Respiratory System (Chapter 23)
Lecture Materials for Amy Warenda Czura, Ph.D.
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Primary Sources for figures and content:

Anatomy of Respiratory System:
1. Upper respiratory system:
   -functions to warm and humidify air
   -nose, nasal cavity, sinuses, pharynx
2. Lower respiratory system:
   A. Conducting portion:
      -bring air to respiratory surfaces
      -larynx, trachea, bronchi, bronchioles
   B. Respiratory portion:
      -gas exchange
      -alveoli

Respiratory Mucosa (mucus membrane)
-lines conduction portions
-pseudostratified columnar epithelium
-usually ciliated
-scattered goblet cells (mucin production)
-lamina propria = areolar CT with
-mucus glands (mucin) and
-serous glands (lysozyme)
Glands produce ~1 quart mucus fluid /day
-cilia move mucus to pharynx to be swallowed (cilia beat slow in cold)

Respiratory System Functions:
1. External respiration (gas exchange)
2. Pulmonary ventilation (move air)
3. Protect respiratory surfaces from:
   -dehydration
   -temp changes
   -invasion by pathogens
4. Produce sound (communication)
5. Provide olfactory sensation (smell)
Respiratory Defense Systems:
1. Mucus: from goblet cells and glands in lamina propria, traps foreign objects
2. Cilia: “mucus escalator”: move carpet of mucus with trapped debris out of respiratory tract
3. Alveolar macrophages: phagocytose particles that reach alveoli

**Cystic fibrosis** = failure of mucus escalator: produce thick mucus which blocks airways and encourages bacteria growth

Smoking → destroys cilia

Inhalation of irritants → chronic inflammation → cancer e.g. squamous cell carcinoma

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2. Nasal Cavity
-divided into right and left by nasal septum
-superior portion has olfactory epithelium
-nasal conchae (superior, middle, inferior) project into cavity on both sides

-nasal conchae cause air to swirl:
  1. Increase likelihood of trapping foreign material in mucus
  2. Provide time for smell detection
  3. Provide time and contact to warm and humidify air

-hard and soft palate form floor

-internal nares open to nasopharynx
-mucosa has large superficial blood supply (warm, moisten air) Epistaxis = nose bleed
-paranasal sinuses in frontal, sphenoid, ethmoid and maxillary bones; lined with respiratory mucosa, connected to nasal cavity, aid in warming/moistening air

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The Upper Respiratory System

1. Nose: only external feature
   Functions:
   1. Opening to airway for respiration
   2. Moisten and warm entering air
   3. Filter and clean inspired air
   4. Resonating chamber for speech
   5. Houses olfactory receptors

Features:
-external nares conduct air into vestibule
-vestibule = space in flexible part, lined with hairs to filter particles, leads to nasal cavity

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Rhinitis = inflammation of nasal mucosa →
↑ mucus production.
Infection → blockage of sinuses: headache from negative pressure

3. Pharynx:
- chamber between internal nares and entrances to larynx and esophagus
- Three parts

A. Nasopharynx: air only
- posterior to nasal cavity
- pseudostratified columnar epithelium
- closed off by soft palate and uvula during swallowing
- pharyngeal tonsil located on posterior wall (inflammation can block airway)
- auditory tubes open here

B. Oropharynx: food and air
- posterior to oral cavity
- stratified squamous epithelium
- palatine and lingual tonsils in mucosa

C. Laryngopharynx: food and air
- lower portion
- stratified squamous epithelium
- continuous with esophagus

Lower Respiratory System
4. Larynx (voice box)
- hyaline cartilages around glottis = opening from laryngopharynx to trachea

Functions of larynx:
1. Provide continuous airway
2. Act as switch to route food and air properly
3. Voice production
- contains epiglottis = elastic cartilage flap, covers glottis during swallowing

- folds of epithelium over ligaments of elastic fibers create vocal folds/cords.
- vocal cords project into glottis
- air passing through glottis vibrates folds producing sound

Pitch controlled by tensing/relaxing cords:
tense & narrow = high pitch

Volume controlled by amount of air

Sound production = phonation

Speech = formation of sound using mouth and tongue with resonance in pharynx, mouth, sinuses and nose

Laryngitis = inflammation of vocal folds due to infection or overuse, can inhibit phonation
5. Trachea
- attached inferior to larynx
- walls composed of three layers:
  1. Mucosa: pseudostratified columnar epithelium, goblet cells, lamina propria with smooth muscle & glands
  2. Submucosa: CT with additional mucus glands
  3. Adventitia: CT with hyaline cartilage rings (keep airway open): 15-20 C-shaped, have opening toward esophagus (allow expansion), ends connected by trachealis muscle

As bronchi get smaller, structure changes:
1. less cartilage in adventitia
2. more smooth muscle in lamina propria
3. epithelium thinner, less cilia, less mucus
4. bronchoconstriction

Trachea, Bronchi and Bronchioles innervated by ANS to control airflow to lungs:
- Bronchioles innervated by vessels, nerves
- Trachea, Bronchi and conducting portion (along with blood vessels) enter lungs at hilum - similar structure as respiratory tree - primary bronchi:
  - trachea branches into right and left primary bronchi
  - similar structure as trachea (no trachealis muscle)
  - right: steeper angle
  - enter lungs at hilum
    (along with blood and lymphatic vessels)

6. Primary bronchi
- inside lungs bronchi branch, get smaller in diameter:
  - branch ~23 times creating the bronchial tree

Asthma = strong bronchoconstriction activated by inflammatory chemicals (histamine), reduces airflow. Epinephrine inhaler mimics sympathetic (bronchodilate)

7. Terminal bronchiole
- smallest bronchi of respiratory tree
- no cartilage
- last part of conducting portion

Trachea, Bronchi and Bronchioles innervated by ANS to control airflow to lungs:
- Sympathetic = bronchodilation
- Parasympathetic = bronchoconstriction

As bronchi get smaller, structure changes:
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- each terminal bronchiole delivers air to one pulmonary lobule (separated by CT)
- inside lobule, terminal bronchiole branches into respiratory bronchioles: no cilia or mucus
- each respiratory bronchiole connects to alveolar sac made up of many alveoli
8. Alveoli
- wrapped in capillaries
- held in place by elastic fibers

-three cell types:
1. **Type I cells**: simple squamous epithelium, lines inside, gas exchange
2. **Type II cells**: cuboidal epithelial cells, produce surfactant (phospholipids + proteins), prevent alveolar collapse
3. **Alveolar macrophages**: phagocytosis of particles

-alveoli connected to neighbors by alveolar pores (equalize pressure)
-Gas exchange occurs across the respiratory membrane (0.5µm thick):
1. Type I cells of alveolus
2. Thin basal lamina (fusion)
3. Endothelial cells of capillary

Pneumonia = inflammation of lungs from infection or injury, fluid in alveoli prevents gas exchange
Pulmonary embolism = block in branch of pulmonary artery, reduced blood flow causes alveolar collapse

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**Respiratory Physiology**

3 steps of respiration:
1. Pulmonary ventilation
2. Gas Diffusion/Exchange
3. Gas Transport to/from tissues

1. **Pulmonary Ventilation**
   - movement of air into/out of alveoli
   - visceral pleura adheres to parietal pleura via surface tension: altering size of pleural cavity will alter size of lungs
   Pneumothorax = injury of thoracic cavity, air breaks surface tension, lungs recoil = atelectasis (collapsed lung)

Mechanics of breathing:
- Boyle’s Law: gas pressure is inversely proportional to volume
- Air flows from area of high pressure to low

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Gross Anatomy of Lungs

- concave base, rests on diaphragm
- right: 3 lobes
- left: 2 lobes (accommodates heart)
- housed in pleural cavity
- cavity lined with parietal pleura
- lungs covered by visceral pleura
- both pleura produce serous pleural fluid to reduce friction during expansion
Pleurisy = inflammation of pleura, can restrict movement of lungs causing breathing difficulty

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**Factors influencing pulmonary ventilation:**
1. Airway resistance
   - diameter of bronchi
   - obstructions
2. Alveolar surface tension
   - surfactant (Type II cells) reduces alveoli surface tension to allow inflation
   *Respiratory distress syndrome* = too little surfactant, requires great force to open alveoli to inhale
3. Compliance
   = effort required to expand lungs and chest
   High compliance = expand easily (normal)
   Low compliance = resist expansion
   Compliance affected by:
   A. CT structure: loss of elastin/replacement by fibrous tissue = ↓ compliance
   *Emphysema* = respiratory surface replaced by scars, ↓ elasticity ↓ compliance, and have loss of surface for gas exchange

**Respiratory Volumes and Capacities:**
- a breath = one respiratory cycle
  (go to handout)

Respiratory rate = breaths/min ~18-20 at rest
Respiratory Minute Volume (RMV/MRV) = respiratory rate X tidal volume ~ 6 L
Not all reaches alveoli, some air remains in conducting portions = anatomic dead space (~1ml / lb body weight)
Alveolar ventilation = air reaching alveoli / min at rest ~ 4.2 L

**Contraction of diaphragm pulls it toward abdomen:**
- lung volume ↑
- air pressure ↓
- air flows in

**Relaxation causes diaphragm to rise in dome shape:**
- lung volume ↓
- air pressure ↑
- air flows out

**Rib cage movements can also contribute:**
- superior = bigger, air in
- inferior = smaller, air out

**B. Alveolar expandability (vs. collapse)**
- ↑ surface tension(↓ surfact.) = ↓ compliance
- fluid (edema) = ↓ compliance
**C. Mobility of thoracic cage**
- less mobility = ↓ compliance

**Inspiration**
- inhalation involves contraction of muscles to increase thoracic volume
  A. Quiet breathing = eupnea
     - diaphragm: moves 75% of air
     - external intercostals: elevate ribs, 25% more
  B. Forced breathing = hyperpnea
     - maximum rib elevation increases respiratory volume 6X: serratus anterior, pectoralis minor, scalenes, sternocleidomastoid

**Expiration**
A. Eupnea: passive, muscles relax, thoracic volume decrease
B. Hyperpnea: abdominal muscles (obliques, transversus, rectus) contract forcing diaphragm up, thoracic volume further decreases
Both tidal volume and respiratory rate are adjusted to meet oxygen demands of body.

2. Gas Exchange
- Air = 79% N₂, 21% O₂, 0.5% H₂O, 0.04% CO₂, trace inert gases
- Partial pressure of gas = concentration in air
- Gases follow diffusion gradients to diffuse into liquid: rate depends on partial pressure and temperature

High Altitude Sickness = ↓ PP O₂ at high altitude causes ↓ diffusion into blood
Decompression Sickness = PP of air gasses high underwater, high amounts of N₂ diffuse into blood. If pressure suddenly decreases, N₂ leaves blood as gas causing bubbles (damage, pain), Hyperbaric chambers used to treat

Diffusion at respiratory membrane efficient:
1. Substantial differences in PP across the membrane
2. Distance is small
3. Gasses are lipid soluble
4. Large surface area for diffusion
5. Coordination of blood and air flow: ↑ blood to alveoli with ↑ O₂

In Lung:
- PP O₂ ↑ in alveoli,
  ↓ in capillary:
  diffuse into capillary
- PP CO₂ ↓ in alveoli,
  ↑ in capillary:
  diffuse into alveoli

In Tissues:
Pressures and flow reversed:
O₂ into tissues
CO₂ into capillary

3. Gas Transport
A. Transport of Oxygen
- 1.5% dissolved in plasma
- most bound to iron ions on heme of hemoglobin in erythrocytes: 4 O₂/Hb,
  ~280 million Hb/RBC = 1 billion O₂/RBC
Hemoglobin saturation = % hemes bound to O₂
  ~ 97.5% at alveoli
  @ ↑ PP O₂ hemoglobin binds O₂
  @ ↓ PP O₂ hemoglobin drops O₂
Carbon Monoxide Poisoning: CO out-competes O₂ for binding to Hb, even at low PP CO₂, causes suffocation (no O₂)

Other factors that affect Hb saturation:
1. Bohr effect: Hb releases O₂ in acidic pH (high CO₂ creates carbonic acid)
2. Temperature: Hb releases O₂ in ↑ temp
3. BPG (2,3-bisphosphoglycerate): produced by healthy RBC during glycolysis,
  ↑ BPG = ↑ O₂ release
4. Pregnancy: fetal Hb = ↑ O₂ binding

Hypoxia = inadequate O₂ delivery to tissues
B. Transport of Carbon Dioxide
1. ~ 70% as Carbonic acid
   - in RBCs and plasma
   - carbonic anhydrase in RBCs catalyze reaction with water:
     CO₂ + H₂O ↔ H₂CO₃ ↔ H⁺ + HCO₃⁻
   - reaction reversed at lungs
2. ~23% as carbaminohemoglobin
3. ~7% dissolved in plasma as CO₂

Regulation of Respiration
(handout)
Age Related Changes
1. Elastic tissue deteriorates:
   - ↓ compliance, ↓ VC
2. Arthritic changes in rib cage:
   - ↓ mobility, ↓ RMV
3. Emphysema, some degree
   - ↓ gas exchange
   Higher risk for smokers, dusty job, etc.