Chapter 12
The Respiratory System

Learning Objectives
• Principles of ventilation and gas exchange
• Causes, clinical effects, complications, and treatment
  – Pneumothorax
  – Atelectasis
  – Tuberculosis
• Differentiate bronchitis vs. bronchiectasis
• COPD, bronchial asthma, RDS: pathogenesis, anatomic and physiologic derangements, clinical manifestations, treatment
• Asbestosis
• Lung carcinoma: types, manifestations, and treatment

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
  – Bronchi: 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, PO₂
    – = 0.20 x 760 mmHg = 152 mmHg

Structure Terminal Air Passages
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)
    - \( \uparrow P_0_1 \) 105 mmHg
    - \( \uparrow P_0_2 \) 20 mmHg
    - \( \downarrow PC0_2 \) 35 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

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
  - Postob 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:
- Giant cell with central necrosis, indicates development of cell-mediated immunity

Multi-nucleated giant cell:
- Tuberculosis

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

Granuloma, tuberculosis
- Central necrosis

Multinucleated giant cell, tuberculosis

Pulmonary tuberculosis, far-advanced
- Extensive consolidation of both lungs
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

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
- Damaged alveolar capillaries leak fluid and protein
- Impaired surfactant production from damaged alveolar lining cells
- Formation of intra-alveolar hyaline membrane

Comparison: Neonatal Versus Adult

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<td>Delivery by cesarean section</td>
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<td>Pathogenesis</td>
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<td>Indirect damage: ↓ pulmonary blood flow from shock or sepsis</td>
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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 emphysema
- 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
**Lung Carcinoma Classification**

- **Classification**
  - Squamous cell carcinoma: very common
  - Adenocarcinoma: very common
  - Large cell carcinoma: large, bizarre epithelial cells
  - Small cell carcinoma: small, irregular dark cells with scanty cytoplasm resembling lymphocytes; very poor prognosis

- **Prognosis**
  - Depends on histologic type
  - Generally poor due to early spread to distant sites

**Histologic Appearance, Lung Carcinoma**

A: Squamous cell carcinoma
B: Small cell carcinoma

**Discussion**

1. Differentiate MDR-TB from XDR-TB. What are the clinical and practical implications of these cases?

2. What socio-economic factors are associated with the increased prevalence of tuberculosis? Under what circumstances may an old inactive tuberculous infection become activated? What types of patients are susceptible to a reactivated tuberculosis?

3. What is the difference between pulmonary emphysema and pulmonary fibrosis? What factors predispose to their development?