Chapter 12
The Respiratory System

Oxygen Delivery: A Cooperative Effort

- Respiratory system oxygenates blood and removes carbon dioxide
- Circulatory system transports gases in the bloodstream

Lung: Structure and Function

- System of tubes conduct air into and out of the lungs
  - Bronch: largest conducting tube
  - Bronchioles: less than 1 mm
  - Terminal bronchioles: smallest
  - Respiratory bronchioles: distal to terminal bronchiole with alveoli projecting from walls; form alveolar ducts and sacs; transport air and participate in gas exchange
- Alveoli: O₂ and CO₂ exchange; surrounded by alveolar septum; with cells that produce surfactant
- Lung divided into lobes consisting of smaller units or lobules
Gas Exchange (1 of 2)

- Two functions of respiration
- Ventilation: movement of air into and out of lungs
  - Inspiration
  - Expiration
- Gas exchange between alveolar air and pulmonary capillaries
  - Atmospheric pressure, sea level = 760 mmHg
  - Partial pressure: part of total atmospheric pressure exerted by a gas
  - Partial pressure of oxygen, $P_{O_2}$
  - $= 0.20 \times 760 \text{ mmHg} = 152 \text{ mmHg}$

Gas Exchange (2 of 2)

- Gases diffuse between blood, tissues, and pulmonary alveoli due to differences in their partial pressures
  - Alveolar air $\rightarrow$ Blood (Pulm capillaries)
  - $↑$ $P_{O_2}$ 105 mmHg $P_{O_2}$ 20 mmHg
  - $↓$ $PCO_2$ 35 mmHg $PCO_2$ 60 mmHg

- Requirements for efficient gas exchange
  - Large capillary surface area in contact with alveolar membrane
  - Unimpeded diffusion across alveolar membrane
  - Normal pulmonary blood flow
  - Normal pulmonary alveoli
Pulmonary Function Tests

- Evaluate efficiency of pulmonary ventilation and pulmonary gas exchange
- Tested by measuring volume of air that can be moved into and out of lungs under normal conditions
- Vital capacity: maximum volume of air expelled after maximum inspiration
- One-second forced expiratory volume (FEV₁): maximum volume of air expelled in 1 second
- Arterial PO₂ and PCO₂
- Pulse oximeter

The Pleural Cavity

- Pleura: thin membrane covering lungs (visceral pleura) and internal surface of the chest wall (parietal pleura)
- Pleural cavity: potential space between lungs and chest wall
- Intrapleural pressure: pressure within pleural cavity
  - Normally lesser than intrapulmonary pressure
  - Referred as “negative pressure” or subatmospheric because it is lesser than atmospheric pressure
  - Tendency of stretched lung to pull away from chest creates a vacuum
  - Release of vacuum in pleural cavity leads to lung collapse

Pneumothorax (1 of 2)

- Escape of air into pleural space due to lung injury or disease
- Stab wound or penetrating injury to chest wall: atmospheric air enters into pleural space
- Spontaneous pneumothorax – no apparent cause; rupture of small, air-filled subpleural bleb at lung apex
- Manifestations
  - Chest pain
  - Shortness of breath
  - Reduced breath sounds on affected side
  - Chest x-ray: lung collapse + air in pleural cavity
Pneumothorax (2 of 2)

- Tension pneumothorax
  - Positive pressure develops in pleural cavity
  - Air flows through perforation into pleural cavity on inspiration but cannot escape on expiration
  - Pressure builds up in pleural cavity displacing heart and mediastinal structures away from affected side
- Chest tube inserted into pleural cavity; left in place until tear in lung heals
  - Prevents accumulation of air in pleural cavity
  - Aids re-expansion of lung

Atelectasis (1 of 2)

- Collapse of lung
- Obstructive atelectasis caused by bronchial obstruction from
  - Mucous secretions, tumor, foreign object
  - Part of lung supplied by obstructed bronchus collapses as air absorbed
  - Reduced volume of affected pleural cavity
  - Mediastinal structures shift toward side of atelectasis
  - Diaphragm elevates on affected side
  - May develop as a postoperative complication

Atelectasis (2 of 2)

- Compression atelectasis
  - From external compression of lung by
    - Fluid
    - Air
    - Blood in pleural cavity
  - Reduced lung volume and expansion
Before atelectasis

Atelectasis of entire left lung

Affected lung appears dense with absorption of air; left half of diaphragm elevated; trachea and mediastinal structures shifted to side of collapse

Pneumonia (1 of 3)

• Inflammation of the lung
  − Exudate spreads through lung
  − Exudate fills alveoli
  − Affected lung portion becomes relatively solid (consolidation)
  − Exudate may reach pleural surface causing irritation and inflammation

• Classification
  − By etiology
  − By anatomic distribution of inflammatory process
  − By predisposing factors

Pneumonia (2 of 3)

• Etiology: most important, serves as a guide for treatment
  − Bacteria, viruses, fungi, Chlamydia, Mycoplasma, Rickettsia

• Anatomic distribution of inflammatory process
  − Lobar: infection of entire lung by pathogenic bacteria
  − Legionnaire’s Disease: gram-negative rod
  − Bronchopneumonia: infection of parts of lobes or lobules adjacent to bronchi by pathogenic bacteria
  − Interstitial or primary atypical pneumonia: caused by virus or Mycoplasma; involves alveolar septa than alveoli; septa with lymphocytes and plasma cells
Pneumonia (3 of 3)

- Predisposing factors
  - Any condition associated with poor lung ventilation and retention of bronchial secretions
  - Postop pneumonia: accumulation of mucous secretions in bronchi
  - Aspiration pneumonia: foreign body, food, vomit
  - Obstructive pneumonia: distal to bronchial narrowing
- Clinical features of pneumonia
  - Fever, cough, purulent sputum, pain on respiration, shortness of breath

Pneumocystis Pneumonia

- Cause: *Pneumocystis carinii*, protozoan parasite of low pathogenicity
- Affects mainly immunocompromised persons
- AIDS, receiving immunosuppressive drugs, premature infants
- Cysts contain sporozoites released from cysts that mature to form trophozoites; sporozoites appear as dark dots at the center of cyst on stained smears
- Organisms attack and injure alveolar lining leading to exudation of protein material into alveoli
- Cough, dyspnea, pulmonary consolidation
- Diagnosis: lung biopsy by bronchoscopy or from bronchial secretions

Tuberculosis

- Infection from acid-fast bacteria, *Mycobacterium tuberculosis*
- Organism has a capsule composed of waxes and fatty substances; resistant to destruction
- Transmission: airborne droplets
- Granuloma: giant cell with central necrosis, indicates development of cell-mediated immunity
- Multi-nucleated giant cells: bacteria + fused monocytes + periphery of lymphocytes and plasma cells
- Organisms lodge within pulmonary alveoli
- Granulomas are formed
- Spreads into kidneys, bones, uterus, fallopian tubes, others
Granuloma, tuberculosis
Central necrosis

Multinucleated giant cell, tuberculosis

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Tuberculosis-Outcome

- Infection arrested and granulomas heal with scarring
- Infection may be asymptomatic, detected only by chest x-ray and/or **Mantoux** test
- Infection reactivated: healed granulomas contain viable organisms reactivated with reduced immunity leading to progressive pulmonary TB
- Spread through blood to other organs (extrapulmonary)
  - Secondary focus of infection may progress even if pulmonary infection has healed
- Diagnosis
  - Skin test (**Mantoux**)
  - Chest x-ray
  - Sputum culture
Reactivated and Miliary Tuberculosis

- Reactivated tuberculosis: active TB in adults from reactivation of an old infection; healed focus of TB flares up with lowered immune resistance
- Miliary tuberculosis
  - Multiple foci (small, white nodules, 1-2 mm in diameter) of disseminated tuberculosis, resembling millet seeds
  - Large numbers of organisms disseminated in body when a mass of tuberculous inflammatory tissue erodes into a large blood vessel
  - Extensive consolidation of one or more lobes of lung
  - At-risk: AIDS and immunocompromised individuals

Drug-Resistant Tuberculosis

- Resistant strains of organisms emerge with failure to complete treatment or premature cessation of treatment
- Multiple drug-resistant tuberculosis, MTB
  - TB caused by organisms resistant to at least two of the anti-TB drugs
  - Course of treatment is prolonged
  - Results less satisfactory
- Extremely drug-resistant tuberculosis, XDR-TB
  - Caused by organisms no longer controlled by many anti-TB drugs
  - Eastern Europe, South Africa, Asia, some cases in the United States

Bronchitis and Bronchiectasis

- Inflammation of the tracheobronchial mucosa
- Acute bronchitis
- Chronic bronchitis: from chronic irritation of respiratory mucosa by smoking or atmospheric pollution
- Bronchiectasis: walls weakened by inflammation become saclike and fusiform
  - Distended bronchi retain secretions
  - Chronic cough; purulent sputum; repeated bouts of pulmonary infection
- Diagnosis: bronchogram
- Only effective treatment: surgical resection of affected segments of lung
Chronic Obstructive Pulmonary Disease (1 of 4)

- Combination of emphysema and chronic bronchitis
- Pulmonary emphysema
  - Destruction of fine alveolar structure of lungs with formation of large cystic spaces
  - Destruction begins in upper lobes eventually affecting all lobes of both lungs
  - Dyspnea, initially on exertion; later, even at rest
- Chronic bronchitis: chronic inflammation of terminal bronchioles; cough and purulent sputum

Chronic Obstructive Pulmonary Disease (2 of 4)

- Three main anatomic derangements in COPD
- Inflammation and narrowing of terminal bronchioles
  - Swelling of bronchial mucosa → reduced caliber of bronchi and bronchioles → increased bronchial secretions → increased resistance to air flow → air enters lungs more readily than it can be expelled → trapping of air at expiration
- Dilatation and coalescence of pulmonary air spaces
  - Diffusion of gases less efficient from large cystic spaces
- Loss of lung elasticity; lungs no longer recoil normally following inspiration

Chronic Obstructive Pulmonary Disease (3 of 4)

- Chronic irritation: smoking and inhalation of injurious agents
- Pathogenesis
  - 1. Inflammatory swelling of mucosa
    - Narrows bronchioles; increased resistance to expiration; causing air to be trapped in lung
  - 2. Leukocytes accumulate in bronchioles and alveoli, releasing proteolytic enzymes that attack elastic fibers of lung’s structural support
  - 3. Coughing and increased intrabronchial pressure convert alveoli into large, cystic air spaces, over-distended lung cannot expel air
  - 4. Retention of secretions predisposes to pulmonary infection
Chronic Obstructive Pulmonary Disease (4 of 4)

• Lungs damaged by emphysema cannot be restored to normal
• Management
  – Promote drainage of bronchial secretions
  – Decrease frequency of superimposed pulmonary infections
  – Surgery does not improve survival, initial benefit is short-term

Bronchial Asthma

• Spasmodic contraction of smooth muscles on walls of bronchi and bronchioles
• Dyspnea and wheezing on expiration
• Greater impact on expiration than on inspiration
• Attacks are precipitated by allergens: inhalation of dust, pollens, animal dander, other allergens
• Treatment
  – Drugs that dilate bronchial walls: epinephrine or theophylline
  – Drugs that block release of mediators from mast cells

Neonatal Respiratory Distress Syndrome

• Progressive respiratory distress soon after birth
• Hyaline membrane disease after red-staining membranes lining alveoli
• Pathogenesis: inadequate surfactant in lungs
  – Alveoli do not expand normally during inspiration
  – Tends to collapse during expiration
• At-risk groups
  – Premature infants
  – Infants delivered by cesarean section
  – Infants born to diabetic mothers
• Treatment
  – Adrenal corticosteroids to mother before delivery
  – Oxygen + surfactant
Neonatal Respiratory Distress Syndrome
Leakage of protein rich in fibrinogen that tends to clot and form adherent eosinophilic hyaline membranes impeding gas exchange.

Adult Respiratory Distress Syndrome
- Shock – major manifestation
- Conditions: fall in blood pressure and reduced blood flow to lungs
  - Severe injury (traumatic shock)
  - Systemic infection (septic shock)
  - Aspiration of acid gastric contents
  - Inhalation of irritant or toxic gases
  - Damage caused by SARS
- Damaged alveolar capillaries leak fluid and protein
- Impaired surfactant production from damaged alveolar lining cells
- Formation of intra-alveolar hyaline membrane

Pulmonary Fibrosis
- Fibrous thickening of alveolar septa from irritant gases, organic, and inorganic particles
  - Makes lungs rigid restricting normal respiratory excursions
  - Diffusion of gases hampered due to increased alveolar thickness
  - Causes progressive respiratory disability similar to emphysemal
- Collagen diseases
- Pneumoconiosis: lung injury from inhalation of injurious dust or other particulate material
  - Silicosis (rock dust) and asbestosis (asbestos fibers)
Lung Carcinoma

- Usually smoking-related neoplasm
- Common malignant tumor in both men and women
- Mortality from lung cancer in women exceeds breast cancer
- Arises from mucosa of bronchi and bronchioles
- Rich lymphatic and vascular network in lungs facilitates metastasis
- Often referred as bronchogenic carcinoma because cancer usually arises from bronchial mucosa
- Treatment: surgical resection or radiation and chemotherapy for small cell carcinoma and advanced tumors