Physiology of Respiratory System

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3rd year\ Lecture 2

Neural Control of Breathing

- No autorhythmic pacemaker cells for respiration, as in the heart
- Exact mechanism for setting the rhythm of respiration remains unknown
- Breathing depends on repetitive stimuli of skeletal muscles from brain
- Neurons in medulla oblongata and pons control unconscious breathing

Neural Control of Breathing

- Voluntary control provided by motor cortex
- Inspiratory neurons: fire during inspiration
- Expiratory neurons: fire during *forced* expiration
- Innervation
  - Fibers of phrenic nerve supply diaphragm
  - Intercostal nerves supply intercostal muscles

Brainstem Respiratory Centers

- Automatic, unconscious cycle of breathing is controlled by three pairs of respiratory centers in the reticular formation of the medulla oblongata and the pons

- Respiratory nuclei in medulla
  - Ventral respiratory group (VRG)
    - Primary generator of the respiratory rhythm
    - Inspiratory neurons in quiet breathing (eupnea) fire for about 2 seconds
    - Expiratory neurons in eupnea fire for about 3 seconds allowing inspiratory muscles to relax
    - Produces a respiratory rhythm of 12 breath per minute
  - Dorsal respiratory group (DRG)
    - Modifies the rate and depth of breathing
    - Receives influences from external sources

Brainstem Respiratory Centers

- Pons
  - Pontine respiratory group (PRG)
    - Modifies rhythm of the VRG by outputs to both the VRG and DRG
    - Adapts breathing to special circumstances such as sleep, exercise, vocalization, and emotional responses

Respiratory Control Centers

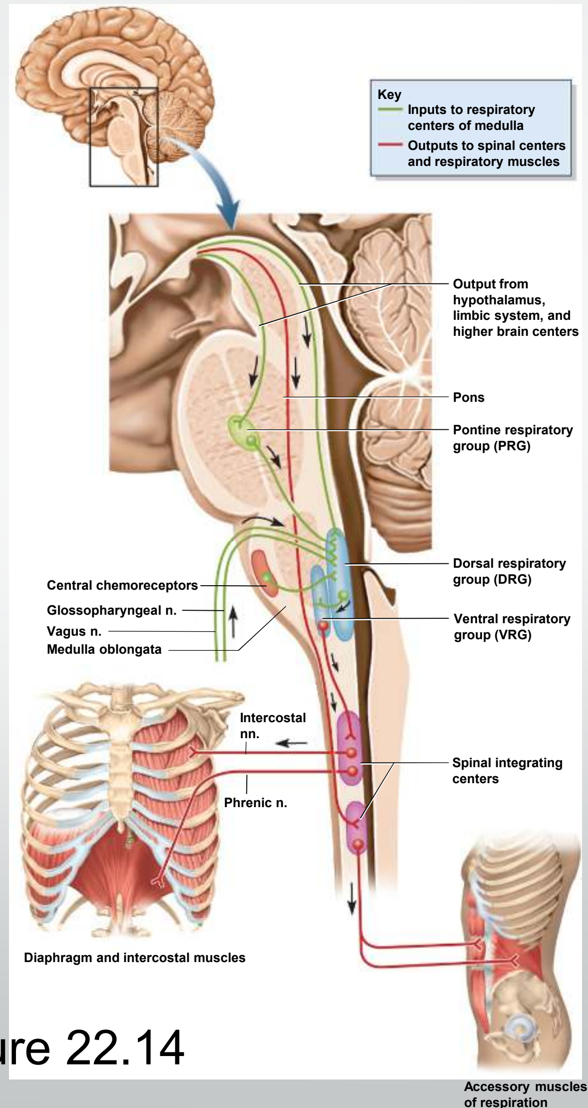


Figure 22.14

Hyperventilation

- Hyperventilation—anxiety-triggered state in which breathing is so rapid that it expels CO_2 from the body faster than it is produced
  - As blood CO_2 levels drop, the pH rises causing the cerebral arteries to constrict
  - This reduces cerebral perfusion which may cause dizziness or fainting
  - Can be brought under control by having the person rebreathe the expired CO_2 from a paper bag

Central and Peripheral Input to the Respiratory Centers

- Central chemoreceptors—brainstem neurons that respond to changes in pH of cerebrospinal fluid
  - pH of cerebrospinal fluid reflects the CO_2 level in the blood
  - By regulating respiration to maintain stable pH, respiratory center also ensures stable CO_2 level in the blood
- Peripheral chemoreceptors—located in the carotid and aortic bodies of the large arteries above the heart
  - Respond to the O_2 and CO_2 content and the pH of blood

Central and Peripheral Input to the Respiratory Centers

- Stretch receptors—found in the smooth muscles of bronchi and bronchioles, and in the visceral pleura
  - Respond to inflation of the lungs
  - Inflation (Hering-Breuer) reflex: triggered by excessive inflation
    - Protective reflex that inhibits inspiratory neurons stopping inspiration

Central and Peripheral Input to the Respiratory Centers

- Irritant receptors—nerve endings amid the epithelial cells of the airway
  - Respond to smoke, dust, pollen, chemical fumes, cold air, and excess mucus
  - Trigger protective reflexes such as bronchoconstriction, shallower breathing, breath-holding (apnea), or coughing

The Peripheral Chemoreceptors

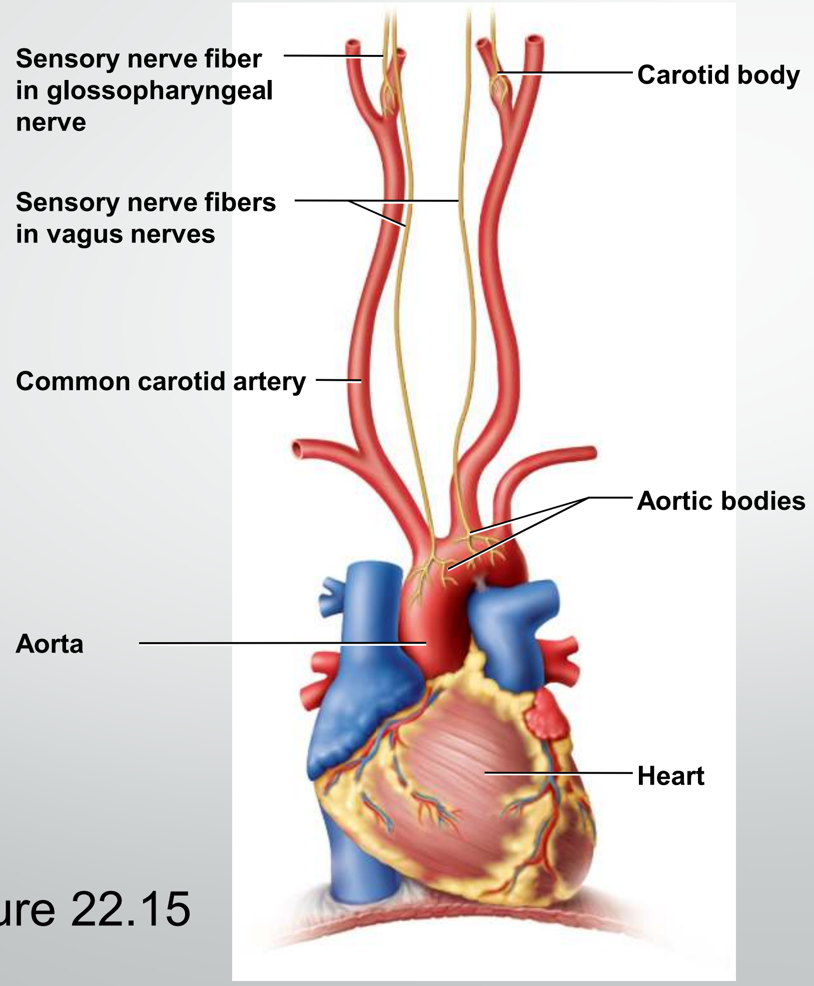


Figure 22.15

Voluntary Control of Breathing

- Voluntary control over breathing originates in the motor cortex of frontal lobe of the cerebrum
  - Sends impulses down corticospinal tracts to respiratory neurons in spinal cord, bypassing brainstem
- Limits to voluntary control
  - Breaking point: when CO_2 levels rise to a point when automatic controls override one's will

Pressure, Resistance, and Airflow

- Respiratory airflow is governed by the same principles of flow, pressure, and resistance as blood flow
  - The flow of a fluid is directly proportional to the pressure difference between two points
  - The flow of a fluid is inversely proportional to the resistance
- Atmospheric pressure drives respiration
  - The weight of the air above us
  - 760 mm Hg at sea level, or 1 atmosphere (1 atm)
    - Lower at higher elevations

Pressure, Resistance, and Airflow

- Boyle's law—at a constant temperature, the pressure of a given quantity of gas is inversely proportional to its volume
  - If the lungs contain a quantity of a gas and the lung volume increases, their internal pressure (intrapulmonary pressure) falls
    - If the pressure falls below atmospheric pressure, the air moves into the lungs
  - If the lung volume decreases, intrapulmonary pressure rises
    - If the pressure rises above atmospheric pressure, the air moves out of the lungs

Inspiration

- The two pleural layers, their cohesive attraction to each other, and their connections to the lungs and their lining of the rib cage bring about inspiration
  - When the ribs swing upward and outward during inspiration, the parietal pleura follows them
  - The visceral pleura clings to it by the cohesion of water and it follows the parietal pleura
  - It stretches the alveoli within the lungs
  - The entire lung expands along the thoracic cage
  - As it increases in volume, its internal pressure drops, and air flows in

Inspiration

- Intrapleural pressure—the slight vacuum that exists between the two pleural layers
  - About −4 mm Hg
  - Drops to −6 mm Hg during inspiration as parietal pleura pulls away
  - Some of this pressure change transfers to the interior of the lungs
    - Intrapulmonary pressure—the pressure in the alveoli drops −3 mm Hg
    - Pressure gradient from 760 mm Hg atmosphere to 757 mm Hg in alveoli allows air to flow into the lungs

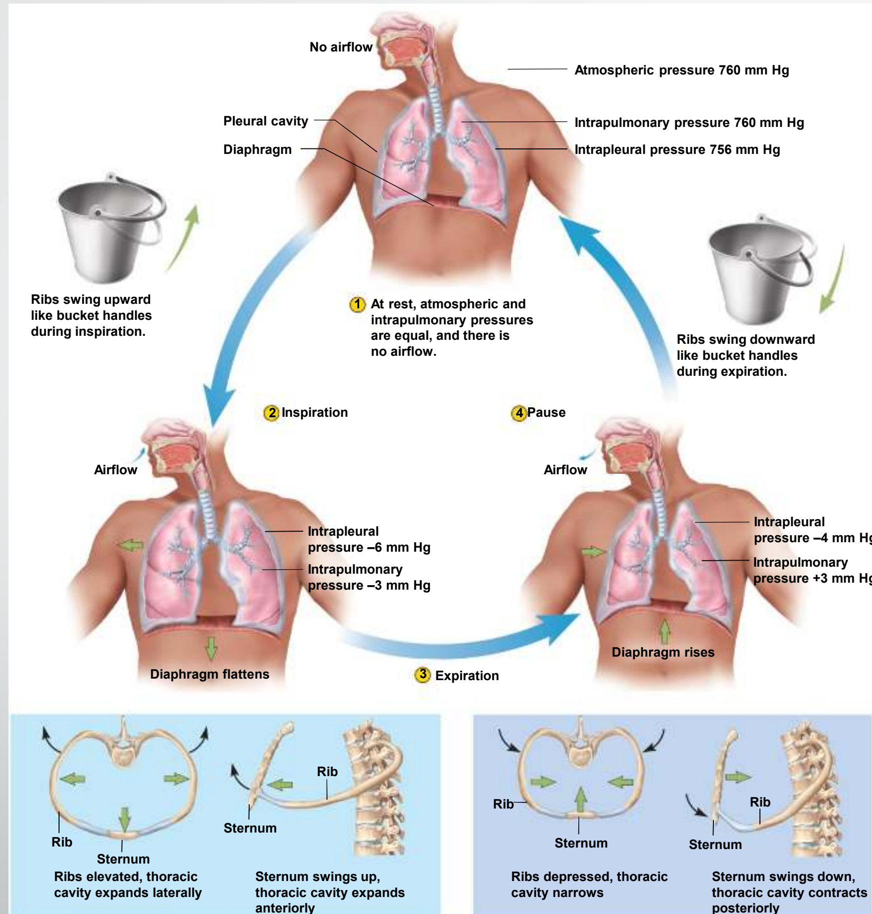
Inspiration

- Another force that expands the lungs is Charles' s law
- Charles' s law—the given quantity of a gas is directly proportional to its absolute temperature
  - On a cool day, 16° C (60° F) air will increase its temperature by 21° C (39° F) during inspiration
  - Inhaled air is warmed to 37° C (99° F) by the time it reaches the alveoli
  - Inhaled volume of 500 mL will expand to 536 mL and this thermal expansion will contribute to the inflation of the lungs

Inspiration

- In quiet breathing, the dimensions of the thoracic cage increase only a few millimeters in each direction
  - Enough to increase its total volume by 500 mL
  - Thus, 500 mL of air flows into the respiratory tract

The Respiratory Cycle



2 In inspiration, the thoracic cavity expands laterally,vertically and anteriorly; intrapulmonary pressure drops 3 mm Hg below atmospheric pressure, and air flows into the lungs.

3 In expiration, the thoracic cavity contracts in all three directions; intrapulmonary pressure rises 3 mm Hg above atmospheric pressure, and air flows out of the lungs.

Figure 22.16

Expiration

- Relaxed breathing
  - Passive process achieved mainly by the elastic recoil of the thoracic cage
  - Recoil compresses the lungs
  - Volume of thoracic cavity decreases
  - Raises intrapulmonary pressure to about +3 mm Hg
  - Air flows down the pressure gradient and out of the lungs
- Forced breathing
  - Accessory muscles raise intrapulmonary pressure as high as +30 mmHg
  - Massive amounts of air moves out of the lungs

Expiration

- Pneumothorax—presence of air in pleural cavity
  - Thoracic wall is punctured
  - Inspiration sucks air through the wound into the pleural cavity
  - Potential space becomes an air-filled cavity
  - Loss of negative intrapleural pressure allows lungs to recoil and collapse
- Atelectasis—collapse of part or all of a lung
  - Can also result from an airway obstruction

Resistance to Airflow

- Pressure is one determinant of airflow; resistance is the other
  - The greater the resistance, the slower the flow
- Three factors influencing airway resistance
  - Diameter of the bronchioles
    - Bronchodilation—increase in the diameter of a bronchus or bronchiole
      - Epinephrine and sympathetic stimulation stimulate bronchodilation
      - Increase airflow
    - Bronchoconstriction—decrease in the diameter of a bronchus or bronchiole
      - Histamine, parasympathetic nerves, cold air, and chemical irritants stimulate bronchoconstriction
      - Suffocation from extreme bronchoconstriction brought about by anaphylactic shock and asthma

Resistance to Airflow

- Three factors influencing airway resistance (cont.)
  - Pulmonary compliance: the ease with which the lungs can expand
    - The change in lung volume relative to a given pressure change
    - Compliance reduced by degenerative lung diseases in which the lungs are stiffened by scar tissue
  - Surface tension of the alveoli and distal bronchioles
    - Surfactant—reduces surface tension of water
    - Infant respiratory distress syndrome (IRDS)—premature babies

Resistance to Airflow

- Thin film of water needed for gas exchange
  - Creates surface tension that acts to collapse alveoli and distal bronchioles
- Pulmonary surfactant produced by the great alveolar cells
  - Decreases surface tension by disrupting the hydrogen bonding in water

Resistance to Airflow

- Premature infants that lack surfactant suffer from infant respiratory distress syndrome (IRDS)
  - Great difficulty in breathing
  - Treated with artificial surfactant until lungs can produce own

Alveolar Ventilation

- Only air that enters the alveoli is available for gas exchange
- Not all inhaled air gets there
- About 150 mL fills the conducting division of the airway
- Anatomic dead space
  - Conducting division of airway where there is no gas exchange
  - Can be altered somewhat by sympathetic and parasympathetic stimulation
- In pulmonary diseases, some alveoli may be unable to exchange gases because they lack blood flow or the respiratory membrane has been thickened by edema or fibrosis

Alveolar Ventilation

- Physiologic (total) dead space
  - Sum of anatomic dead space and any pathological alveolar dead space
- A person inhales 500 mL of air, and 150 mL stays in anatomical dead space, then 350 mL reaches alveoli
- Alveolar ventilation rate (AVR)
  - Air that ventilates alveoli (350 mL) X respiratory rate (12 bpm) = 4,200 mL/min.
  - Of all the measurements, this one is most directly relevant to the body's ability to get oxygen to the tissues and dispose of carbon dioxide
- Residual volume—1,300 mL that cannot be exhaled with maximum effort

Spirometry—The Measurement of Pulmonary Ventilation

- Spirometer—a device that recaptures expired breath and records such variables as rate and depth of breathing, speed of expiration, and rate of oxygen consumption
- Respiratory volumes
  - Tidal volume: volume of air inhaled and exhaled in one cycle during quiet breathing (500 mL)
  - Inspiratory reserve volume: air in excess of tidal volume that can be inhaled with maximum effort (3,000 mL)
  - Expiratory reserve volume: air in excess of tidal volume that can be exhaled with maximum effort (1,200 mL)

Respiratory Volumes and Capacities

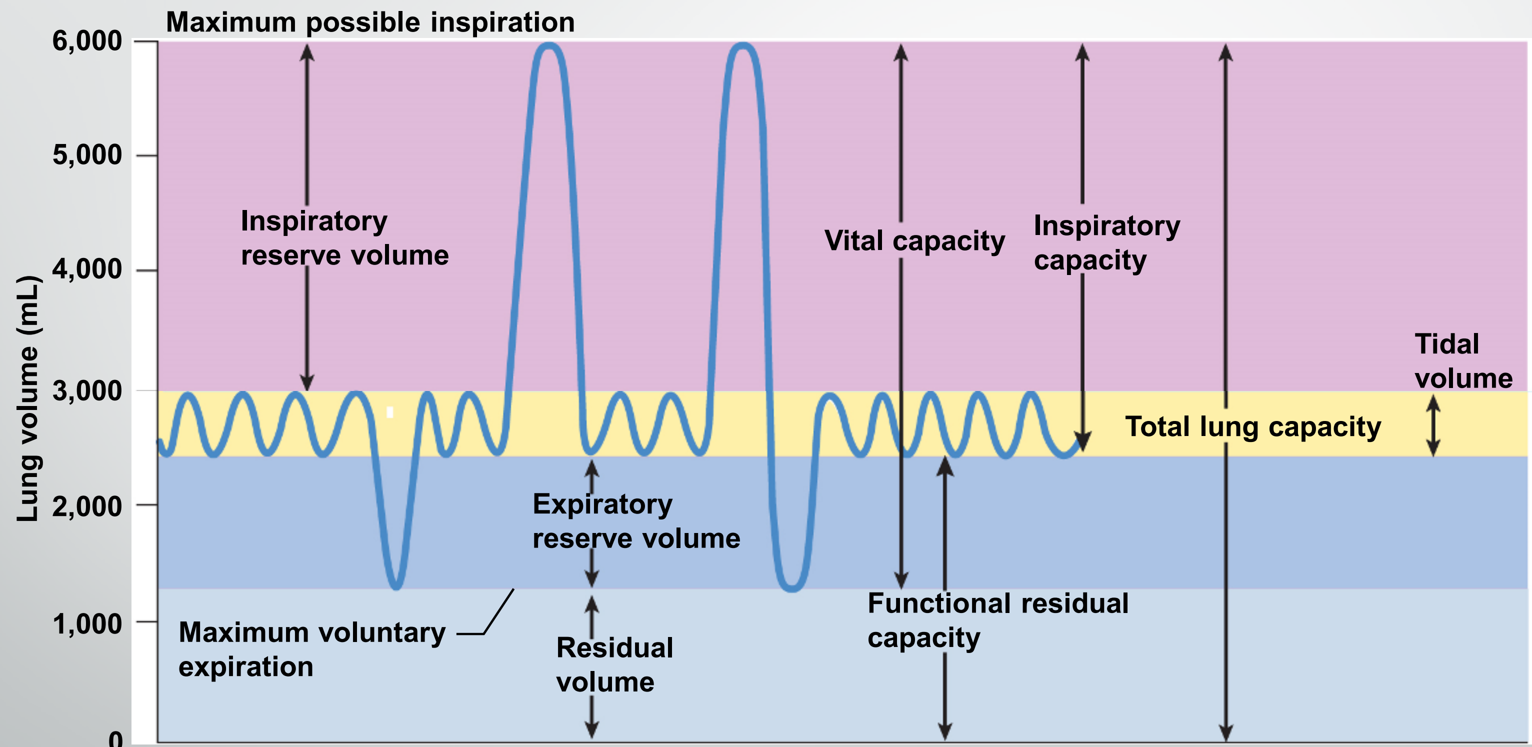


Figure 22.18

Spirometry—The Measurement of Pulmonary Ventilation

Cont.

- Residual volume: air remaining in lungs after maximum expiration (1,300 mL)
- Vital capacity: total amount of air that can be inhaled and then exhaled with maximum effort
  - VC = ERV + TV + IRV (4,700 mL)
    - Important measure of pulmonary health
- Inspiratory capacity: maximum amount of air that can be inhaled after a normal tidal expiration
  - IC = TV + IRV (3,500 mL)

Spirometry—The Measurement of Pulmonary Ventilation

Cont.

- Functional residual capacity: amount of air remaining in lungs after a normal tidal expiration
  - FRC = RV + ERV (2,500 mL)
- Total lung capacity: maximum amount of air the lungs can contain
  - TLC = RV + VC (6,000 mL)

Spirometry—The Measurement of Pulmonary Ventilation

- Spirometry—the measurement of pulmonary function
  - Aid in diagnosis and assessment of *restrictive* and *obstructive* lung disorders
- Restrictive disorders—those that reduce pulmonary compliance
  - Limit the amount to which the lungs can be inflated
  - Any disease that produces pulmonary fibrosis
  - Black lung disease, tuberculosis

Spirometry—The Measurement of Pulmonary Ventilation

- Obstructive disorders—those that interfere with airflow by narrowing or blocking the airway
  - Make it harder to inhale or exhale a given amount of air
  - Asthma, chronic bronchitis
  - Emphysema combines elements of restrictive and obstructive disorders

Spirometry—The Measurement of Pulmonary Ventilation

- Forced expiratory volume (FEV)
  - Percentage of the vital capacity that can be exhaled in a given time interval
  - Healthy adult reading is 75% to 85% in 1 second
- Peak flow
  - Maximum speed of expiration
  - Blowing into a handheld meter
- Minute respiratory volume (MRV)
  - Amount of air inhaled per minute
  - TV x respiratory rate (at rest 500 x 12 = 6,000 mL/min.)
- Maximum voluntary ventilation (MVV)
  - MRV during heavy exercise
  - May be as high as 125 to 170 L/min

Variations in the Respiratory Rhythm

- Eupnea—relaxed, quiet breathing
  - Characterized by tidal volume 500 mL and the respiratory rate of 12 to 15 bpm
- Apnea—temporary cessation of breathing
- Dyspnea—labored, gasping breathing; shortness of breath
- Hyperpnea—increased rate and depth of breathing in response to exercise, pain, or other conditions
- Hyperventilation—increased pulmonary ventilation in excess of metabolic demand

Variations in the Respiratory Rhythm

- Hypoventilation—reduced pulmonary ventilation
- Kussmaul respiration—deep, rapid breathing often induced by acidosis
- Orthopnea—dyspnea that occurs when person is lying down
- Respiratory arrest—permanent cessation of breathing
- Tachypnea—accelerated respiration