Cardiovascular System 3 – Blood Vessels, Flow and Pressure

A. Blood Vessels

**arteries** - *conducting vessels*; high pressure; thick elastic walls
- large arteries function as “pressure reservoirs”
- elastic recoil of arteries maintains blood flow during relaxation of the heart

**arterioles** - *resistance vessels*; small, variable radius; smooth muscle in walls,
- vasoconstriction/vasodilation regulates blood flow to tissues
- pressure drops in arterioles because of high resistance

**capillaries** - *exchange vessels*; microscopic, very thin walls (endothelium only)
- huge total surface area
- leaky walls allow fluid to filter out and back in
- *capillary bed* - interconnected network of capillaries supplied by arteriole, drained by venule
- flow through capillaries is regulated by arterioles and *precapillary sphincters*

**venules** - collecting vessels; low pressure; small, thin walls

**veins** - *conducting vessels*; lowest pressure; compliant walls expand and collapse easily
- veins and venules function as “volume reservoirs”
- *valves* in veins ensure one-way flow back to heart

Skeletal muscle pump - compresses veins to force blood toward the heart
Respiratory pump - pressure drop in the thoracic cavity also helps return blood to the heart

Overall vascular circuit is arranged *in series*
- pressure drops continuously from arteries → arterioles → capillaries → venules → veins

Blood supplies to different organs are arranged *in parallel*
- high pressure, oxygenated blood is delivered to all organs
- independent regulation of blood flow to different organs

B. Blood Flow, Pressure and Resistance

1. Blood Pressure (P)

Pressure is the driving force for fluid flow.

\[ \text{Flow} = \Delta P/R \quad \Delta P = \text{pressure drop} \ (P_1 - P_2) \]

Total \( \Delta P \) of the systemic circuit \( \approx \) **mean arterial pressure** (MAP)

MAP is the driving force for blood flow through the entire systemic circulation.

- **Pulse pressure** = Systolic P – Diastolic P
  - *example*: 120 mm Hg – 75 mm Hg = 45 mm Hg

  \[ \text{MAP} = \text{Diastolic P} + \frac{1}{3} \ (\text{Pulse P}) \]
  - *example*: 75 + \( \frac{1}{3} \) (45) = 90 mm Hg

- BP is much lower in the pulmonary circuit because it has much lower resistance.

2. Blood Flow

Total blood flow through the cardiovascular system = **cardiac output** (CO)

- cardiac output = heart rate \( \times \) stroke volume
- cardiac output is the same in the systemic and pulmonary circuits
- blood flow to each organ depends on *resistance* of the vessels that supply the organ

3. Resistance (R)

- effect of frictional forces in the blood and vessels that dissipate energy and reduce flow
- as flow travels through resistance, pressure drops

Resistance is a function of:
  a. *viscosity* of the blood (\( \uparrow \) RBCs \( \rightarrow \) viscosity)
  b. length (L) of blood vessels
  c. **radius** (r) of blood vessels: \( R \propto \frac{1}{r^4} \)
  - vessel radius is the major determinant of resistance
  - small changes in radius cause large changes in resistance and flow
  - if radius increases 2X \( \rightarrow \) resistance decreases 16X, flow increases 16X
Vascular resistance is altered by constriction and dilation of arterioles (resistance vessels). As resistance increases:
1. blood flow decreases
2. blood pressure increases upstream of the resistance

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 X TPR**  normal MAP ≈ 90 mm Hg

1. Factors that affect arterial blood pressure
   a. heart rate ↑ HR → ↑ CO → ↑ BP
   b. stroke volume ↑ SV → ↑ CO
   c. blood volume ↑ blood volume → ↑ venous return → ↑ SV → ↑ CO
   d. vascular resistance ↑ TPR → ↑ BP

2. Homeostatic Control of Blood Pressure

**Cardiovascular control center** is located in the medulla oblongata:
- receives and integrates inputs from sensory receptors and higher brain centers
- activates the **autonomic NS** to control cardiovascular responses and regulate BP

**arterial baroreceptors** - stretch receptors located in carotid arteries and aortic arch

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

Homeostatic responses to regulate blood pressure involve changes in **cardiac output** and **total peripheral resistance**.

**sympathetic NS effects:**
\[
\begin{align*}
\uparrow \text{HR (β}_1\text{)} & \rightarrow \uparrow \text{CO} \\
\uparrow \text{contractility (β}_1\text{)} & \rightarrow \uparrow \text{CO} \\
\uparrow \text{vasoconstriction (α}_1\text{)} & \rightarrow \uparrow \text{TPR} \\
\end{align*}
\]
\[ \rightarrow \uparrow \text{BP} \]

**parasympathetic NS:**
\[ \downarrow \text{HR (muscarinic)} \rightarrow \downarrow \text{CO} \rightarrow \downarrow \text{BP} \]
(no effect on contractility or vascular resistance)

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 from cellular metabolism
        - hyperemia: increase in blood flow to tissue in response to ↑ metabolic demand
        - ischemia: insufficient blood flow to tissue
   b. Hormones and Peptides
      - Epi → β₂ adrenergic receptors → vasodilation in skeletal muscle
      - ADH (vasopressin) → vasoconstriction in most tissues
      - angiotensin II → vasoconstriction
      - nitric oxide (NO) → vasodilation
      - histamine → vasodilation
      - bradykinin → vasodilation
      - paracrine regulators

Paracrine regulators
- prostaglandins → vasodilation or vasoconstriction
Cardiovascular System 3a – Microcirculation

E. Capillary Circulation

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

Blood flows slowly through the capillaries because of their large total cross sectional area.

2. Exchange Across Capillaries
   Substances are exchanged across the capillary endothelium via
   1. diffusion
   2. transcytosis
   3. bulk flow - fluid transfer between capillaries and interstitial fluid
      - in most organs, water and small molecules can pass through small gaps between
        capillary endothelial cells
      - blood cells and proteins (normally) stay behind in the capillary
      - fenestrated capillaries have pores which increase filtration across the capillary wall
        (e.g. in kidneys)

   a. Fluid Flow across the Capillary Wall: Filtration and Reabsorption
      filtration out of a capillary is driven by blood pressure in the capillary ($P_{cap}$)
      reabsorption back into capillary is driven mostly by colloid osmotic pressure (COP or $\pi$)
      (oncotic pressure) due to plasma proteins (albumin) in the capillaries
      COP $\approx$ 25 mmHg (negative pressure)

      Filtration and reabsorption of fluid is determined by the balance between blood pressure
      ($P_{cap}$) and COP in the capillary.

      Net filtration pressure  $NFP \approx P_{cap} - COP$

      at arteriole end: $P_{cap} > COP \rightarrow NFP$ is positive $\rightarrow$ filtration
      at venule end: $P_{cap} < COP \rightarrow NFP$ is negative $\rightarrow$ reabsorption

      - total filtration exceeds reabsorption by about 2-3 L/day
      - excess fluid is collected by the lymphatic system and returned to veins

   edema - accumulation of excess fluid in interstitial space; can be localized or widespread
      - results when filtration >> reabsorption

      1) histamine - increases capillary permeability, plasma proteins leak out
      2) high arterial BP - can increase $BP_{cap}$ slightly, but regulated by local vasoconstriction
      3) high venous BP (back pressure) - increases $BP_{cap}$, not well regulated
         (e.g., venous obstruction, congestive heart failure)
      4) lymphatic obstruction (lymphedema) - due to parasites, injury, or unknown causes