Cardiovascular System 3 – Blood Vessels, Flow and Pressure

A. Blood Vessels

**arteries** - *conducing vessels*; high pressure, thick walls, elastic arteries ("pressure reservoir") and muscular arteries

**arterioles** - *resistance vessels*; small diameter, smooth muscle in walls, vasoconstriction/vasodilation regulates blood flow to capillaries

**capillaries** - *exchange vessels*; microscopic, very thin walls (endothelium)

fluid filters out/in, permeability: continuous < fenestrated < sinusoid

**venules** – collecting vessels; small, thin walls

**veins** - low pressure conducting vessels; thin walls, high compliance ("volume reservoir")

valves ensure one-way flow back to heart

Overall circuit is arranged in *series*

→ pressure drops continuously from arteries to capillaries to veins

Blood supplies to different organs are arranged in *parallel*

→ high pressure, oxygenated blood delivered to all organs

→ independent regulation of blood flow to different organs

B. Blood Flow and Blood Pressure

**Flow** = \( \Delta P/R \)

1. **Cardiac output (CO)** = Total blood flow

2. **Blood pressure** difference (\( \Delta P \)) between arteries and veins is the driving force for blood flow.

   **Mean arterial pressure (MAP)** = Total \( \Delta P \) of the systemic circulation

   \[ \text{MAP} = \text{diastolic } P + 1/3 (\text{systolic } P - \text{diastolic } P) \approx 90 \text{ mm Hg} \]

3. **Resistance (R)** - factors that oppose or reduce blood flow
   a. blood viscosity (↑RBCs → ↑viscosity)
   b. length (L) of blood vessel
   c. **radius (r)** of blood vessel: \( R \alpha 1/r^4 \)
      - vessel radius (diameter) is the major factor that determines resistance
      - small change in vessel radius results in large change in resistance and flow
      
      if diameter ↑2X → resistance ↓16X, flow ↑16X

Total Peripheral Resistance (TPR) is the resistance of entire systemic circuit

\[ \text{MAP} = \text{CO} \times \text{TPR} \]

C. Regulation of Blood Pressure

**Arterial BP (MAP) = CO \times TPR**

- normal MAP \( \approx 90 \text{ mm Hg} \)

1. Factors that affect arterial blood pressure
   a. heart rate \( \uparrow \text{HR} \rightarrow \uparrow \text{CO} \rightarrow \uparrow \text{BP} \)
   b. stroke volume \( \uparrow \text{SV} \rightarrow \uparrow \text{CO} \rightarrow \uparrow \text{BP} \)
   c. blood volume \( \uparrow \text{BV} \rightarrow \uparrow \text{SV} \rightarrow \uparrow \text{CO} \rightarrow \uparrow \text{BP} \)
   d. vascular resistance \( \uparrow \text{TPR} \rightarrow \uparrow \text{BP} \)

2. Homeostatic Control of Blood Pressure

   **cardiovascular control center** located in the medulla oblongata,

   - integrates inputs from sensory receptors and higher brain centers

   - activates autonomic NS to regulate BP

   **arterial baroreceptors** - stretch receptors located in aorta and carotid arteries

   \( \downarrow \text{BP} \rightarrow \downarrow \text{stretch of artery walls} \rightarrow \downarrow \text{frequency of APs} \rightarrow \uparrow \text{sympathetic NS activation} \)

   sympathetic NS effects:
   \[ \begin{align*}
   &\uparrow \text{HR (\( \beta_1 \))} \rightarrow \uparrow \text{CO} \\
   &\uparrow \text{contractility (\( \beta_1 \))} \rightarrow \uparrow \text{CO} \\
   &\uparrow \text{vasoconstriction (\( \alpha_1 \))} \rightarrow \uparrow \text{TPR}
   \end{align*} \]

3. Negative feedback control examples:
   a. hemorrhage
   b. exercise
D. Control of Blood Flow to Tissues

1. Intrinsic control (autoregulation)
   a. metabolic control
      - response of vascular smooth muscle to local chemical changes due to metabolism
        hyperemia - increase in blood flow to tissue in response to ↑ metabolic demand
        ischemia - insufficient blood flow to tissue
   b. Extrinsic control
      a. Autonomic NS
         sympathetic NS: NE → α₁ adrenergic receptors → vasoconstriction in most tissues
      b. Hormones
         Epi → β₂ adrenergic receptors → vasodilation in skeletal muscle
         ADH (vasopressin) → vasoconstriction in most tissues
         Paracrine regulators
         nitric oxide (NO) → vasodilation
         prostaglandins → vasodilation or vasoconstriction

E. Capillary Circulation (Microcirculation)

1. Flow Through Capillary Beds
   blood flow (perfusion) through capillaries is highly variable
   regulated by:
   - arteriolar smooth muscle (vasoconstriction/vasodilation)
   - precapillary sphincters

2. Exchange Across Capillary Walls
   fluid and substances exchanged across endothelium via diffusion, transcytosis, and bulk flow
   a. Bulk flow across capillary walls
      filtration out of a capillary – driven mostly by blood pressure in the capillary (BP<sub>cap</sub>)
      reabsorption back into capillary – driven mostly by colloid osmotic pressure (COP)
      (oncotic pressure) which due to plasma proteins (albumin) that stay in capillaries
      COP ≈ 25 mmHg
   b. Filtration and reabsorption
      determined by the balance between BP and COP in the capillary.
      Net filtration pressure NFP ≈ BP<sub>cap</sub> – COP
      at arteriole end: BP<sub>cap</sub> > COP → NFP is positive → filtration
      at venule end: BP<sub>cap</sub> < COP → NFP is negative → reabsorption
      - total filtration exceeds reabsorption by ~2-3 L/day
      - excess interstitial fluid is collected by the lymphatic system and returned to veins
      edema results when filtration >> reabsorption
      (1) histamine - increases capillary permeability, plasma proteins leak out
      (2) high arterial BP - can increase BP<sub>cap</sub> slightly, regulated by local vasoconstriction
      (3) high venous BP (back pressure) - increases BP<sub>cap</sub>, hard to regulate
         (e.g., venous obstruction, congestive heart failure)