Functions of the Respiratory System

• Gas Exchange

• Voice Production

• Regulation of plasma pH

• Odor Detection

• Prevention of Infection
Pulmonary Ventilation
Exchange of air btwn lungs and atmosphere

• In order for air to move there must be a PG

• When breathing in:
  – \( \text{Lung P} < \text{Atmospheric P} \)

• When breathing out:
  – \( \text{Lung P} > \text{Atmospheric P} \)
Alveolar Gas Exchange
Exchange of CO₂ & O₂ btwn lung air and plasma

What's higher: PO₂ in lung air or PO₂ in lung blood?
Gas Transport

- Oxygen = 98.5% via Hb

- Carbon dioxide = 70% dissolved in plasma as bicarbonate
Systemic Gas Exchange
Exchange of CO₂ & O₂ btwn plasma and tissue fluid

What’s higher: PO₂ in ISF or PO₂ in blood?
Cellular Respiration

• Breakdown of nutrients for production of ATP

• Mitochondria

• $O_2$ is used and $CO_2$ is produced.
Conducting zone

- Nose
- Nasal cavity
- Pharynx
- Larynx
- Trachea
- Bronchus
- Bronchiole
- Terminal bronchiole

Respiratory zone

- Respiratory bronchiole
- Alveolar duct
- Alveoli
Conducting Zone

• Primary function is air transport

• Secondary functions:
  – Removing the 3 P’s
  – Adding heat
  – Adding water
On a mild November day as inspired air passes through the conducting zone...

- Its temperature will:
- Its $H_2O$ content will:
- Its pathogen content will:
- Its particle content will:
- Its $O_2$ content will:
- Its $CO_2$ content will:
Respiratory Mucosa

- Lines most of the conducting zone
- Pseudostratified ciliated columnar epithelium with goblet cells.
- Underlain by vascular CT with mucous and serous glands
Respiratory Zone

- Alveoli

- Found within:
  - Respiratory bronchioles
  - Alveolar ducts
  - Alveolar sacs.
Pseudostratified ciliated columnar epithelium lines the nasal cavity, paranasal sinuses, nasopharynx, trachea, main and lobar bronchi.

Simple ciliated columnar epithelium lines the segmental bronchi and large bronchioles.

Simple ciliated cuboidal epithelium lines the small terminal and respiratory bronchioles (with progressive loss of cilia).

Simple squamous epithelium lines the alveolar ducts and forms alveoli.
Nose

External Nose

Internal Nasal Cavity

Nasal Septum

Nares
Vestibule
Vibrissae
Bones and Cartilage of the Nasal Septum
Nose

- **Roof**
  - Frontal, sphenoid, ethmoid

- **Floor = Hard palate**
  - Palatine processes of maxillae
  - Horizontal plates of palatine bones

- **Walls**
  - Maxillae
  - Palatines
  - Conchae
Nasal Conchae

- Surface area

- Airflow

- Time
Nasal Conchae
Posterior Nasal Apertures (Choanae)
Paranasal Sinuses

• 5

• Functions:
  – Produce mucus
  – Lighten the skull
  – Create resonance

• Drainage
Paranasal Sinuses
Pharynx

- 3 regions:
  - Nasopharynx
  - Oropharynx
  - Laryngopharynx
Nasopharynx

- Posterior nasal apertures (Choanae)
- Soft palate
- Uvula
- Pseudo tonsil
- Auditory tubes
Oropharynx

- Uvula - Epiglottis.
- Tonsils
- Strat Sq
Laryngopharynx

- Epiglottis - Division between larynx and esophagus.

- Strat sq
Larynx

- Routes food and air down the appropriate tube
- 9 cartilages.
- Membranes, ligaments, epithelia, muscles, nerves and blood vessels.
- Mostly pseudo
Epiglottis

Hyoid bone

Thyroid cartilage

Cuneiform cartilage

Corniculate cartilage

Arytenoid cartilage

Cricoid cartilage

Trachea
Sphincter Function
Trachea

- Runs from larynx to bronchi
- Basic conducting zone functions
Trachea
Lung Anatomy

- Apex
- Superior lobe
- Oblique fissure
- Pulmonary veins
- Main bronchus
- Pulmonary artery
- Root of the lung
- Cardiac impression
- Cardiac notch
- Oblique fissure
- Lingula
- Middle lobe
- Horizontal fissure
- Hilum
- Base
- Inferior lobe
- Right lung
- Left lung
Lung Anatomy

- Superior lobe
- Apex
- Oblique fissure
- Cardiac notch
- Middle lobe
- Inferior lobe
- Horizontal fissure
- Base

(a) Lateral views

Right lung

Left lung
Lung and Bronchi

- Right main bronchus
- Right lobar bronchus
- Right segmental bronchus
- Smaller bronchi
- Left main bronchus
- Left lobar bronchus
- Left segmental bronchus
- Smaller bronchi
Smaller bronchi
Segmental bronchi
Lobar bronchi
Main bronchi

Bronchi
Cartilage

No cartilage

Alveoli

Respiratory bronchiole

Terminal bronchiole

Bronchiole

Smaller bronchi

Lobar bronchi

Segmental bronchi

Cartilage plates

Left main bronchus

Trachea

Cartilage rings

Muscularis

Submucosa

Mucosa

Bronchoconstricted

Bronchodilated

Cross sections of bronchioles

Terminal bronchiole

Alveoli

Respiratory bronchiole

No cartilage

Cartilage
As we go down the bronchial tree…

• The amount of cartilage present will:

• The relative amount of smooth muscle present will:

• The number of cilia will:

• The number of goblet cells will:

• The available surface area will:

• The thickness of the epithelium will:
• Diameter <1mm.

• Lack cartilage

• Terminal bronchioles.

• Respiratory bronchioles.
Respiratory/Exchange Zone

- Respiratory bronchioles
  - Beginning
  - Alveoli
  - Simple cuboidal epithelium.
  - Give rise to alveolar ducts.

- Alveolar ducts
  - Side-by-side alveoli.
  - Give rise to alveolar sacs – dead ends consisting of alveoli.
Alveoli

• Sites of exchange
• Simple squamous
• 300 million.
Alveolar Cells

- Erythrocyte
- Pulmonary capillaries
- Alveolar type I cell
- Alveolar type II cell
- Alveolar macrophages
- Alveolar pores
- Interalveolar septum
Respiratory Membrane

- Interalveolar septum
- Nucleus of capillary endothelial cell
- Nucleus of alveolar type I cell
- Erythrocyte
- Capillary
- Alveolus
- Alveolar epithelium
- Fused basement membranes of the alveolar epithelium and the capillary endothelium
- Respiratory membrane
- Capillary endothelium

Diffusion of O₂
Diffusion of CO₂
Pleurae = Double layered serosa covering each lung.
Atmosphere

Atmospheric pressure (760 mm Hg)

Pleural cavity (intrapleural pressure)

756 mm Hg

Alveolar volume of lungs (intrapulmonary pressure)

760 mm Hg
Transpulmonary Pressure $= 0 \text{ mmHg}$
Intrapulmonary pressure = atmospheric pressure

1. Intrapulmonary pressure = atmospheric pressure
   atm = 760 mm Hg
   756 mm Hg (Intrapleural pressure)
   760 mm Hg (Intrapulmonary pressure)
   | Diaphragm |

2. Intrapulmonary pressure becomes less than atmospheric pressure; air flows in
   atm = 760 mm Hg
   754 mm Hg
   Alveolar volume increases
   Intrapulmonary pressure decreases
   Pleural cavity volume increases
   Air flows in (~500 mL per quiet breath)

3. Intrapulmonary pressure = atmospheric pressure
   atm = 760 mm Hg
   754 mm Hg (Intrapleural pressure)
   760 mm Hg (Intrapulmonary pressure)

4. Intrapulmonary pressure becomes greater than atmospheric pressure; air flows out
   atm = 760 mm Hg
   756 mm Hg
   Alveolar volume decreases
   Intrapulmonary pressure increases
   Pleural cavity volume decreases
   Intrapleural pressure increases
   Air flows out (~500 mL per quiet breath)
Pressure and volume are inversely related.

Boyle’s Law: $P_1 V_1 = P_2 V_2$

$V_1 = 1.0 \text{ L}$  
$P_1 = 100 \text{ mm Hg}$

$V_2 = 0.5 \text{ L}$  
$P_2 = 200 \text{ mm Hg}$
The Quiet Inspiratory Sequence

Air moves into the lung if intrapulmonary P < atmospheric P.

We ↓ intrapulmonary P by increasing lung volume.

We increase lung volume by increasing thoracic volume. (Remember the pleural fluid!)

We increase thoracic volume by contracting skeletal muscles.
Muscles of Quiet Inspiration
Muscles of Quiet Inspiration

- Serratus anterior
- External intercostals
- Diaphragm
- Vertebrae
- Rib
- Sternum
Forced Inspiration

• The pressure gradient will need to be even bigger
• So, lung pressure will need to be even lower
• So, lung volume will need to be even bigger
• So, thoracic volume will need to be even bigger
• How do we do this?
More Motor Units

[Diagram of the ribcage with labeled parts: Sternum, Ribs, Diaphragm, Intercostal muscles]
Muscles of Forced Inspiration
Quiet Expiratory Process

1. Phrenic nerve and intercostal nerves cease firing.

2. Diaphragm and external intercostals relax

3. Thoracic volume decreases

4. Lung volume decreases

5. Intrapulmonary P increases

6. Air flows out of the alveoli
He had serious chronic emphysema. How does that related to his barrel-chestedness?
Forced Expiration

- The pressure gradient will need to be even bigger
- So, lung pressure will need to be even bigger
- So, lung volume will need to be even smaller
- So, thoracic volume will need to be even smaller
- *How do we do this?*
Airway Resistance

• Normally insignificant b/c
  – Airways are relatively wide
  – Air has a low viscosity
Surface Tension

cohesion

An alveolus

H₂O
Type II alveolar cell – secretes pulmonary surfactant
Type I alveolar cell
Interstitial fluid
Pulmonary capillary
Alveolar fluid lining with pulmonary surfactant
Alveolar macrophage
Erythrocyte
An autoimmune disease that caused destruction of type 2 alveolar cells would cause surfactant levels to...

This would cause alveolar surface tension to _____________; and the amount of energy used to inflate the lungs would ______________.
Compliance

- Lung Compliance
- Thoracic Compliance
Atmospheric Composition

- CO$_2$ 0.04%
- N$_2$ 78.6%
- O$_2$ 20.9%
- H$_2$O 0.46%
Alveolar Gas Composition

- CO$_2$  5.2%
- N$_2$   74.9%
- O$_2$   13.7%
- H$_2$O  6.2%
3 Factors Affecting Alveolar Gas Exchange

• Ventilation-Perfusion Coupling

• Thickness of the Respiratory Membrane

• Partial Pressure Gradients and Solubilities
Thickness of the Respiratory Membrane

- Alveolar epithelium
- Nucleus of endothelial cell
- Capillary
- Endothelium
- Surfactant
- Fused basement membranes
- Alveolar air space

Diagram showing the thickness of the respiratory membrane, typically ranging from 0.1 to 1.5 micrometers, with variations in normal and pneumonia conditions.
Partial Pressure Gradients

Alveolus

Po₂ = 104 mm Hg
Pco₂ = 40 mm Hg

Respiratory membrane

Capillary endothelium

Fused basement membranes

Alveolar endothelium

PO₂ = 40 mm Hg
PCO₂ = 45 mm Hg

Blood flow in pulmonary capillary

Alveolar gas exchange
Systemic Gas Exchange

Blood flow in systemic capillary

- \( \text{PO}_2 = 95 \text{ mm Hg} \)
- \( \text{PCO}_2 = 40 \text{ mm Hg} \)

- \( \text{PO}_2 = 40 \text{ mm Hg} \)
- \( \text{PCO}_2 = 45 \text{ mm Hg} \)

Tissue cells

Plasma membrane

Interstitial fluid

Capillary endothelium
Oxygen Transport

- 98.5% bound to Hb
- 1.5% dissolved in plasma
- Oxyhemoglobin vs. reduced hemoglobin.
- How many $O_2$ molecules per hemoglobin?
HHb + O$_2$ $\leftrightarrow$ HbO$_2$ + H$^+$

Which way will the reaction go when oxygen levels are high?

Which way will the reaction go when oxygen levels are low?

What effect will carbon dioxide have on the direction of the rxn?

What effect will heat have on the direction of the rxn?

What effect will low pH have on the direction of the rxn?
Hemoglobin % Saturation

- Lungs
- Systemic arteries
- Systemic veins
- Venous reserve

Po$_2$ (mm Hg)

Percent $O_2$ saturation of hemoglobin

Points: (a), (b), (c), (d), (e)
Carbon Dioxide Transport

- 10% dissolved in plasma.

- 20% as carbaminohemoglobin (HbCO$_2$) in RBCs.

- 70% as bicarbonate (HCO$_3^-$) in plasma.
Carbon Dioxide Transport

Tissue cell

Interstitial fluid

CO₂

CO₂ + H₂O → H₂CO₃ → HCO₃⁻ + H⁺ (Slow)

CO₂ + H₂O → H₂CO₃ → HCO₃⁻ + H⁺ (Fast, via Carbonic anhydrase)

CO₂ + Hb → HbCO₂ (Carbamino-hemoglobin)

Red blood cell

HbO₂ → O₂ + Hb

Blood plasma

Binds to plasma proteins

Chloride shift (in) via transport protein

CO₂ (dissolved in plasma)

HCO₃⁻

Cl⁻

HHb

O₂ (dissolved in plasma)
Blood plasma

Alveoli:

$CO_2$ (dissolved in plasma)

$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$

$CO_2$ + Hb $\rightarrow$ HbCO$_2$ (Carbaminohemoglobin)

$CO_2$ + Hb $\rightarrow$ HbCO$_2$ (Carbaminohemoglobin)

Red blood cell:

$O_2 + HHb \rightarrow HbO_2 + H^+$

Blood plasma:

$O_2$ (dissolved in plasma)
Control of Respiration

- Medulla Oblongata
  - Ventral respiratory group
  - Dorsal respiratory group

- Pontine respiratory group
Control of Respiration

- Dorsal respiratory group
  - Helps integrate sensory info.

- Pontine respiratory group
  - Modifies breathing during sleep, exercise, etc.
VRG = Primary Control Center

- Inspiratory neurons
  - Stimulate phrenic and intercostal nerves

- Expiratory neurons
  - Inhibition of inspiratory neurons

- Mainly influenced by CSF pH

- Also influenced by plasma pH, P\text{CO}_2, and plasma P\text{O}_2
Central Chemoreceptors Signal the VRG

• Ventral medulla

• Measure CSF pH

• CSF pH is inversely related to CSF $Pco_2$

• CSF $Pco_2$ is directly related to plasma $Pco_2$
An increase in plasma CO$_2$ will cause...

- Plasma $P_{\text{CO}_2}$ to:
- CSF $P_{\text{CO}_2}$ to:
- CSF $H^+$ to:
- CSF pH to:
- Respiration rate to:
- Respiration depth to:
Peripheral Chemoreceptors Signal the VRG

- Aortic bodies and carotid bodies
- Measure plasma $P_{CO_2}$, $P_{O_2}$, and pH
- Less sensitive
Secondary Factors Influencing Respiratory Rate
Respiratory Acidosis

- Hypoventilation would have what effect on plasma pH?
Respiratory Alkalosis

- Hyperventilation would have what effect on plasma pH?
Metabolic Acidosis

- What happens to plasma pH?
- What are possible causes?
- How would the respiratory system attempt to compensate?
Metabolic Alkalosis

• What happens to plasma pH?

• What are possible causes?

• How would the respiratory system attempt to compensate?