9: Alterations of Pulmonary Functions

Learning objectives

- Explain the pathophysiology of obstructive and restrictive lung diseases
- Discuss the pathophysiology and the various clinical presentations of COPD, chronic bronchitis/emphysema, bronchial asthma, bronchiectasis, emphysema
- Discuss sleep breathing disorder (eg.OSA), aspiration, atelectasis, pulmonary fibrosis, inhalation disorders, pulmonary edema, ARDS
- Explain the pathophysiology and clinical presentations pulmonary hypertension
- Explain the pathophysiology and clinical presentation of deep vein thrombosis and pulmonary embolism
- Explain the pathophysiology and clinical presentation of selected childhood pathologies: cystic fibrosis, upper airway obstruction and infections

Definitions: Alterations of Pulmonary Functions

Term	Definition
Chest wall disorders	Disorders that compromise chest wall and restrict respiration
Dyspnea	Uncomfortable breathing/shortness of breath
Empyema	Pus in the pleural space
Flail chest	Multiple adjacent ribs are broken in multiple places Segment of ribs are separated
Hemoptysis	Coughing up blood
INHALATION DISORDERS	- Entry of a substance with air inhalation into respiratory tract
Acute Respiratory Distress Syndrome (ARDS)	- Fulminant form of respiratory failure characterized by diffuse alveolo-capillary injury
Atelectasis	- Lung collapse resulting in reduced or absent gas exchange - May affect part or all of one lung - It can be a disease, or it can be caused by a disease
Pulmonary Edema	- Fluid inside the lungs
Pulmonary Fibrosis	- Scarring of lung tissue

OBSTRUCTIVE LUNG DISORDERS	- Pulmonary diseases characterized by airway obstruction that is worse with expiration
Bronchial asthma	- Acute/chronic inflammatory/immune disorder of the airways
Chronic bronchitis	- Chronic inflammatory response within bronchi: - Hyper-secretion of mucus, chronic productive cough at least 3 months/year & at least 2 consecutive years
Bronchiectasis	- Permanent enlargement of bronchioles most commonly secondary to infection
Emphysema	- Permanent enlargement of alveoli accompanied by destruction of alveolar walls without obvious fibrosis
Respiratory Tract Infections	
Pneumonia	- Inflammation of the lung tissue
Acute Bronchitis	- Acute inflammation of the bronchi - Commonly follows a viral infection of upper resp tract - No pulmonary consolidation or chest infiltrates
Obstructive sleep apnea (OSA)	- Partial or complete upper airway obstruction during sleep
Orthopnea	- Dyspnea when a person is lying down
Paroxysmal nocturnal dyspnea (PND)	- Attacks of severe shortness of breath/cough at night during sleep
Pneumothorax	- Abnormal collection of air in pleural cavity
Pleural Effusion	- Excess fluid accumulation in the pleural cavity
PULMONARY FUNCTION DISORDERS IN CHILDREN	
Cystic fibrosis (CF)	- Autosomal recessive genetic disorder - Thick tenacious secretions affecting multiple systems (pulmonary and GI)
Croup	- URT infection causing barking like cough
Acute Epiglottitis	- Severe, rapidly progressing, life-threatening infection of epiglottis and surrounding area
PULMONARY VASCULAR DISORDERS	

Pulmonary embolism (PE)	- Occlusion within pulmonary vascular bed by: blood clot, fat/air bubble
Pulmonary Hypertension	- Elevation of pressure in pulmonary vasculature - Pressure > 20 mm or elevation by 5-10 mm Hg above normal
RESTRICTIVE LUNG DISEASES	- Diseases characterized by restriction of full expansion of lungs
Lung Aspiration	- Entry of material from oropharynx or GI into respiratory tract - Types of aspirate: pharyngeal secretions, food/drink, gastric content
Stridor	- High-pitched breath sound due to turbulent air flow in larynx or lower resp tract

Review: Nervous System Anatomy and Physiology

- **Respiratory system is composed of two parts**:
  - Upper and lower respiratory tracts
    - Everything after larynx = Lower Respiratory
- Respiratory system can be divided into *conducting* and *respiratory* components

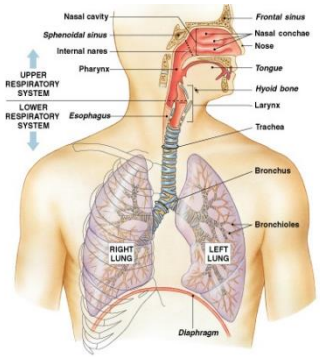


Figure 1: Anatomy of the upper and lower respiratory tracts

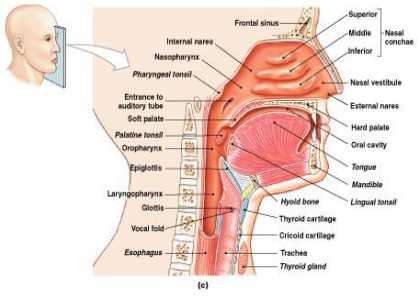


Figure 2: Anatomy of the upper respiratory tract

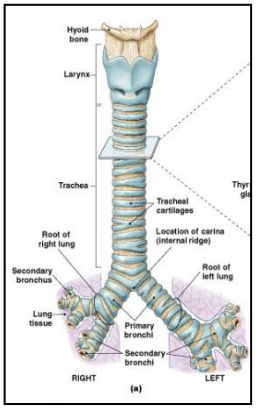


Figure 3: Conducting components of the lower respiratory tract

- Structure of lung alveoli and physiology of gas exchange

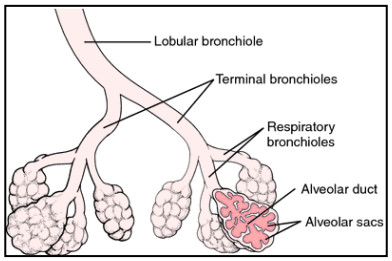


Figure 4: Cross section of alveoli of the lower respiratory tract

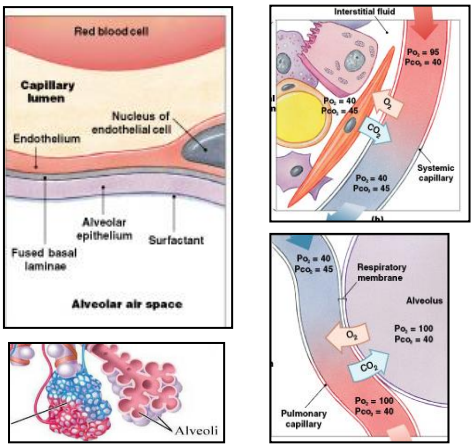


Figure 5: Sites and surfaces of gas exchange

- Structure and function of the pleural fluid
- Pulmonary & systemic circuits
- **Respiratory volumes (4) and capacities (4):**
  - Inspiratory reserve volume
  - Tidal volume
  - Expiratory reserve volume
  - Residual volume
  - Inspiratory capacity
  - Vital capacity
  - Functional residual capacity
  - Total lung capacity

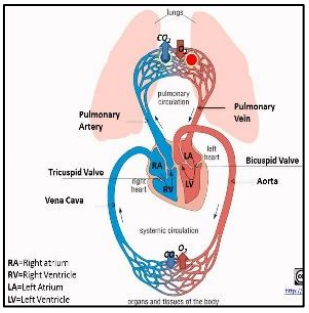


Figure 6: Pulmonary and systemic circuits

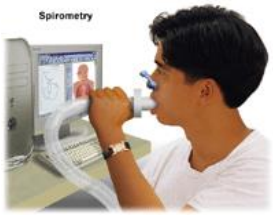


Figure 7: Spirometry measurement of respiratory volumes and capacities

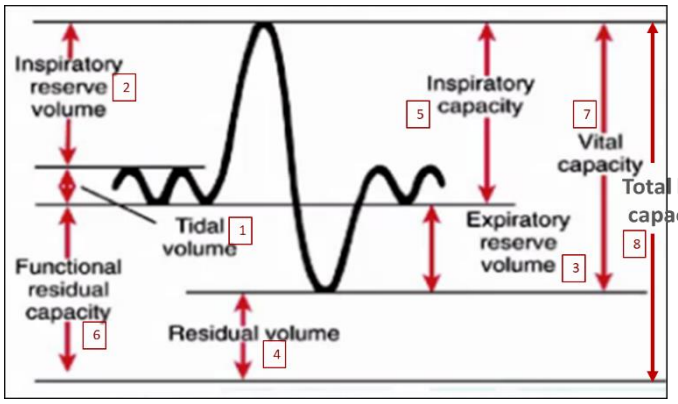


Figure 8: Respiratory volumes (#1-4) and capacities (#5-8)

Manifestations of Pulmonary Diseases

- *Dyspnea:*
  - Uncomfortable breathing/shortness of breath
-
  - Dyspnea when a person is lying down
- *Paroxysmal nocturnal dyspnea* (PND):
  - Attacks of severe shortness of breath/cough at night during sleep

Orthopnea:

- Cough:
  - Protective reflex
  - Acute/chronic
- Pain
- *Stridor:*
  - high-pitched breath sound due to turbulent air flow in larynx or lower
- Wheezes & crackles:
  - **Video**: https://www.youtube.com/watch?v=xnubmmeDWrw&list=PLLKSXV1ibO86qgE2y9cMqNFmh6LfOa8RM

- **Abnormal respiratory rate/ pattern**:
  - Tachypnea/ bradypnea
  - Hyperpnea/hypopnea/apnea
  - Kussmaul respiration – DKA (or any acidosis)
  - Cheyne-Stokes respiration
- Abnormal sputum
  - Can be colored or clear, can increase or decrease in amount and frequency
- *Hemoptysis:*
  - Coughing up blood (cancer or TB)
- *Empyema:*
  - Pus in the pleural space, not a disease but a manifestation

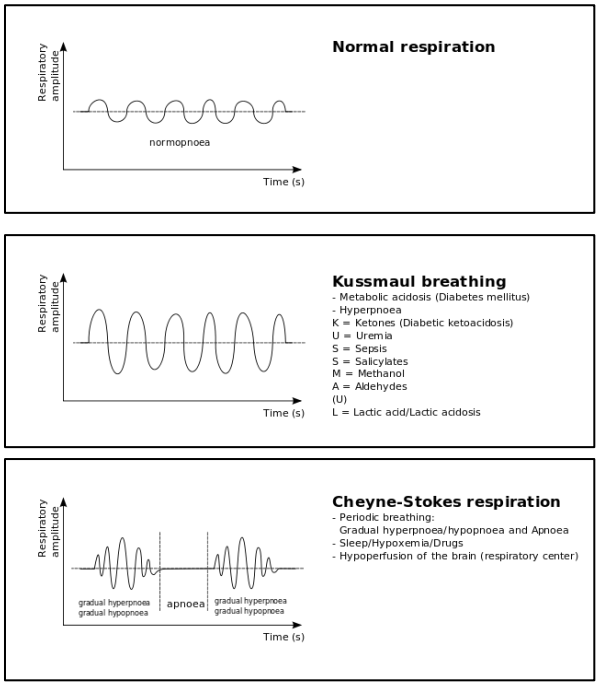


Figure 9: Respiratory rates and patterns.

- Hypoventilation
  - Leads to Hypercapnia
- Hyperventilation
  - Hypocapnia
- Cyanosis
- Clubbing

Disorders of the Respiratory System

Chest Wall Disorders

- Disorders that compromise chest wall and restrict respiration

Causes:

- Deformities
- Musculoskeletal disorders
- Immobilization
- Obesity

Pathophysiology:

- Mechanical restrictions of inspiration and expiration

Clinical manifestations:

- Breathing difficulty
- Of the underlying condition

Flail Chest

- Multiple adjacent ribs are broken in multiple places, separating a segment

Etiology:

- Severe trauma, falls

Pathophysiology:

- Segment of chest wall moves independently in the opposite direction of the lung's intention
- Due to difference in pressure, flail segment goes in while the rest of the chest is moving out (vice versa) → *paradoxical breathing*

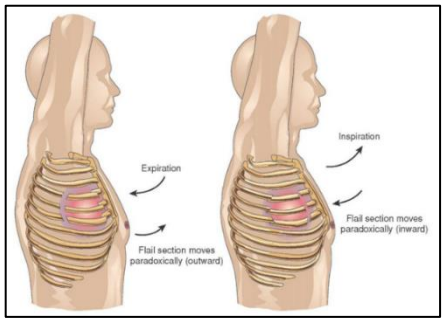


Figure 10. Paradoxical breathing

Clinical manifestations:

- Chest pain
- Dyspnea

Pneumothorax

- Abnormal collection of air in pleural space

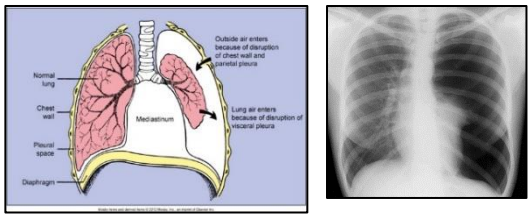


Figure 11. Pneumothorax

Etiology:

- Physical trauma
- Complication of medical/surgical intervention

Pathophysiology:

- Uncoupling of the lung from the chest wall, air interferes with normal respiration
- Increased pressure inside > atmospheric pressure,
  - Compresses the lung
  - Lung collapse (atelectasis)
- Pressure displaces the mediastinum and cause cardiopulmonary impairment
- Xray: black = air, tissue and fluid = white

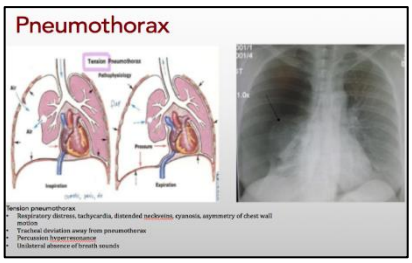


Figure 12. Tension pneumothorax with mediastinal deviation

Types:

- **Spontaneous pneumothorax**:
  - Rupture of a subpleural bleb
- **Secondary pneumothorax:**
  - Due to lung pathology, e.g. COPD
- **Open pneumothorax:**
  - Stab or bullet wounds
- **Tension pneumothorax:**
  - One-way valve allowing air and pressure to increase progressively inside pleural space
    - Significant impairment of respiration and/or circulation

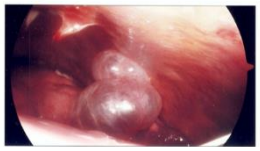


Figure 13. Subpleural bleb

Clinical manifestations & diagnosis:

- Chest pain, resp. distress
- Diminished breath sounds
- Hyper-resonant on percussion
- X-ray

Pleural Effusion

- Excess fluid accumulation in the pleural cavity

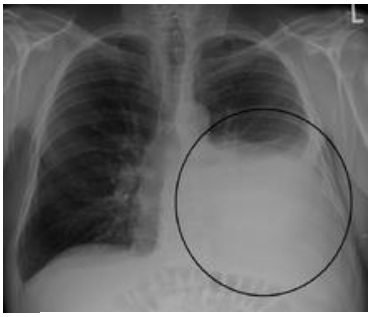


Figure 14. Pleural effusion

Causes/Types

- **Transudative effusion**
  - Congestive heart failure
  - Liver cirrhosis
  - Nephrotic syndrome
- **Exudative effusion**
  - Infection
  - Malignancy
  - Pulmonary embolism, infarction
  - Pancreatitis
  - Hemothorax
  - Trauma

Pathophysiology:

- Fluid limits expansion of lungs; impair breathing
- Increased hydrostatic pressure
- Injuries to the pleural lining
- >300 ml = detectable clinical signs
- Xray: tissue and fluid = white

Clinical manifestations & diagnosis:

- Chest pain (sharp pain worsen by cough or deep breaths)
- Impaired chest movement on the affected side
- Dullness to percussion over the fluid
- Diminished breath sounds on the affected side
- Pleural friction rub
- X ray confirms condition

9: Pulmonary Disorders

Restrictive lung diseases

- Pulmonary, extra-pulmonary, diseases characterized by <u>restriction of full expansion of lungs</u>
- **Pathology**: ↓ lung volume, ↓ ventilation/oxygenation, ↑effort in breathing

Main manifestation:

- Dyspnea

Common diseases/conditions:

- Aspiration
- Atelectasis
- Pulmonary fibrosis
- Inhalation disorders
- Pulmonary edema
- ARDS

Obstructive lung diseases

- Pulmonary diseases characterized by airway obstruction that is worse with expiration
- **Pathology**:
    - Inflamed and easily collapsible airways, frequent medical visits/ hospitalizations

Main manifestations:

- Cough, dyspnea, and wheezing

Common diseases/conditions:

- COPD
- Chronic bronchitis/Emphysema
- Bronchial Asthma
- Bronchiectasis
- Sleep breathing disorder (E.g. OSA)

Restrictive Lung disorders

Lung Aspiration

- Entry of material from oropharynx or GI into resp. tract
- Types of aspirate: pharyngeal secretions, food/drink, gastric content

Etiology:

- Medical procedure; during positive pressure ventilation
- Meconium aspiration syndrome

Risk factors:

- Impaired consciousness (TBI), alcohol or drug overdose, general anesthesia
- Tracheal intubation, presence of gastric tube

Pathophysiology:

- Depends on particle size, volume, chemical composition of aspirated material, and underlying patient health status
- Air way obstruction
- Damage of lung tissue (acidity, microbes)

Clinical manifestations:

- Range from no effect, to pneumonia, to death within minutes from asphyxiation

9: Inhalation Disorders

- Entry of a substance with air inhalation into resp. tract

Types and Causes:

- Toxic gases: e.g. CO, SO_2
- Pneumoconiosis (occupational lung disease)
  - Silica
  - Asbestos
  - Coal

Pathophysiology & clinical manifestations:

- Depend on dose inhaled, particle size, underlying patients' health status

Atelectasis

- Lung collapse resulting in reduced or absent gas exchange
- May affect part or all of one lung
- It can be a disease, or it can be caused by a disease

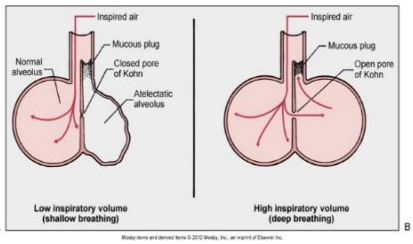


Figure 15: Atelectasis

Etiology and Pathophysiology:

- Post-surgical (most common cause)
- Airway block (foreign body, mucus plug, tumor, lymph node, tubercle)
- Poor surfactant

Clinical manifestations:

- Breathing difficulty (rapid and shallow)
- Low oxygen saturation
- Cyanosis
- Pleural effusion (transudate type)

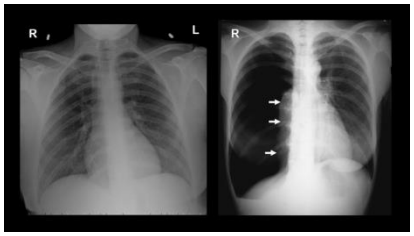


Figure 16: Atelectasis on an x-ray

Pulmonary Fibrosis

- Scarring of lung tissue (alveoli)

Etiology:

- Idiopathic
- Inhalation, e.g. asbestos
- Inflammation, e.g. pneumonitis
- Autoimmune, e.g. SLE

Pathophysiology:

- Replacement of normal lung parenchyma with fibrous tissue
- Reduction of lung compliance
- Defective perfusion

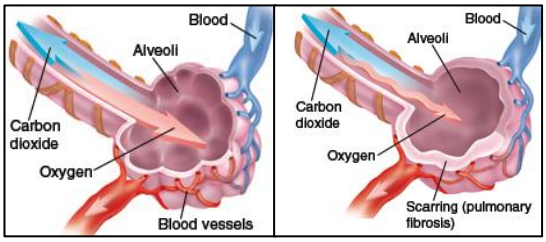


Figure 17: Replacement of normal lung tissue with fibrous tissue

Clinical manifestations & evaluation:

- Progressive dyspnea with exertion
- X-ray to show fibrosis

Pulmonary Edema

- Fluid inside the lungs

Etiology and diseases associated with lung edema:

- Left side valvular dysfunction
- Left ventricular failure
- Injury to capillary endothelium
- Blockage of lymphatic vessel

Pathophysiology:

- Increase in atrial pressures
- Increase in capillary permeability
- Accumulation of fluid in interstitial space
- Increased pulmonary capillary hydrostatic pressure

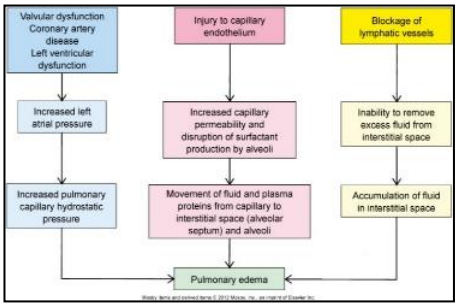


Figure 18: Pathophysiology of Pulmonary Edema

Clinical manifestations:

- **Dyspnea**, orthopnea, PND
- Cough (pink, frothy sputum)
- Excessive sweating, anxiety, pale skin
- **Anxious**

Acute Respiratory Distress Syndrome (ARDS)

- Fulminant form of respiratory failure characterized by diffuse alveolo-capillary injury

Causes:

- Sepsis **(main reason)**
- Multiple trauma
- Pneumonia
- Near drowning
- Drug overdose

Pathophysiology:

- Injury to the pulmonary capillary endothelium
- Pulmonary edema
- Inflammation and platelet activation
- Surfactant inactivation/loss

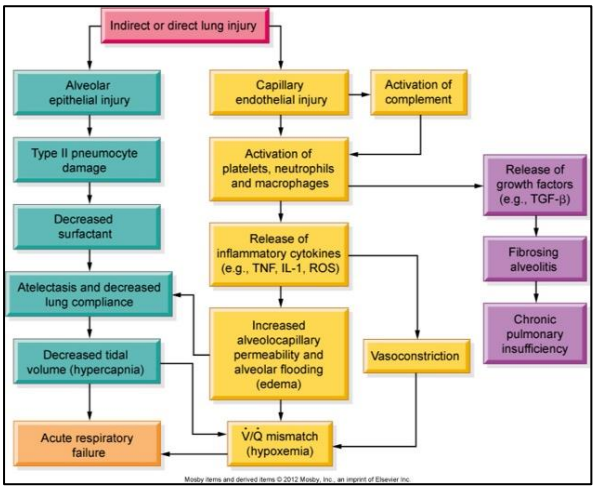


Figure 19: Pathophysiology of ARDS

Clinical manifestations & diagnosis:

- Dyspnea and hypoxemia
- Hypoventilation, increased Pco2
- Respiratory acidosis
- Hypotension

9: Obstructive Lung disorders

Bronchial Asthma

- **The number 1 respiratory disease**
- Acute/chronic inflammatory/immune disorder of the airways

Etiology:

- Complex environmental and genetic factors

Pathophysiology:

- Children and adults
- Hyper-responsive airways
- Bronchospasm, inflammation, vascular congestion, increased mucous secretion
- IgE mediated degranulation of mast cells
- May lead to status asthmaticus

Precipitating factors:

- Allergens, drugs, others

Clinical manifestations/ diagnosis:

- *Expiratory wheezing, dyspnea, tachypnea, cough
- Spirometry, family history, symptoms, etc.

*Seen everywhere in the world. The terminal airways are blocked from mucus and inflammation of the wall. This is an inflammatory disorder that is IgE mediated from mast cell degeneration. The smooth muscle wall responds quickly to antigen in exposed air. This disease can be acute or chronic and can run in a family. Status asthmaticus = severe acute asthmatic attack.

Chronic Bronchitis

- Chronic inflammatory response within bronchi:
    - Hyper-secretion of mucus, chronic productive cough at least 3 months/year & at least 2 consecutive years

Cause:

- **Smoking** (main reason)
- Air pollution
- Long term exposure to irritants (occupation related)
- Genetic factors

Pathophysiology:

- Constant irritation will mucus production, size & number of mucous glands
- Mucus is thicker than normal
- Secondary bacterial infection adds to this inflammatory state

Clinical manifestations & evaluation:

- Chronic, worsening productive cough
- Diffuse, bilateral wheezes & rhonchi
- Spirometry can measure the amount of airflow obstruction
- Usually complicated by emphysema
- Colored sputum = secondary bacterial infection

Bronchiectasis

- Permanent enlargement of bronchioles most commonly secondary to infection.
    - “ectasis” = dilation. You lose wall elasticity

Etiology:

- Cystic fibrosis (50%), COPD
- Infection; pneumonia, tuberculosis
- Immune disorders

Pathophysiology:

- Chronic inflammation

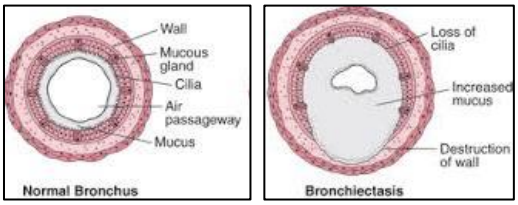
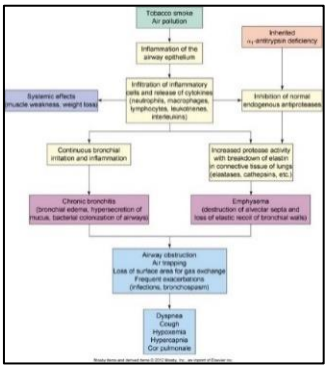


Figure 20: Pathophysiology of bronchiectasis compared to normal bronchus

- Accumulation of/inability to clear secretions
- Progressive destruction of the normal lung architecture

Clinical manifestations:

- Chronic cough, green/yellow sputum, dyspnea
- Breath indicative of active infection
- Crepitation/crackles base of the lung



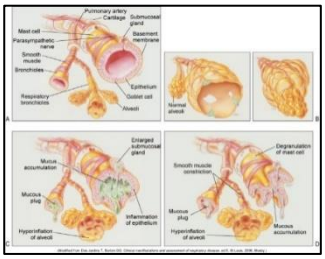


Figure 21(a)(b): Pathophysiology of obstructive pulmonary disease

Complications:

- Emphysema
- Secondary amyloidosis

Emphysema

- Permanent enlargement of alveoli accompanied by destruction of alveolar walls without obvious fibrosis

Etiology:

- COPD **(main reason)**

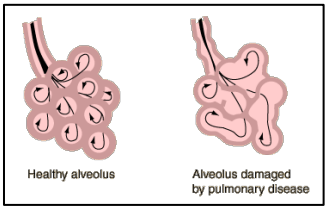


Figure 22: Damaged alveolus of pulmonary disease

Pathophysiology:

- Loss of elastic recoil
- Dilation and combining air spaces reduces surface area for oxygen exchange
- Ruptured alevoli

Clinical manifestations

- As in other COPD
- Labored breathing
- **Barrel chest**

*Respiratory Tract Infections

Pneumonia:

- Discussed in detail in LUSL2036
- **Pathophysiology**:
    - Acute inflammation; accumulation of neutrophils & macrophages, inflammatory mediators, congestion, exudate release, etc.
    - Consolidation (inflamed, thickened and scarred airway)

Tuberculosis

- Discussed in detail in LUSL2036
- **Pathophysiology**:

- Chronic inflammation, tubercle formation, caseous necrosis

Acute bronchitis

- Acute inflammation of the bronchi
- Commonly follows a viral infection of upper resp tract
- Similar symptoms to pneumonia but does not demonstrate pulmonary consolidation and chest infiltrates

Obstructive Sleep Apnea

- Partial or complete upper airway obstruction during sleep

Etiology:

- Adenotonsillar hypertrophy is the most common cause.
- Pharyngeal web = hyperplasia tissue that blocks the nasopharynx.
- At night the nasopharynx relaxes → high CO2 so patient wakens abruptly to temporarily correct breathing pattern (fix apnea).

Pathophysiology:

- Mild, moderate, severe based on AHI (apnea-hypopnea index)
- Disruption of normal ventilation and sleep patterns
- Oxidative stress
  - The cells get tired. The endothelium releases NO to dilate the vessels to help with O2
- Hypercoagulability and CV complications

Clinical Manifestations and Diagnosis:

- Snoring and labored breathing during sleep
- Daytime sleepiness
- Chronic mouth breathing
- Sleep studies (Polysomnography**)**
- **Sleep questionnaires**:
  - Berlin and *STOP-Bang

9: Pulmonary Vascular Disorders

Pulmonary Embolism (PE)

- Occlusion within pulmonary vascular bed by clot (thrombus, embolus), fat/air bubble, amniotic fluid droplet

Etiology and Pathophysiology:

- Deep vein thrombosis (DVT) in the lower limb
- Virchow triad
- Hypoxemia, low oxygen saturation
- Perfusion is affected, not ventilation

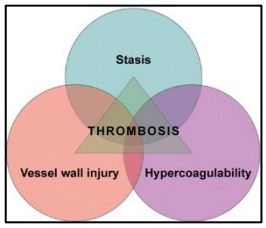


Figure 23: Virchow's triad

Clinical manifestations and evaluation:

- Dyspnea, chest pain on inspiration
- Tachycardia, cyanosis, hypotension

Lab and radiology:

- Elevated D-dimer
- CT & pulmonary angiography
- Doppler US

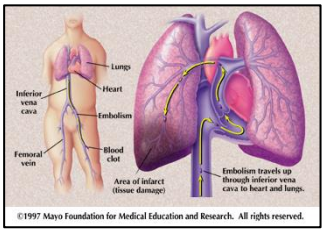
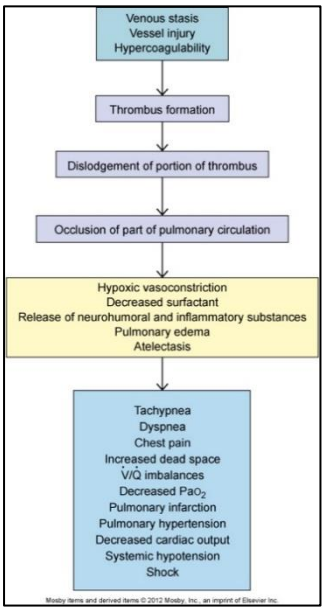


Figure 24: Pathophysiology of pulmonary embolism



Pulmonary Hypertension

- Elevation of pressure in pulmonary vasculature
- Pressure > 20 mm or elevation by 5-10 mm Hg above normal

Etiology & classifications:

- Primary pulmonary hypertension (Idiopathic)
- Pulmonary hypertension due to left heart disease
  - E.g. mitral valve
- Pulmonary hypertension due to lung disease/hypoxia
  - E.g. COPD
- Pulmonary hypertension due thrombo-embolic disease
  - E.g. lung clots

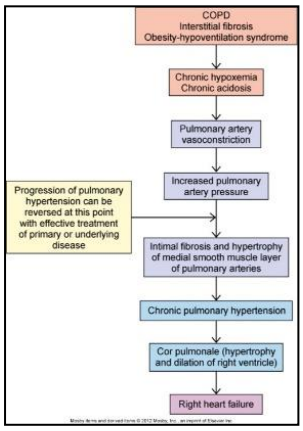


Figure 25: Pathophysiology of pulmonary hypertension

Clinical manifestations:

- Dyspnea
- Fatigue
- Dizziness

Complications:

- RT ventricular failure
- **Cor Pulmonale:**
  - RV enlargement/failure secondary to pulmonary hypertension

9: Malignancies of the Respiratory Tract:

Lung (bronchogenic) cancer

Etiology & risk factors:

- Cigarette smoking: most common cause (heavy smokers 20 x > risk than nonsmokers)
- Environmental or occupational risk factors e.g. asbestos, radon

Types:

- **Non-small cell carcinoma:**
  - Squamous cell carcinoma
  - Adenocarcinoma
  - Large cell carcinoma
- **Small cell carcinomas:**
  - Highly malignant
  - Can arise outside lungs (prostate, cervix, LN)
  - Can be hormone secreting (paraneoplastic)

9: Selected Pulmonary Function Disorders in Children - Chapter 27

Cystic Fibrosis

Etiology & Pathophysiology:

- Autosomal recessive- mutations in transmembrane conductance regulator ***(CFTR) gene***
  - Damages the chloride channels that helps make the mucus, this reduces the water, so the mucus is now thick
- Multisystem disease
- Exocrine or mucus-producing glands secrete abnormally thick mucus
- In the lungs, thick secretions obstruct the bronchioles and predispose to chronic lung infections
- Chronic inflammation leads to hyperplasia of goblet cells, bronchiectasis, pneumonia, hypoxia, fibrosis, etc.

Upper Airway Obstruction with Croup

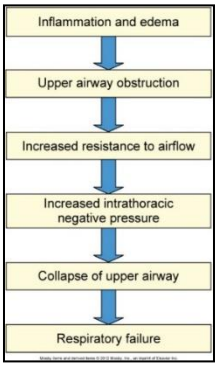


Figure 26: Pathophysiology of Croup

- *Croup*:
  - URT infection causing barking like cough
- One cause of stridor (noisy breathing) (others are fb.)
- Acute laryngotracheobronchitis:
  - Children from 6 months to 5 years
  - Commonly caused by a virus (influenza, or RSV)
  - Usually occurs after an episode of rhinorrhea, sore throat, low-grade fever
  - URT inflammation → obstruction → stridor (~70% narrowing)
  - Life-threatening

*Acute Epiglottitis

- Severe, rapidly progressive, life-threatening infection of the epiglottis and surrounding area
- Historically caused by *Haemophilus influenzae* type B
  - 80%-90% decreased incidence due to HIB vaccination

Manifestations:

- High fever
- Irritability
- Sore throat
- Inspiratory stridor/ muffled voice
- Severe respiratory distress

Aspiration Disorders

Etiology and pathophysiology:

- Aspiration of foreign bodies
  - In children, ages of 1-3
  - Any foreign substance: food, meconium (neonates), secretions (salivary or gastric), or environmental
  - Inflammation of the lung tissue (aspiration pneumonitis)
- Lung damage depends on volume and pH of aspirate
- Leading cause of death in children specially, neurologically compromised

Clinical Manifestations:

- Coughing
- Choking

- Gagging
- Wheezing
- Symptoms depend on size/ nature of the foreign body

Respiratory distress syndrome (RDS) of newborn

Etiology & Pathophysiology:

- Prematurity & lack of adequate surfactant
- Primarily a disease of preterm infants
- Widespread atelectasis, respiratory distress, and pulmonary hypertension

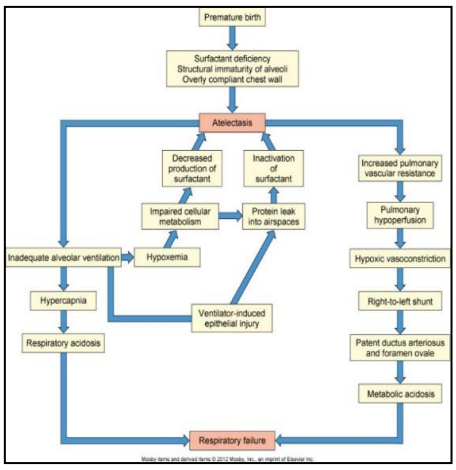


Figure 27: Pathophysiology of RDS of the newborn

Clinical manifestations:

- Tachypnea
- Expiratory grunting
- Nasal flaring
- Dusky skin