Objectives:

1. Review respiratory anatomy.
2. Understand mechanics of breathing.
3. Learn lung volumes & respiratory vocabulary
4. Learn gas exchange at lungs & at body tissues
5. Learn autonomic regulation of respiration.
7. Respiratory control of acid/base balance.

Anatomy of Respiratory System

2 Zones of Respiratory System:

1) Conduction Zone = from oral/nasal cavities to,

- Oral cavity
- Pharynx
- Larynx
- Trachea
- Carina of trachea
- Right main bronchus
- Right lobe
- Left main bronchus
- Left lobe
- Terminal bronchioles

2) Respiratory Zone
2) **Respiratory zone**

**Respiratory bronchioles** = smallest bronchioles, branch from tertiary bronchioles.

**Alveolar sacs** = honey-comb shaped, 1-cell thick sacs for gas exchange.

[~300 mill in lungs! ~760 sq ft area!]

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**Diagrammatic view of capillary-alveoli relationships**

**QUEST:** Is this a pulmonary artery or vein?

**Quest:** Is this a pulmonary artery or vein?

**How gases are exchanged w/blood**

Surrounded by arterial & venous capillaries ("capillary plexus") for gas exchange between alveoli & blood.
2 Types Alveolar Cells:

Type 1 Alveolar Cells = Make up wall of alveolus. 97% of total lung surface area where most gas exchange occurs.

Type 2 Alveolar Cells - secrete **surfactant**

*Surfactant =

Why is surfactant important?

Non-obstructive Atelectasis =

____________________________

____________________________

____________________________

Not to be confused with Obstructive Atelectasis =

____________________________

____________________________

____________________________
**Surfactants ↓ intra-alveolar pressure & prevent collapse**

**Infant Respiratory Distress Syndrome (IRDS)**
- Surfactant is produced > 28 weeks (7-8 months)
- Babies are born < 28 wks - not enough surfactant. High surface tension inside alveoli, results in collapsed alveoli, which collapses lung (non-obstructive atelectasis)
- Tx = synthetic surfactant delivered into baby’s lungs & mechanical ventilator until Type 2 alveolar cells can make surfactant.

**Acute Respiratory Distress Syndrome (ARDS)**
- Due to inflammation from infection (septic shock)
- Results in protein (serum) secretion in lungs.
- Fluid dilutes surfactant, ↑ surface tension, alveoli collapse,
- ↓ lung compliance, could cause lung collapse (non-obstructive atelectasis)

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**Refresher of the thoracic cavity:**

**Membranes of the lungs:**
- **Visceral pleura**
- **Parietal pleura**
  - Lines the pleural cavities

**Intrapleural space =**

*Lungs normally fill thoracic cavity, pleura pressed together.*
- Serous fluid layer between pleura decreases friction

*Parietal pleura held tight against thoracic wall by surface tension of water layer.*
- As thoracic cage changes volume (with breathing) so do lungs.*
2. Mechanics of Respiration

1) Air moves from high to low pressure
- Depends on where pressure is greatest
- Atmospheric air pressure = constant (760 mmHg)
- Lung air pressure depends on volume of thoracic cavity

2) Air pressure in lungs (closed chamber) changes with volume of chamber
   "Boyle’s Law" = as volume of closed chamber ↑, air pressure within _______
   as volume of closed chamber ↓, air pressure within _______

   Translates to lung volume & air pressure within lungs ("intrapulmonary pressure"):
   As thoracic volume ↑ lung volume ↑ & intrapulmonary pressure ______
   As thoracic volume ↓ lung volume ↓ & intrapulmonary pressure ______

Boyle’s Law

Chamber volume larger BUT air pressure lower

Chamber volume smaller BUT air pressure higher
Inspiration
- Intrapulmonary pressure = pressure inside lungs
  - During inhalation – is lower than atmospheric pressure (-3 mmHg)
  - During exhalation – is above atmospheric pressure (+3 mmHg)

Expiration
- Intrapulmonary pressure = pressure inside lungs
  - During inhalation – is lower than atmospheric pressure (-3 mmHg)
  - During exhalation – is above atmospheric pressure (+3 mmHg)

Intrapleural pressure = pressure between the pleural membranes due to elastic recoil (parietal pleura sticks to wall)
  - During inhalation – is lower than atmospheric (-6 mmHg)
  - During exhalation – is still lower atmospheric (-3 mmHg)

*** intrapleural pressure should ALWAYS be negative. If air enters this space, the lung can detach from thoracic wall, trapped air puts pressure on lung, & lung can collapse. ***

Transpulmonary pressure = difference between intrapulmonary & intrapleural pressure (is ALWAYS above atmospheric pressure).
**Physical properties of the lungs:**

**A) Surface tension** = pressure resulting from thin film of water lining alveoli that resists their expansion.

_Law of LaPlace & surface tension in alveoli:_
- Pressure is greater the smaller alveoli become (w/exhalation).
- Pressure is smaller in larger alveoli (w/inhalation).

**B) Compliance** = ability of lungs to expand with skeletal muscle activity. [Allows changes in thoracic volume to change lung volume.]
- more lung compliance = greater capacity for “stretchiness”
- less lung compliance = less capacity for “stretchiness”

**C) Elasticity/Recoil** = tendency of lungs to return to normal shape after either inflating (inhalation) or deflating (exhaling).

**A) Surface Tension & Law of La Place**

_“Law of LaPlace” = air pressure within alveolar sac depends on surface tension and size of alveolar sac:_

Large alveoli – have lower surface tension & air pressure within them (expanding with air is easier w/large alveoli)

Small alveoli – have higher surface tension & air pressure within them. (expanding with air is harder w/small alveoli)

**anything that functionally ↓ alveolar size:**
- ↑ surface tension & intra-alveolar pressure
- ↓ gas exchange &
- ↓ respiratory capacity

**Greater:**
- Air pressure
- Surface tension

**Lower:**
- Air pressure
- Surface tension

Fig 16.10
B) Lung compliance

Factors that increase compliance:
- pulmonary “surfactants”

Disease:
- Chronic Obstructive Pulmonary Disease (COPD) = umbrella term for chronic bronchiole inflammation (includes emphysema, asthma, chronic bronchitis).
  - Leads to bronchiole scar-tissue (fibrosis), causes bronchoconstriction
  - mucus buildup ↑ resistance & ↓ compliance
  - ↓ expiratory reserve volume (90% SMOKERS!)

Ex: Emphysema = causes excessive lung compliance! Loss of - - Destroyed alveoli & alveolar walls weakened,
- Alveoli expand easily, but also collapse easily.

Asthma = inflammation of bronchioles.
- Bronchoconstriction (bronchospasms)
- Tx = anti-inflammatories & bronchodilator (or B2 agonist albuterol).

**anything that functionally ↓ alveolar size: like fluid buildup
- dilute surfactant
↑ surface tension & intra-alveolar pressure
↓ gas exchange &
↓ respiratory capacity

Smoking & Emphysema
Lung damage from smoking causes chronic bronchitis and formation of scar tissue (fibrosis)

Factors that decrease compliance:
- **Fluid in lungs** – from pneumonia or edema

- **Pulmonary fibrosis** = buildup of fibrous tissue in lungs stiffens them (Ex. from breathing in small particles that accumulate in lungs:
  - **Ex: Silicosis** = (inhalation of fine glass, rock, or sand particles)

  **Ex: Anthracosis (black lung disease)** = inhalation of coal dust.
Pneumothorax in lung

“Pneumothorax” = ______________________________________________________________.

(Can be traumatic or tension)

- Air trapped between the two pleural membranes removes the pressure gradient.

Result = can’t expand lungs to get air to enter! Lung collapses.

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Clinical Applications

If air enters the intrapleural space and thereby raises the intrapleural pressure, the difference in pressure between the inside of the lungs (intrapulmonary pressure) and the outside of the lungs (intrapleural pressure) is abolished. As a result, the lung is no longer stuck to the thoracic wall; this is like releasing a stretched rubber band, and the lung’s elastic recoil causes it to collapse. The condition of air entering the intrapleural space and causing the collapse of a lung is known as a pneumothorax. Fortunately, a pneumothorax usually causes only one lung to collapse, because each lung is contained in a separate pleural compartment.
Cystic Fibrosis
- Genetic disorder affecting Cl- channels on alveoli membrane.

Results in buildup of mucus within alveoli causing:
- Dilutes surfactant
- ↓ decreased functional alveolar size
- ↑ surface tension & intra-alveolar pressure
  (harder for alveoli to expand)
- ↓ with gas exchange
- Warmth & moisture (mucus) aids bacterial growth.
  (Vulnerable to pneumonia)

Review

- The respiratory system
  – The respiratory zone (respiratory bronchioles & alveoli)
    • External respiration, internal respiration
  – The conducting zone (oral cavity to 3° bronchioles)
    • Warming/humidification, filtration, cleaning
  – Ventilation, gas exchange, oxygen utilization
    • Intrapulmonary pressure, intrapleural pressure, transpulmonary pressure
    • Boyle’s Law
- Physical properties of the lungs
  – Lung compliance, elasticity, & surface tension
    • Role of surfactant
**3. Lung Volumes & Respiratory Vocabulary**

**Spirometry** = clinical evaluation of pulmonary (respiratory) function, which allows diagnosis of lung disorders.

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**TABLE 12.1 Terms Used to Describe Lung Volumes and Capacities**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung Volumes</td>
<td>The four nonoverlapping components of the total lung capacity</td>
</tr>
<tr>
<td>Tidal volume</td>
<td>The volume of gas inspired or expired in an unforced respiratory cycle</td>
</tr>
<tr>
<td>Inspiratory reserve volume</td>
<td>The maximum volume of gas that can be inspired during forced breathing in addition to tidal volume</td>
</tr>
<tr>
<td>Expiratory reserve volume</td>
<td>The maximum volume of gas that can be expired during forced breathing in addition to tidal volume</td>
</tr>
<tr>
<td>Residual volume</td>
<td>The volume of gas remaining in the lungs after a maximum expiration</td>
</tr>
<tr>
<td>Lung Capacities</td>
<td>Measurements that are the sum of two or more lung volumes</td>
</tr>
<tr>
<td>Total lung capacity</td>
<td>The total amount of gas in the lungs after a maximum inspiration</td>
</tr>
<tr>
<td>Vital capacity</td>
<td>The maximum amount of gas that can be expired after a maximum inspiration</td>
</tr>
<tr>
<td>Inspiratory capacity</td>
<td>The maximum amount of gas that can be inspired after a normal tidal expiration</td>
</tr>
<tr>
<td>Functional residual capacity</td>
<td>The amount of gas remaining in the lungs after a normal tidal expiration</td>
</tr>
</tbody>
</table>
Additional Respiratory Vocabulary:

**Apnea** = absence of breathing

**Dyspnea** = labored or difficult breathing

**Eupnea** = normal breathing at rest

**Hyperventilation** = excessively rapid ventilation (will decrease alveolar CO2)

**Hypoventilation** = low ventilation (will increase alveolar CO2)

**Pneumothorax** = presence of gas in intrapleural space causing lung collapse

---

Physiology in Health and Disease

People with pulmonary disorders frequently complain of dyspnea, which is a feeling of “shortness of breath.” The dyspnea, wheezing, and other symptoms of asthma are produced by increased resistance to airflow through the bronchioles (asthma is an obstructive pulmonary disorder, as discussed previously). The increased resistance to airflow is caused by bronchoconstriction and inflammation that may be provoked by allergic reactions (chapter 11). Asthma may be treated on a sustained basis with glucocorticoid drugs (related to cortisol) that inhibit inflammation, thereby preventing or reducing the severity of “attacks.” New drugs (such as Singular) that block the action of leukotrienes, a type of regulatory fatty acid (related to prostaglandins) that promote asthma, are now also available for this purpose. Acute asthma attacks are commonly treated with inhaled drugs (such as Albuterol) that stimulate the β₂-adrenergic receptors (a type of receptor for epinephrine and norepinephrine; see chapter 6) that promote dilation of the bronchioles.

Alveolar tissue is destroyed in emphysema, resulting in fewer but larger alveoli (see fig. 12.8). The loss of alveoli reduces the ability of the bronchioles to remain open during expiration, causing air trapping during expiration when the bronchioles collapse. The most common cause of emphysema is cigarette smoking, which indirectly causes different protein-digesting enzymes to destroy the lung tissue. The loss of alveoli and air trapping reduces gas exchange, so that people with emphysema have difficulty in both oxygenating the blood and eliminating carbon dioxide. Because of this, people with emphysema must often breathe from an oxygen tank.

Chronic obstructive pulmonary disease (COPD) is characterized by chronic inflammation with narrowing of the airways and destruction of the alveolar walls. Included in the COPD category is emphysema and chronic obstructive bronchiolitis, which refers to fibrosis and obstruction of the bronchioles. The condition results in a faster age-related decline in the FEV, (discussed previously). COPD differs from asthma in that, unlike asthma, COPD is not reversible with the use of a bronchodilator such as Albuterol. Also unlike asthma, COPD is not helped much by inhaled glucocorticoids (drugs related to hydrocortisone). The vast majority of people with COPD are smokers, and stopping smoking once COPD has begun does not seem to stop its progression. In addition to the pulmonary problems directly caused by COPD, this condition increases the risk of pneumonia, pulmonary emboli (traveling blood clots), and heart failure. Patients with COPD may develop cor pulmonale—pulmonary hypertension with eventual failure of the right ventricle. COPD is now the fifth leading cause of death in the United States, and scientists have estimated that by 2020 it will become the third leading cause of death worldwide.
4. Basics of Gas Exchange at Lungs and at Body Tissues

Gas exchange between 2 structures is dependent on pressure gradient of dissolved O₂ & CO₂

* Gas moves from side with higher pressure (from dissolved gases) to side with lower pressure & visa versa

* Gas wants to move “downhill” from high to low pressure!

Gas exchange between lung alveoli & pulmonary vessels:

> Alveolar PO₂ = 105 mmHg, higher than that in pulmonary arteries (40 mmHg)

> Alveolar PCO₂ = 40 mmHg, lower than that in pulmonary arteries (46 mmHg)
Gas exchange between systemic capillaries & tissues:

> Tissue PO2 (<100 mmHg) = lower than O2-rich arterial blood (100 mmHg)

> Tissue PCO2 (>40 mmHg) = higher than that in arterial blood (40 mmHg)

Review

- Pulmonary function tests (spirometry)
- Alveolar PO$_2$ lower than atmospheric
- Gas exchange at tissues & at alveoli of lungs
  Depends on differences in partial pressures of O$_2$ and CO$_2$
Motor neurons from 2 brain areas control breathing muscles:

1) Voluntary Breathing
   = primary motor cortex of frontal cerebral lobe.

2) Involuntary Breathing
   Medulla – respiratory center regulates respiratory rate.
   Pons – apneustic center (stimulate inhalation)
   – pneumotaxic center (inhibit inhalation)

What happens to minute ventilation after:

• Hypoventilation?

• Hyperventilation?

• Exercise?
Autonomic motor control breathing involves:

Chemoreceptors:
- Aorta & carotid artery chemoreceptors
- Medulla chemoreceptors

Hemoglobin =
- 4 protein chains w/4 iron-containing heme (pigments)
- Each heme group binds with 1 O2 molecule
- Each RBC has ~280 million hemoglobin molecules (each RBC can carry ~billion O2 molecules! (4 X 280 million)
- Hemoglobin bound to O2 = “oxyhemoglobin” (Arterial blood 97% saturated w/oxyhemoglobin = bright red)
- Hemoglobin lacking O2 = “deoxyhemoglobin” (venous blood dull red or maroon)
**Hemoglobin Disorders:**

**Carbon Monoxide** = odorless, color-less gas that binds w/hemoglobin to create **carboxyhemoglobin** in RBCs.

Carboxyhemoglobin has lower affinity for O2.

**Result:**
> Hypoxia (called carboxyhemoglobinemia)
> Death
Methemoglobinemia = disorder in which hemoglobin’s iron (a component of heme) is “ferric” rather than “ferrous”. 
> this hemoglobin called methemoglobin (pronounce as “met-hemoglobin”)
> Methemoglobin has ↓ ability to release (unload) O2 at tissues.
> Tissues chronically O2-starved.
> Patients are hypoxic & BLUE!

“Blue baby syndrome” = babies turn blue (hypoxia) from drinking milk made w/nitrate contaminated water. Nitrate causes formation of methemoglobin.

Neonatal jaundice At birth switch from hemoglobin-F (fetal) to hemoglobin-A (adult)
- Body removes RBCs with hemoglobin f.
- Liver removes biliruben from destroyed hemoglobin f.
- Liver sometimes not mature enough to remove biliruben.
- Biliruben builds up.
- Baby turns yellow. (happens in up to 50% newborns)

Treatment:
“blue light exposure” – breaks biliruben down to water-soluble form excreted by kidneys.
Sickle Cell Anemia = homozygous recessive condition in which body produces RBCs with hemoglobin-S rather than hemoglobin-A.
- Hemoglobin-S turns RBCs into sickle-shape.
- Sickled RBCs carry less O2 (cause hypoxia)
- Sickled RBCs tend to form clots (thrombus)
- Patients more prone to embolism.
- More prone to ischemic events.
Review

• Regulation of breathing
  – Medulla & pons
• Chemoreceptors
  – central, peripheral
• Hemoglobin O₂ transport:
  – Oxyhemoglobin & deoxyhemoglobin
  – Abnormal hemoglobin (carboxyhemoglobin, methemoglobin)
  – Neonatal jaundice
  – Sickle cell

7. Respiratory Control of Acid/Base Balance

Normal Blood pH = 7.35 – 7.45
Blood pH maintained by buffering CO₂ with HCO₃⁻

Blood Acid/Base balance has 2 components:

1) Respiratory component = where CO₂ (a volatile acid) in blood eliminated by lungs (exhalation).
   - Increased respiratory rate ↑blood pH.
   - Decreased respiratory rate ↓ blood pH.

2) Metabolic component = non-volatile acids in blood (i.e. lactic acid, fatty acids, ketones) eliminated by liver, kidneys, or other organs.
Acidosis = increased acids in blood (pH below 7.35)
Alkalosis = decreased acids in blood (pH above 7.45)

Respiratory acidosis = ↓ blood pH due to ↓ respiratory rate (hypoventilation) – not enough CO2 waste exhaled by lungs.

Respiratory alkalosis = ↑ blood pH due to ↑ respiratory rate (hyperventilation) – too much CO2 exhaled by lungs.

Metabolic acidosis = excess metabolic production of acids (i.e. ketosis) OR loss of bases (i.e. bicarbonate) from chronic diarrhea or kidney problems (excrete too much HCO3-)

Metabolic alkalosis = too much bicarbonate (not enough excreted by kidneys) OR loss of metabolic acids such as with chronic vomiting (lose HCL).

Review

• Acid / Base imbalance
  – Metabolic Acidosis & Alkalosis versus
  – Respiratory Acidosis & alkalosis