Functions of the Respiratory System

• Gas Exchange

• Voice Production

• Regulation of plasma pH

• Odor Detection

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

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

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

• When breathing out:
  – $\text{Lung } P > \text{ Atmospheric } P$
Alveolar Gas Exchange
Exchange of CO\textsubscript{2} & O\textsubscript{2} btwn lung air and plasma
Gas Transport

- Oxygen = 98.5% via Hb

- Carbon dioxide = 70% dissolved in plasma as bicarbonate
Systemic Gas Exchange
Exchange of $\text{CO}_2$ & $\text{O}_2$ btwn plasma and tissue fluid
Cellular Respiration

• Breakdown of nutrients for production of ATP

• Mitochondria

• $O_2$ is used and $CO_2$ is produced.
Structural Divisions

Upper respiratory tract

Lungs

Lower respiratory tract

Nose

Nasal cavity

Pharynx

Larynx

Trachea

Bronchus

Bronchiole

Terminal bronchiole
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

![Diagram of Respiratory Mucosa]

- Mucus
- Goblet cell
- Epithelium
- Basement membrane
- Lamina propria
- Blood vessel
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

Nares
Vestibule
Vibrissae

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

dilated vein
dilated vein
cartilage
bone
nasal cavity
Posterior Nasal Apertures (Choanae)
Paranasal Sinuses

- 5

- Functions:
  - Produce mucus
  - Lighten the skull
  - Create resonance

- Drainage
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
1. Epiglottis
2+3. Cuneiform cartilage
4+5. Corniculate cartilage
6+7. Arytenoid cartilage
8. Cricoid cartilage — a complete ring
9. Thyroid cartilage

Body of hyoid bone
Vestibular fold (false vocal cord)
Vocal fold (true vocal cord)

Tracheal cartilages

Sagittal section (anterior on the right)
Sphincter Function
Trachea

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

- Clavicle
- Scapula
- Ribs
- Heart
- Sternum
- Base of left lung
- Base of right lung
- Diaphragm
- Vertebral column
Lung Anatomy
Lung Anatomy

(a) Lateral views

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

Right lung

Left lung
Right main bronchus
Right lobar bronchus
Right segmental bronchus
Smaller bronchi

Left main bronchus
Left lobar bronchus
Left segmental bronchus
Smaller bronchi

Larynx
Trachea

Smaller bronchi
Segmental bronchi
Lobar bronchi
Main bronchi
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:
Bronchioles

• 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

Diffusion of CO₂, Diffusion of O₂

Alveolus
Respiratory membrane
Alveolar epithelium
Fused basement membranes of the alveolar epithelium and the capillary endothelium
Capillary endothelium
Pleurae = Double layered serosa covering each lung.
Pleurae
Important Pressures

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 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
   759 mm Hg
   Air flows in (~500 mL per quiet breath)
   Pleural cavity volume increases
   Intrapleural pressure decreases
   Alveolar volume increases
   Intrapulmonary pressure decreases

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

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

Boyle’s Law: \( P_1 V_1 = P_2 V_2 \)

\[
\begin{align*}
V_1 &= 1.0 \text{ L} \\
P_1 &= 100 \text{ mm Hg} \\
V_2 &= 0.5 \text{ L} \\
P_2 &= 200 \text{ mm Hg}
\end{align*}
\]
The Quiet Inspiratory Sequence

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

We $\downarrow$ 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

Pleural space

Diaphragm
Muscles of Quiet Inspiration

- Serratus anterior
- External intercostals
- Diaphragm
- Vertebrae
- Rib
- Sternum
Intercostal nerves

Phrenic nerve
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
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
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

- CO₂ 0.04%
- N₂ 78.6%
- O₂ 20.9%
- H₂O 0.46%
Alveolar Gas Composition

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

• Ventilation-Perfusion Coupling

• Thickness of the Respiratory Membrane

• Partial Pressure Gradients and Solubilities
### Ventilation-Perfusion Coupling

**Bronchiole dilates**

- Pulmonary arteriole

**Bronchiole constricts**

- Increased $\text{Pco}_2$ in air within bronchiole
- Decreased $\text{Pco}_2$ in air within bronchiole

**Alveolus**

**Capillary bed**

(a) Changes in bronchioles
Ventilation-Perfusion Coupling

Arterioles dilate

Arterioles constrict

Increased $\text{Po}_2$
or
Decreased $\text{Pco}_2$
in blood

Decreased $\text{Po}_2$
or
Increased $\text{Pco}_2$
in blood

(b) Changes in arterioles
Thickness of the Respiratory Membrane

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

Normal
- Bronchiole
- Air sacs (alveoli)
- Fluid in air sacs
- Pneumonia

Windpipe (trachea)

Lung

Bronchus
Partial Pressure Gradients

- Alveolus
- Po$_2$ = 104 mm Hg
- Pco$_2$ = 40 mm Hg

- Respiratory membrane
- Alveolar endothelium
- Fused basement membranes
- Capillary endothelium

- Alveolar gas exchange

- Po$_2$ = 40 mm Hg
- Pco$_2$ = 45 mm Hg

- Oxygen (O$_2$)
- Carbon Dioxide (CO$_2$)

- Blood flow in pulmonary capillary
Blood flow in systemic capillary

$Po_2 = 95 \text{ mm Hg}$
$Pco_2 = 40 \text{ mm Hg}$

$Po_2 = 40 \text{ mm Hg}$
$Pco_2 = 45 \text{ mm Hg}$

Systemic Gas Exchange
Oxygen Transport

- 98.5% bound to Hb
- 1.5% dissolved in plasma
- Oxyhemoglobin vs. reduced hemoglobin.
- How many $O_2$ molecules per hemoglobin?
HHb + O₂ ⇌ HbO₂ + 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
Carbon Dioxide Transport

- 10% dissolved in plasma.

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

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

\[
\begin{align*}
\text{CO}_2 & \text{ (dissolved in plasma)} \\
\text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{CO}_3 \\
\text{H}_2\text{CO}_3 & \rightarrow \text{HCO}_3^- + \text{H}^+ \\
\text{CO}_2 + \text{Hb} & \rightarrow \text{HbCO}_2 \text{ (Carbamino-hemoglobin)} \\
\text{HbO}_2 & \rightarrow \text{O}_2 + \text{Hb} \\
\end{align*}
\]

- Binds to plasma proteins
- Chloride shift (in) via transport protein

Red blood cell

Blood plasma
Carbon Dioxide Transport

\[
\text{CO}_2 \text{ (dissolved in plasma)}
\]

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+
\]

\[
\text{CO}_2 + \text{Hb} \rightarrow \text{HbCO}_2 \text{ (Carbaminohemoglobin)}
\]

\[
\text{O}_2 + \text{HHb} \rightarrow \text{HbO}_2 + \text{H}^+
\]
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, $\text{Pco}_2$, and plasma $\text{Po}_2$
Central Chemoreceptors Signal the VRG

- Ventral medulla

- Measure CSF pH

- CSF pH is inversely related to CSF P\textsubscript{CO}_2

- CSF P\textsubscript{CO}_2 is directly related to plasma P\textsubscript{CO}_2
An increase in plasma CO$_2$ will cause...

- Plasma Pco$_2$ to:
- CSF Pco$_2$ 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 $\text{Pco}_2$, $\text{Po}_2$, 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?