three times as quickly (0.75 seconds) through the pulmonary capillary and still be adequately oxygenated

Partial Pressure Gradients and Gas Solubilities

- Although carbon dioxide has a lower partial pressure gradient:
  - It is 20 times more soluble in plasma than oxygen
  - It diffuses in equal amounts with oxygen

Partial Pressure Gradients

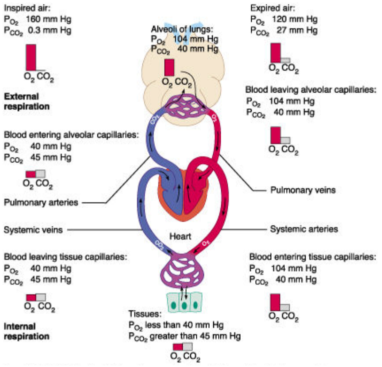


Figure 21.17

Oxygenation of Blood

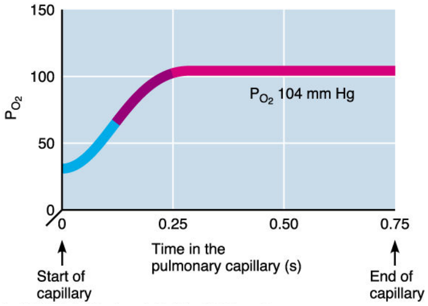


Figure 21.18

Ventilation-Perfusion Coupling

- Ventilation – the amount of gas reaching the alveoli
- Perfusion – the blood flow reaching the alveoli
- Ventilation and perfusion must be tightly regulated for efficient gas exchange
- Changes in P_{CO2} in the alveoli cause changes in the diameters of the bronchioles
  - Passageways servicing areas where alveolar carbon dioxide is high *dilate*
  - Those serving areas where alveolar carbon dioxide is low *constrict*

Ventilation-Perfusion Coupling

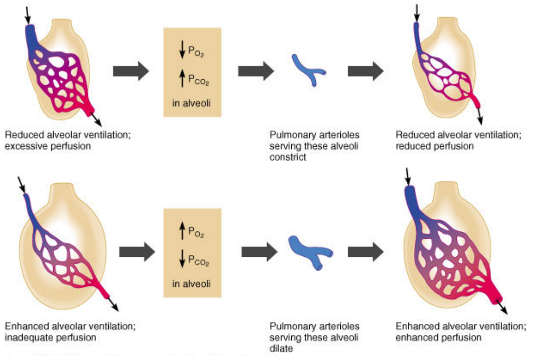


Figure 21.19

Surface Area and Thickness of the Respiratory Membrane

- Respiratory membranes:
  - Are only 0.5 to 1 μm thick, allowing for efficient gas exchange
  - Have a total surface area (in males) of 50–70 m^2 (40 times that of one's skin)
  - Thicken if lungs become waterlogged and edematous, whereby gas exchange is inadequate and oxygen deprivation results
  - Decrease in surface area with emphysema, when walls of adjacent alveoli break

Internal Respiration

- The factors promoting gas exchange between systemic capillaries and tissue cells are the same as those acting in the lungs
  - The partial pressures and diffusion gradients are reversed
  - P_{O2} in tissue is always lower than in systemic arterial blood
  - P_{O2} of venous blood draining tissues is 40 mm Hg and P_{CO2} is 45 mm Hg

Oxygen Transport

- Molecular oxygen is carried in the blood bound to hemoglobin (Hb) within red blood cells and dissolved in plasma
  - Each hemoglobin molecule binds 4 oxygen in a rapid and reversible process
  - The hemoglobin-oxygen combination is called *oxyhemoglobin* (HbO_2)
- Hemoglobin that has released oxygen is called *reduced hemoglobin* (HHb)

$$\underset{\text{Tissues}}{\overset{\text{Lungs}}{HHb + O_2 \leftrightarrow HbO_2 + H^+}}$$

Hemoglobin (Hb)

- Saturated hemoglobin – when all four hemes of the molecule are bound to oxygen
- Partially saturated hemoglobin – when one to three hemes are bound to oxygen
- The rate in which hemoglobin binds and releases oxygen is regulated by:
  - P_{O2}, temperature, blood pH, P_{CO2}, and the concentration of BPG (an organic chemical)
    - These factors ensure adequate delivery of oxygen to tissue cells

Influence of P_{O2} on Hemoglobin Saturation

- Hemoglobin saturation plotted against P_{O2} produces a oxygen-hemoglobin dissociation curve
- 98% saturated arterial blood contains 20 ml oxygen per 100 ml blood (20 vol %)
- As arterial blood flows through capillaries, 5 ml oxygen are released
- The saturation of hemoglobin in arterial blood explains why breathing deeply increases the P_{O2} but has little effect on oxygen saturation in hemoglobin

Hemoglobin Saturation Curve

- Hemoglobin is almost completely saturated at a P_{O2} of 70 mm Hg
- Further increases in P_{O2} produce only small increases in oxygen binding
- Oxygen loading and delivery to tissue is adequate when P_{O2} is below normal levels
- Only 20–25% of bound oxygen is unloaded during one systemic circulation
- If oxygen levels in tissues drop:
  - More oxygen dissociates from hemoglobin and is used by cells
  - Respiratory rate or cardiac output need not increase

Hemoglobin Saturation Curve

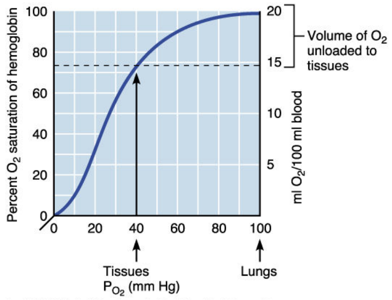


Figure 21.20

Other Factors Influencing Hemoglobin Saturation

- Temperature, H^+, P_{CO2}, and BPG:
  - Modify the structure of hemoglobin and alter its affinity for oxygen
  - Increase:
    - Decrease hemoglobin's affinity for oxygen
    - Enhance oxygen unloading from the blood
  - Decrease act in the opposite manner
- These parameters are all high in systemic capillaries where oxygen unloading is the goal

Other Factors Influencing Hemoglobin Saturation

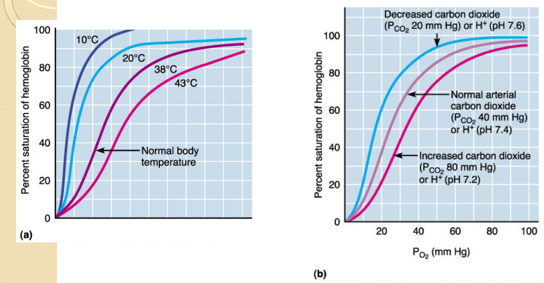


Figure 21.21a, b

Factors That Increase Release of Oxygen by Hemoglobin

- As cells metabolize glucose, carbon dioxide is released into the blood, causing:
  - Increases in P_{CO2} and H^+ concentration in capillary blood
  - Declining pH (acidosis) weakens the hemoglobin-oxygen bond (Bohr effect)
- Metabolizing cells have heat as a by-product and the rise in temperature increases BPG synthesis
- All these factors ensure oxygen unloading in the vicinity of working tissue cells

Hemoglobin–Nitric Oxide Partnership

- Nitric oxide (NO) is a vasodilator that plays a role in blood pressure regulation
- Hemoglobin is a vasoconstrictor and a nitric oxide scavenger (heme destroys NO)
- However, as oxygen bind to hemoglobin:
  - Nitric oxide binds to a cysteine amino acid on hemoglobin
  - Bound nitric oxide is protected from degradation by hemoglobin's iron

Hemoglobin–Nitric Oxide Partnership

- The hemoglobin is released as oxygen is unloaded, causing vasodilation
- As deoxygenated hemoglobin picks up carbon dioxide, it also binds nitric oxide and carries these gases to the lungs for unloading

Carbon Dioxide Transport

- Carbon dioxide is transported in the blood in three forms
  - Dissolved in plasma – 7 to 10%
  - Chemically bound to hemoglobin – 20% is carried in red blood cells as carbaminohemoglobin
  - Bicarbonate ion in plasma – 70% is transported as bicarbonate (HCO_3^-)

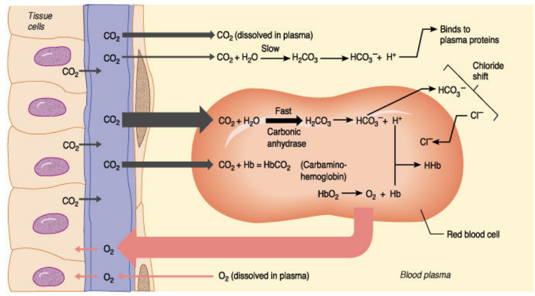
Transport and Exchange of Carbon Dioxide

- Carbon dioxide diffuses into red blood cells and combines with water to form carbonic acid (H_2CO_3), which quickly dissociates into hydrogen ions and bicarbonate ions

CO_2	+	H_2O	↔	H_2CO_3	↔	H^+	+	HCO_3^-
Carbon dioxide		**Water**		**Carbonic acid**		**Hydrogen ion**		**Bicarbonate ion**

- In red blood cells, carbonic anhydrase reversibly catalyzes the conversion of carbon dioxide and water to carbonic acid

Transport and Exchange of Carbon Dioxide



(a) Oxygen release and carbon dioxide pickup at the tissues

Figure 21.22a

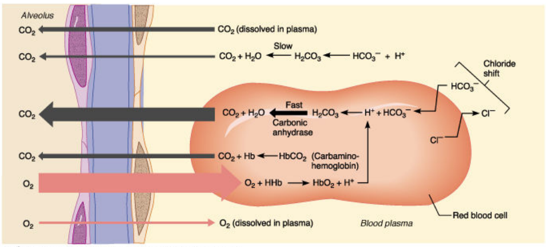
Transport and Exchange of Carbon Dioxide

- At the tissues
  - Bicarbonate quickly diffuses from red blood cells into the plasma
  - Chloride shift – to counterbalance the outrush of negative bicarbonate ions from the red blood cells, chloride ions (Cl^-) move from the plasma into the erythrocytes

Transport and Exchange of Carbon Dioxide

- At the lungs, these processes are reversed
  - Bicarbonate ions move into the red blood cells and bind with hydrogen ions to form carbonic acid
  - Carbonic acid is then split by carbonic anhydrase to release carbon dioxide and water
  - Carbon dioxide then diffuses from the blood into the alveoli

Transport and Exchange of Carbon Dioxide



(b) Oxygen pickup and carbon dioxide release in the lungs

Figure 21.22b

Haldane Effect

- The amount of carbon dioxide transported is markedly affected by the P_{O2}
- Haldane effect – the lower the P_{O2} and hemoglobin saturation with oxygen, the more carbon dioxide can be carried in the blood
- At the tissues, as more carbon dioxide enters the blood:
  - More oxygen dissociates from hemoglobin (Bohr effect)
  - More carbon dioxide combines with hemoglobin, and more bicarbonate ions are formed
- This situation is reversed in pulmonary circulation

Haldane Effect

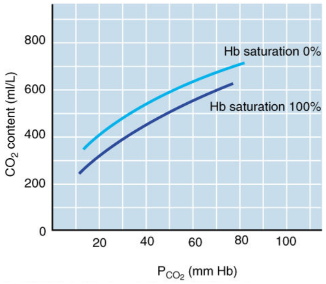


Figure 21.23

Influence of Carbon Dioxide on Blood pH

- The carbonic acid–bicarbonate buffer system resists blood pH changes
- If hydrogen ion concentration in blood begins to rise, it is removed by combining with HCO_3^-
- If hydrogen ion concentrations begin to drop, carbonic acid dissociates, releasing H^+
- Changes in respiratory rate can also:
  - Alter blood pH
  - Provide a fast-acting system to adjust pH when it is disturbed by metabolic factors

Control of Respiration: Medullary Respiratory Centers

- The dorsal respiratory group (DRG), or inspiratory center:
  - Is located near the root of nerve IX
  - Appears to be the pacesetting respiratory center
  - Excites the inspiratory muscles and sets eupnea (12-15 breaths/minute)
  - Becomes dormant during expiration
- The ventral respiratory group (VRG) is involved in forced inspiration and expiration

Control of Respiration: Medullary Respiratory Centers

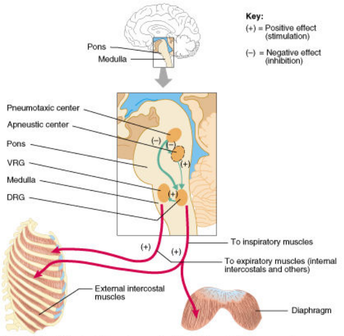


Figure 21.24

Control of Respiration: Pons Respiratory Centers

- Pons centers
  - Influence and modify activity of the medullary centers
  - Smooth out inspiration and expiration transitions and vice versa
- Pneumotaxic center – continuously inhibits the inspiration center
- Apneustic center – continuously stimulates the medullary inspiration center

Respiratory Rhythm

- A result of reciprocal inhibition of the interconnected neuronal networks in the medulla
- Other theories include:
  - Inspiratory neurons are pacemakers and have intrinsic automaticity and rhythmicity
  - Stretch receptors in the lungs establish respiratory rhythm

Depth and Rate of Breathing

- Inspiratory depth is determined by how actively the respiratory center stimulates the respiratory muscles
- Rate of respiration is determined by how long the inspiratory center is active
- Respiratory centers in the pons and medulla are sensitive to both excitatory and inhibitory stimuli

Depth and Rate of Breathing

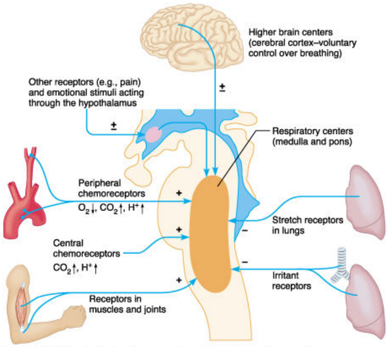


Figure 21.25

Depth and Rate of Breathing: Reflexes

- Pulmonary irritant reflexes – irritants promote reflexive constriction of air passages
- Inflation reflex (Hering-Breuer) – stretch receptors in the lungs are stimulated by lung inflation
- Upon inflation, inhibitory signals are sent to the medullary inspiration center to end inhalation and allow expiration

Depth and Rate of Breathing: Higher Brain Centers

- Hypothalamic controls – act through the limbic system to modify rate and depth of respiration
  - Example: breath holding that occurs in anger
- A rise in body temperature acts to increase respiratory rate
- Cortical controls – direct signals from the cerebral motor cortex that bypass medullary controls
  - Examples: voluntary breath holding, taking a deep breath

Depth and Rate of Breathing: P_{CO2}

- Changing P_{CO2} levels are monitored by chemoreceptors of the brain stem
- Carbon dioxide in the blood diffuses into the cerebrospinal fluid where it is hydrated

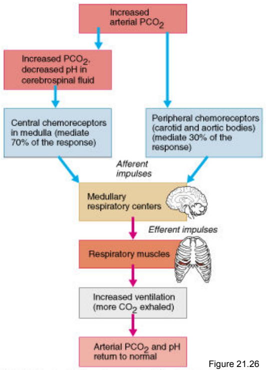
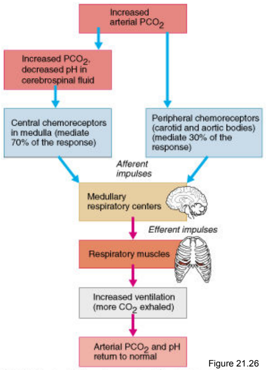


Figure 21.26

Depth and Rate of Breathing: P_{CO2}

- Resulting carbonic acid dissociates, releasing hydrogen ions
- P_{CO2} levels rise (hypercapnia) resulting in increased depth and rate of breathing


Increased arterial PCO_2

Increased PCO_2, decreased pH in cerebrospinal fluid

Central chemoreceptors in medulla (mediate 70% of the response)

Peripheral chemoreceptors (carotid and aortic bodies) (mediate 30% of the response)

Afferent impulses

Medullary respiratory centers

Efferent impulses

Respiratory muscles

Increased ventilation (more CO_2 exhaled)

Arterial PCO_2 and pH return to normal

Figure 21.26

Depth and Rate of Breathing: P_{CO2}

- Hyperventilation – increased depth and rate of breathing that:
  - Quickly flushes carbon dioxide from the blood
  - Occurs in response to hypercapnia
- Though a rise in CO_2 acts as the original stimulus, control of breathing at rest is regulated by the hydrogen ion concentration in the brain
- Hypoventilation – slow and shallow breathing due to abnormally low P_{CO2} levels
  - Apnea (breathing cessation) may occur until P_{CO2} levels rise

Depth and Rate of Breathing: P_{CO2}

- Arterial oxygen levels are monitored by the aortic and carotid bodies
- Substantial drops in arterial P_{O2} (to 60 mm Hg) are needed before oxygen levels become a major stimulus for increased ventilation
- If carbon dioxide is not removed (e.g., as in emphysema and chronic bronchitis), chemoreceptors become unresponsive to P_{CO2} chemical stimuli
- In such cases, P_{O2} levels become the principal respiratory stimulus (hypoxic drive)

Depth and Rate of Breathing: Arterial pH

- Changes in arterial pH can modify respiratory rate even if carbon dioxide and oxygen levels are normal
- Increased ventilation in response to falling pH is mediated by peripheral chemoreceptors
- Acidosis may reflect:
  - Carbon dioxide retention
  - Accumulation of lactic acid
  - Excess fatty acids in patients with diabetes mellitus
- Respiratory system controls will attempt to raise the pH by increasing respiratory rate and depth

Respiratory Adjustments: Exercise

- Respiratory adjustments are geared to both the intensity and duration of exercise
- During vigorous exercise:
  - Ventilation can increase 20 fold
  - Breathing becomes deeper and more vigorous, but respiratory rate may not be significantly changed (hyperpnea)
- Exercise-enhanced breathing is not prompted by an increase in P_{CO2} nor a decrease in P_{O2} or pH
  - These levels remain surprisingly constant during exercise

Respiratory Adjustments: Exercise

- As exercise begins:
  - Ventilation increases abruptly, rises slowly, and reaches a steady state
- When exercise stops:
  - Ventilation declines suddenly, then gradually decreases to normal
- Neural factors bring about the above changes, including:
  - Psychic stimuli
  - Cortical motor activation
  - Excitatory impulses from proprioceptors in muscles

Respiratory Adjustments: High Altitude

- The body responds to quick movement to high altitude (above 8000 ft) with symptoms of acute mountain sickness – headache, shortness of breath, nausea, and dizziness
- Acclimatization – respiratory and hematopoietic adjustments to altitude include
  - Increased ventilation – 2–3 L/min higher than at sea level
  - Chemoreceptors become more responsive to P_{CO2}
  - Substantial decline in P_{O2} stimulates peripheral chemoreceptors

Chronic Obstructive Pulmonary Disease (COPD)

- Exemplified by chronic bronchitis and obstructive emphysema
- Patients have a history of:
  - Smoking
  - Dyspnea, where labored breathing occurs and gets progressively worse
  - Coughing and frequent pulmonary infections
- COPD victims develop respiratory failure accompanied by hypoxemia, carbon dioxide retention, and respiratory acidosis

Asthma

- Characterized by dyspnea, wheezing, and chest tightness
- Active inflammation of the airways precedes bronchospasms
- Airway inflammation is an immune response caused by release of IL-4 and IL-5, which stimulate IgE and recruit inflammatory cells
- Airways thickened with inflammatory exudates magnify the effect of bronchospasms

Tuberculosis

- Infectious disease caused by the bacterium *Mycobacterium tuberculosis*
- Symptoms include fever, night sweats, weight loss, a racking cough, and spitting up blood
- Treatment entails a 12-month course of antibiotics

Lung Cancer

- Accounts for 1/3 of all cancer deaths in the US
- 90% of all patients with lung cancer were smokers
- The three most common types are:
  - Squamous cell carcinoma (20–40% of cases) arises in bronchial epithelium
  - Adenocarcinoma (25–35% of cases) originates in peripheral lung area
  - Small cell carcinoma (20–25% of cases) contains lymphocyte-like cells that originate in the primary bronchi and subsequently metastasize