Hemodynamics

- Flow of blood through the circulatory system
- Based on interrelationships between:
  - Pressure
  - Resistance
  - Flow rate

\[ F = \frac{\Delta P}{R} \]
Hemodynamics: Pressure & Resistance

- Pressure
  - Blood flows from high → low pressure

- Resistance
  - Length of the vessel
  - Viscosity of the blood
  - Radius of the vessel
    - A small change in vessel diameter can have a dramatic impact on resistance!

  \[
  \text{Resistance} = \frac{\text{Length} \times \text{viscosity}}{\text{Radius}^4}
  \]
**Hemodynamics: Pressure & Resistance**

*Poiseuille’s Law*

\[ F = \pi \Delta P r^{4}/8\eta L \]

- Poiseuille’s law relates the pressure difference (\( \Delta P \)) across a vessel to the flow rate (\( F \)) through that vessel, the vessel’s radius (\( r \)), and the vessel’s length (\( L \)). It also includes the fluid’s viscosity (\( \eta \)).

**Blood Vessels**

- **Pulmonary capillaries**
- **Pulmonary arteries**
- **Pulmonary veins**
- **Systemic veins**
- **Systemic capillaries**
- **Arteries**
- **Arterioles**
- **Aorta** (major systemic artery)
- **Smaller arteries branching off to supply various tissues**

**Arteries**

*Rapid transit system & pressure reservoir*

- Heart contracting and emptying
- Arteries
- Arterioles
- From veins
- To capillaries
- From veins
- Heart relaxing and filling
Arteries (cont.)

- 2 types of connective tissue:
  - Collagen fibers & Elastin fibers

*Allow for strength & elasticity*

Arteries (cont.)

- Blood pressure & pulse pressure

![Graph of arterial pressure over time]

- Systolic pressure
- Mean pressure
- Diastolic pressure

Left ventricle -> Large arteries -> Arterioles -> Capillaries -> Venules and veins
Arterioles

- Major source of resistance
- Little elastic tissue
- Primarily smooth muscle
  - Heavily innervated by sympathetic nerve fibers
  - Promotes vascular tone
    - Ability to vasoconstrict and vasodilate

Caused by:
- Myogenic activity
- Oxygen (O₂)
- Carbon dioxide (CO₂) and other metabolites
- Endothelin
- Sympathetic stimulation
- Vasopressin; angiotensin II
- Cold
Total peripheral resistance

Arteriolar radius

Blood viscosity

Number of red blood cells

Concentration of plasma proteins

Local (intrinsic) control

Extrinsic control

Myogenic responses to stretch

Vasopressin

Heat, cold application (therapeutic use)

Angiotensin II

Histamine release (involved with injuries and allergic responses)

Epinephrine and norepinephrine

Local metabolic changes in O₂, CO₂, other metabolites

Sympathetic activity (exerts generalized vasoconstrictor effect)

Capillaries

- Exchange of materials between blood & tissues
- High rates of diffusion
  - Short distance
  - Thin
  - Narrow
  - Extensive network

Velocity of flow (mm/sec)

Anatomical distribution

Total cross-sectional area (cm²)

Blood flow rate (liters/min)

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Capillary permeability

- Exchangeable proteins are moved across by vesicular transport.
- Small, water-soluble substances pass through the pores.
- Lipid-soluble substances pass through the endothelial cells.
- O₂, CO₂, Na⁺, K⁺, glucose, amino acids cross the capillary wall.
- Plasma proteins generally cannot cross the capillary wall.

Transport across capillary wall

- Water-filled pores in the endothelial cell.
- Plasma proteins are exchanged with the interstitial fluid.
- Exchangeable proteins are moved across by vesicular transport.

Capillary to Tissue Exchange

- Circulating plasma (20% of extracellular fluid).
- Interstitial fluid (80% of extracellular fluid).
- Cells in the tissues.
- Tissues and cells exchanging substances.
Glucose + O$_2$ → CO$_2$ + H$_2$O + ATP

Solute exchange

**Bulk Flow**

1. Capillary blood pressure
2. Plasma-colloid osmotic pressure (proteins)
3. Interstitial fluid hydrostatic pressure
4. Interstitial fluid-colloid osmotic pressure (proteins)

**Lymphatic System**
Lymph Fluid pressure on the outside of the vessel pushes the endothelial cell's free edge inward, permitting entrance of interstitial fluid (now lymph).

Fluid pressure on the inside of the vessel forces the overlapping edges together so that lymph cannot escape.

Systemic circulation

Pulmonary circulation

Initial lymphatics

Blood capillaries

Arteries

Veins

Heart

Lymph node

Precapillary sphincters

Arteriole

Smooth muscles

Precapillary sphincter

Metarteriole

Capillary

Venule
Tissue metabolic activity

- O₂, CO₂ and other metabolites

Relaxation of precapillary sphincters

- Capillary blood flow

Delivery of O₂, rapid removal of metabolites

Number of open capillaries

- Diffusion distance from cell to open capillary

Capillary surface area available for exchange

- Concentration gradient for these materials between blood and tissue cells

Exchange between blood and tissue to support increased metabolic activity

Delivery of O₂, more rapid removal of CO₂ and other metabolites

- Pulmonary vessels 9%
- Systemic arteries 13%
- Systemic arterioles 2%
- Systemic capillaries 5%
- Systemic veins 64%

Veins & Venous Return

- Heart 7%
- Systemic veins 64%
- Systemic capillaries 5%
- Systemic arterioles 2%
- Systemic arteries 13%
- Pulmonary vessels 9%

Cardiac output

- Stroke volume
- End-diastolic volume

Passive bulk flow shift of fluid from interstitial fluid into plasma

Salt and water retention

Blood volume

- Venous return
- Venous valves (mechanically prevent backflow of blood)

Cardiac suction effect

- Pressure in heart (pressure gradient)

Respiratory pump

- Pressure in chest veins (pressure gradient)

Skeletal muscle pump

- Pressure in chest veins (pressure gradient)

- Short-term control measures
- Long-term control measures

Pressure imparted to blood by cardiac contraction

- Pressure in chest veins (pressure gradient)

Sympathetic vasoconstrictor activity

- Pressure in chest veins (pressure gradient; venous capacity)

Sympathetic vasodilator activity

- Pressure in chest veins (pressure gradient; venous capacity)
Blood

1. Plasma
   - Liquid portion of blood
   - Contains ions, proteins, hormones

2. Cells
   - Red blood cells (Erythrocytes)
     ✓ Contain hemoglobin to carry oxygen
   - White blood cells (Leukocytes)
   - Platelets
     ✓ Important in blood clotting

Blood

Is a high or low HEMATOCRIT a problem?

Erythrocytes

Reduced oxygen-carrying capacity

Relieves

Kidney

Erythropoietin

Developing erythrocytes in red bone marrow

Increased oxygen-carrying capacity

Erythrocytes
Blood terms associated w/ RBCs

- **Hematocrit**
  - Percent of blood composed of cells

- **Polycythemia**
  - Excess production of red blood cells causing an abnormal increase in red blood cells

- **Anemia**
  - Abnormally low red blood cell count

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Leukocytes

- **Primary function:** *defense*

- **White Blood Cells (WBCs)**

  - **Individual functions:**
    1. Neutrophils (~60-70%): follow infection/bacteria
    2. Eosinophils (~1-4%): allergies & internal parasites
    3. Basophils (0.25-0.5%): mast cells
    4. Monocytes (2-6%): macrophages
    5. Lymphocytes (25-33%): provide specific immunity

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Platelets

[Diagram of platelets and blood clotting process]