The Respiratory System

Chapter 23

Functions of the respiratory system

- Gas exchange between air and circulating blood
- Moving air to and from the exchange surface of the lungs
- Protection of respiratory surfaces
- Production of sound
- Providing olfactory sensations

Organization of the Respiratory System

- The respiratory system can be divided into:
  - The upper respiratory system; consisting of the nose, nasal cavity, paranasal sinuses, and pharynx
  - The lower respiratory system; consisting of the larynx, trachea, bronchi, bronchioles, and alveoli of the lungs

The Respiratory tract

- The respiratory tract refers to the conducting passageways that carry air to and from the alveoli
  - The upper respiratory passages filter and humidify incoming air
  - The lower passageways include delicate conduction passages and alveolar exchange surfaces where gas exchange occurs

Respiratory Mucosa

- The respiratory mucosa lines the conducting portion of respiratory tract
- The respiratory mucosa is the respiratory epithelium and underlying connective tissue
- It’s function is to condition (warm and moisten) and filter the air as it moves toward the respiratory surfaces
- Numerous goblet cells and mucus glands in the upper respiratory tract provide lubrication and protection
The nose and nasal cavity consists of:

- External nares
- Nasal cavity
- Vestibule (space inside the flexible tissue of nose)
- Superior, middle and inferior conchae
- Hard and soft palates
- Internal nares

The pharynx

- The pharynx is shared by the digestive and respiratory systems
- It is divided into three sections:
  - Nasopharynx – superior portion
  - Oropharynx – continuous with the oral cavity
  - Laryngopharynx – between the hyoid bone and the esophagus

The larynx

- Inhaled air leaves the pharynx and enters the larynx through the glottis
- The larynx is a cartilaginous structure that surrounds and protects the glottis
- The cartilages of the larynx are
  - Three large cartilages
    - Thyroid, cricoid, and epiglottis
  - Paired cartilages
    - Arytenoids, corniculate, and cuneiform
- The vocal ligaments and vocal folds guard the entrance to the glottis and are highly elastic
Sound production

- Sound is produced by air passing through the glottis and vibrating the vocal folds
- Pitch depends on the diameter, length, and tension in the vocal folds
- Sound production at the larynx is termed phonation, one component of speech
- Clear speech requires articulation; the modification of sound by other structures, the pharynx, oral cavity, nasal cavity, and paranasal sinuses

The Trachea

- The trachea extends from the sixth cervical vertebra to the fifth thoracic vertebra
- It is a tough, flexible tube connecting the larynx to the bronchi
- It is held open by 15-20 C-shaped tracheal cartilages in submucosa

The primary bronchi

- The trachea branches within the mediastinum into the right and left bronchi
- Before branching further each bronchi enters the lungs at the hilus, a groove on the medial surface of the lungs
The Lungs

• Each lung is a blunt cone, the tip, or apex, of which points superiorly
• The apex on each side extends into the base of the neck superior to the first rib
• The base of each lung rests on the superior surface of the diaphragm
• The lobes of the lungs are separated by fissures
  – Right lung has three lobes
  – Left lung has two lobes

The bronchial tree

• The bronchial tree is a system of tubes formed from the primary bronchi and their branches
  – The primary bronchi branch into secondary or lobar bronchi
  – Secondary bronchi go to each lobe of the lungs
  – Secondary bronchi branch into tertiary or segmental bronchi
  – Each tertiary bronchus supplies air to a single bronchopulmonary segment
  – As branching proceeds, the cartilage in the walls decreases and smooth muscle increases

Bronchioles

• Each tertiary bronchus branches several times within the bronchiopulmonary segment, giving rise to several bronchioles
• There are roughly 6500 of the finest conducting branches, the terminal bronchioles
• The walls of the bronchioles lack cartilaginous support and are dominated by smooth muscle
• Sympathetic activation leads to bronchodilation, parasympathetic stimulation leads to bronchoconstriction
Bronchioles

- Bronchioles ultimately branch into terminal bronchioles
- Each terminal bronchiole branches to become several respiratory bronchioles
- Each terminal bronchiole delivers air to a single pulmonary lobule
- Each pulmonary lobule is delimited by interlobular septa, branches of the connective tissue framework of the lungs

Alveolar Ducts and Alveoli

- Respiratory bronchioles are connected to individual alveoli and to multiple alveoli by alveolar ducts
- An alveolar duct ends at an alveolar sac
- Each alveolar sac is a common chamber connected to up to 150 million alveoli
- An extensive capillary network and network of elastic fibers is associated with each alveolus

Alveolar Ducts and Alveoli

- The alveolar epithelium consists of type I cells (simple squamous epithelium)
- Roaming alveolar macrophages patrol the epithelium and engulf foreign particles
- Type II, or septal cells, are scattered among type I cells and secrete surfactant, a mixture of phospholipids and proteins, that forms a superficial coating over a thin layer of water
- Surfactant reduces the surface tension in the liquid coating the alveolar surfaces
- Without surfactant the delicate alveolar walls would collapse under the surface tension
Alveolar Ducts and Alveoli

• Gas exchange occurs across the respiratory membrane of the alveoli
• This membrane is a composite structure consisting of
  – The squamous epithelial lining of the alveolus
  – The endothelial cells of an adjacent capillary
  – The fused basal lining between those two cell layers
• The total distance separating alveolar air from blood averages 0.5μm

The blood supply to the lungs

• The conducting passageways receive blood from external carotids, thyrocervical, and bronchial arteries
• The respiratory exchange surfaces receive blood from the arteries of the pulmonary circuit
• Pulmonary veins return blood to the left atrium

The pleural cavities and pleural membranes

• Each lung is covered by a serous membrane called a pleura
• The pleura consist of two layers:
  – The parietal pleura attaches to the walls of the pleural cavity
  – The visceral pleura adheres to the surface of the lungs
• Pleural fluid is secreted by each pleura and fills and lubricates the space between the pleura reducing friction as you breath

Respiratory Physiology

• Respiration refers to two integrated processes
• External respiration includes all the processes involved in the exchange of oxygen and carbon dioxide between the body’s interstitial fluids and the external environment
• Internal respiration is the absorption of oxygen and the release of carbon dioxide by cells

Respiratory Physiology

• We will focus on three integrated steps involved in external respiration
• Pulmonary ventilation, moving air in and out of the lungs
• Gas diffusion, across the respiratory membrane and across capillary walls
• Transport of oxygen and carbon dioxide between alveolar capillaries and capillary beds in other tissues
Pulmonary ventilation

- The movement of air during pulmonary ventilation depends upon pressure and volume
- Specifically the pressure within and the volume of the lungs
- Boyle’s law (P=1/V) states that there is an inverse relationship between the pressure and volume of a gas
- Double the volume you get half the pressure, half the volume you get double the pressure

Pulmonary ventilation

- Air flows from regions of high pressure to regions of low pressure
- This tendency for directed airflow, plus Boyle’s law provides the basis for pulmonary ventilation
- A single respiratory cycle consists of an inspiration, and an exhalation
- The volume of air moved in a single respiratory cycle is the tidal volume
- Each changes the volume of the lungs and the direction of airflow (read 832)

Modes of Breathing

- During quiet breathing or eupnea, inhalation involves contraction of the diaphragm and external intercostals, exhalation is passive
- Diaphragmatic, or deep breathing contraction of the diaphragm is responsible for inhalation, exhalation is passive
- In costal, or thoracic breathing, the ribcage changes volume during inhalation, exhalation is passive
- Forced breathing, or hyperpnea involves active inspiration and expiration involving accessory muscles in addition to the diaphragm and external intercostals

Respiratory Rates

- Your respiratory rate is the number of breaths taken each minute, in adults, 12-18
- The respiratory minute volume (V_{E}) is equal to the respiratory rate (f) and tidal Volume (V_{T})
- Alveolar ventilation (V_{A}) is the amount of air reaching the alveoli each minute
- Not all inhaled air reaches the alveoli approximately 30% of the tidal volume remains in the conducting passageways or anatomical dead space
Respiratory Volumes

- Vital capacity is the tidal volume plus expiratory and inspiratory reserve volumes
- The expiratory reserve volume (ERV) is the amount of air that can be voluntarily expelled after a normal respiratory cycle
- The inspiratory reserve volume (IRV) is the amount of air that can be forcefully inhaled over and above the tidal volume
- Residual volume is the amount of air left in the lungs even after maximum exhalation, (1200ml in male, 1100 ml in females)

Gas Exchange

- Gas exchange occurs between blood and alveolar air across the respiratory membrane
- To understand gas exchange we must first understand the partial pressures of the gases involved, and the diffusion of molecules between a gas and a liquid

Gas Laws

- Dalton’s Law states that individual gases in a mixture exert pressure proportional to their abundance
- In other words, the partial pressure of a gas is the pressure contributed by that gas in a mixture of gases
- For air at sea level \( P_{N2} + P_{O2} + P_{H2O} + P_{CO2} = 760 \text{ mm Hg} \)
- Henry’s law states that the amount of gas in solution is directly proportional to its partial pressure
- When a gas under pressure contacts a liquid, the pressure forces gas into the liquid until an equilibrium between the partial pressure of the gas and the amount of gas in the liquid is reached

Diffusion and respiratory function

- Gas exchange across respiratory membrane is efficient because:
  - There are differences in partial pressure
  - There is a small diffusion distance
  - Gases involved are lipid-soluble
  - There is a large surface area of all alveoli
  - There is coordination of blood flow and airflow
Partial pressures in Alveolar air and Alveolar capillaries

- Blood arriving in the pulmonary arteries has a lower $P_{O_2}$ and a higher $P_{CO_2}$ than does alveolar air.
- Diffusion between the alveolar air and pulmonary capillaries thus elevates blood $P_{O_2}$ and lowers its $P_{CO_2}$.
- By the time it reaches the pulmonary venules the blood has reached equilibrium with the alveolar air.

Partial pressures in the Systemic circuit

- Normal interstitial fluid has a $P_{O_2}$ of 40 mm Hg, as a result oxygen diffuses out of the capillaries and carbon dioxide diffuses in, until capillary partial pressures are the same as those in the tissues.
- Likewise, systemic blood has a $P_{CO_2}$ of 40 mm Hg and inactive peripheral tissues a $P_{CO_2}$ of 45 mm Hg, thus carbon dioxide diffuses into the blood as oxygen diffuses out.

Gas Pickup and Delivery

- Oxygen and Carbon dioxide have limited solubility in blood plasma.
- This problem is solved by RBCs, which remove dissolved oxygen and carbon dioxide from plasma and bind them (in the case of oxygen) or use them to manufacture soluble compounds (in the case of carbon dioxide).
- Because these reactions remove dissolved gases from the blood plasma, diffusion continues, because equilibrium is never reached.
- These reactions are temporary and completely reversible.

Oxygen Transport

- Most of the oxygen in your blood is carried by RBCs bound to hemoglobin.
- Each hemoglobin molecule can carry four oxygen molecules, one for each heme complex.
- The percentage of hemoglobin molecules containing bound oxygen at any given moment is termed the hemoglobin saturation.
- The most important factors affecting hemoglobin’s affinity for oxygen are; the $P_{O_2}$ of blood, blood pH, temperature, and the ongoing metabolic activity within RBCs.
Oxygen Hemoglobin Dissociation Curve

- Each arriving molecule of oxygen that binds to hemoglobin increases the affinity of hemoglobin for the next oxygen molecule.
- At $P_O_2$ above 60 mm Hg, hemoglobin saturation is >90%.
- Functionally this means that hemoglobin can provide oxygen over the normal range of $P_O_2$ in body tissues.

Carbon dioxide transport

- After entering the bloodstream carbon dioxide is either, converted to carbonic acid, bound to the protein portion of hemoglobin, or dissolved in plasma.
- Typically 7% is dissolved in plasma, 23% bound to hemoglobin, and 70% as carbonic acid.

Carbon dioxide is the principal molecule responsible for changes in blood pH.
- Carbon dioxide forms carbonic acid in blood plasma decreasing pH and also decreasing the affinity of hemoglobin for oxygen, thus in physiologically active tissues that are generating carbon dioxide, hemoglobin gives up its oxygen more readily.

Hemoglobin and BPG

- As RBCs conduct glycolysis, they produce 2,3 bisphosphoglycerate (BPG).
- For any given partial pressure of oxygen the presence of BPG increases the release of oxygen from hemoglobin.
- Thyroid hormones, growth hormone, epinephrine, androgens, and a high blood pH, all increase the concentration of BPG and improve oxygen delivery to tissues.
Control of Respiration

- Under normal conditions, the cellular rates of absorption and generation are matched by the capillary rates of delivery and removal.
- If diffusion rates at peripheral and alveolar capillaries become unbalanced, homeostatic mechanisms intervene to restore equilibrium.
- Such mechanisms involve local tissue regulation, and changes in depth and rate of respiration controlled by the respiratory centers of the brain.

Local Regulation

- Local regulation of gas transport and alveolar function includes:
  - Lung perfusion (bloodflow to the alveoli)
  - Alveolar ventilation (changes in bronchiole diameter)

Respiratory centers in the brain

- Respiratory centers in the brain regulate the activities of respiratory muscles and control the frequency and depth of pulmonary ventilation.
- Respiratory rhythmicity centers in the medulla oblongata set the pace of respiration.
- In the pons, apneustic and pneumotaxic centers regulate the rate and depth of respiration.

Voluntary Control of Respiration

- Respiratory center activity can be modified by activity of the cerebral cortex.
- Conscious thought processes tied to strong emotions, such as fear or anger.
- Emotional state can lead to activation of the sympathetic (bronchodilation and increased respiratory rate) or parasympathetic (the opposite).

Changes in the respiratory system at birth

- Upon taking the first breath; forceful inhalation must overcome surface tension in the collapse lungs as inhaled air enters the respiratory passages for the first time and the bronchial tree and most of the alveoli are inflated.
- The exhalation that follows does not empty the lungs completely, because the ribcage does not return to its completely collapsed state.
- Subsequent breaths complete inflation of the alveoli.