Ch 17: Mechanics of Breathing

**Functional division of respiratory system:**
- respiratory zone
- conducting zone

**Key Topics:**
- Structure and function of respiratory pumps
- **Gas exchange** with blood
- Role of surfactant and pressure differences on rate of exchange
- Regulation of respiration

Developed by John Gallagher, MS, DVM
Functions of the Respiratory System

- Oxygen exchange
  - Air to blood
  - Blood to cells (?)

- Carbon dioxide exchange
  - Cells to blood
  - Blood to air

- Regulation of body pH
  - $\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^-$

- Protection from pathogens, irritants

- Vocalization
Terminology

- Inspiration = Inhalation
- Expiration = Exhalation
- Ventilation
- Exchange
Review Anatomy

- Lungs: – thin walled, moist exchange surface (75 m²)
  - Alveoli
- Ribs & skin protect
- Respiratory muscles create the pressure gradient that moves air
  - Diaphragm
  - Intercostals

Fig 17-1

External Respiration

Cellular Respiration
Gas Laws \( p \, 565 \)

Partial Pressure = the pressure (in mm Hg) of a single gas in a mixture. An expression of concentration of a gas. (Chapt 18)

Atmospheric Pressure = 760 mm Hg at sea level; often reported as 0 mm Hg

- Air is a mix of gases: **Dalton’s law**
  \[ \text{Total } P = \sum \text{Ps of individual gases} \]
  Calculate partial pressure of \( O_2 \) in dry air at sea level

- Gases move down their pressure gradients

- Pressure-volume relationship:

- **Boyle’s law**: \( P_1V_1 = P_2V_2 \)
  - Describes the collisions of the gas molecules with both other gas molecule and the walls of the chamber
Ventilation

- = Breathing

- Pulmonary Function Tests use Spirometer

- Measure volume of air moved during ventilation
More Terminology

- Tidal Volume: Volume moved during normal respiration
  - Approx 500 ml
- Inspiratory Reserve Volume: The additional volume after a tidal inspiration
  - Approx 3000 ml
- Expiratory Reserve Volume: The additional volume after a tidal expiration
  - Approx 1100 ml
- Residual volume: What’s left after Expiratory Reserve Volume is exhaled
  - Harder to measure, approx 1200 ml
The Airways: Conduction of Air from Outside to Alveoli

- 3 upper airway functions:
  - Warming
  - Moisturizing
  - Filtration

- Mucociliary escalator depends on secretion of watery saline – note: Cystic Fibrosis (genetic disease) interferes with mucus clearance

- Effectiveness of nose vs. mouth breathing (Respirators!)

Compare to Fig. 17.8
Breathing and Ventilation

- Air flows due to pressure gradients (*analogous to blood*)

- Inspiration:
  - Contraction of diaphragm (60-75%) of volume change
  - External intercostals and scalenes (25-40%)

- Expiration
  - Relaxation of inspiratory muscles
  - Elastic recoil of pleura and lung tissue reinforce muscle recoil

\[ \text{Flow Rate} \propto \frac{\Delta P}{R} \]
Alveolar and Intrapleural Pressures

Lungs unable to expand and contract on their own

During inspiration, intrapleural pressure becomes subatmospheric

Lungs “stuck” to thoracic cage by pleural fluid bond and vacuum

Pneumothorax?

Fig 17-12
More Terminology

- **Compliance**: ability of lungs to stretch
  - Low compliance in fibrotic lungs (and other restrictive lung diseases) and when not enough surfactant

- **Elasticity** (= Elastance): ability to return to original shape
  - Low Elasticity in case of emphysema due to destruction of elastic fibers.

- Normal lung is both compliant AND elastic
Surfactant

- Surface tension at all air-fluid boundaries due to?
- Surface tension opposes alveolar expansion
- **Surfactant** = detergent like complex of proteins & PL: Disrupts cohesive forces between water molecules ⇒ ↓ **surface tension** ⇒ Easier inflation of alveoli ⇒ ↓ work of breathing
- RDS, p 576

Unequal attraction produces tension at liquid surface

Drop of water
Airways Resistance

- Also influences work of breathing.
- Primary determinant: airway diameter
  - Tracheal diameter is not “adjustable”
  - Bronchiole diameter is adjustable
- Under nervous, hormonal and paracrine control
  - **Parasympathetic:**
  - **Sympathetic:**
    - Epinephrine ($\beta_2$ receptors):
  - **Histamine:**
  - **CO$_2$**
Matching Ventilation with Alveolar Blood Flow (Perfusion)

- Mostly local regulation
- Lung has collapsible capillaries ⇒ Reduced blood flow at rest in lung apex (reserve capacity of body)
- $\uparrow [CO_2]$ in exhaled air ⇒ bronchodilation
- $\downarrow [O_2]$ in ECF around pulmonary arterioles ⇒ vasoconstriction of arteriole (blood diverted) – opposite of systemic circulation!