Cardiovascular System: Vessels

- Over 60,000 miles of vessels per human body

Blood Vessel Anatomy:

- Elastic Arteries
- Muscular Arteries
- Arterioles

- Capillaries
- Veins

Cardiovascular System – Vessels

- Arteries (away from heart)
- Capillaries
- Veins (toward heart)

Blood Vessel Anatomy:

- Vessels composed of distinct tunics:
  1) Tunica intima
  2) Tunica media
  3) Tunica externa

Blood Vessel Anatomy:

- Function:
  1) Circulate nutrients / waste
  2) Regulate blood pressure

Blood Vessel Anatomy:

- Arteries:
  - Major groups:
    1) Elastic Arteries (conducting arteries):
      - Large, thick-walled (near heart)
      - T [elastic fibers] (pressure reservoir)
    2)Muscular Arteries (distributing arteries):
      - Delivers blood to organs
      - T [smooth muscle] (vasoconstriction)
    3) Arterioles:
      - Control blood into capillaries
      - Neural / hormonal / local controls

- Arteriosclerosis:
  - Hardening / stiffening of arteries

Blood Vessel Anatomy:

- Types of Capillaries:
  1) Continuous
  2) Fenestrated
  3) Sinusoidal

Cardiovascular System – Vessels

- Oxygen / Carbon Dioxide exchange

Cardiovascular System – Vessels

- Function:
  - Alteration of arteriole size
  - Alteration of cardiac output
  - Combination of two above

Cardiovascular System – Vessels

- D: Diameter
- T: Thickness

Cardiovascular System – Vessels

- Marieb & Hoehn (Human Anatomy and Physiology, 8th ed.) – Table 19.1

Cardiovascular System – Vessels

- Arteries (away from heart)
- Capillaries
- Veins (toward heart)

Cardiovascular System – Vessels

- Only tunic present in capillaries

Cardiovascular System – Vessels

- Lumen
- Tunica intima
- Tunica media
- Tunica externa

Cardiovascular System – Vessels

- Vasomotor stimulation = vasoconstriction
- Vasomotor relaxation = vasodilation

Cardiovascular System – Vessels

- Endothelium (simple squamous epithelium)
- Connective tissue (elastic fibers)

Cardiovascular System – Vessels

- Vasa vasorum

Cardiovascular System – Vessels

- Protects / anchors vessel

Cardiovascular System – Vessels

- Tunica intima
- Tunica media
- Tunica externa

Cardiovascular System – Vessels

- Only tunic present in capillaries

Cardiovascular System – Vessels

- Stabilized by pericytes (smooth muscle cells)
Capillaries do not function independently – Instead they form interweaving networks called capillary beds

- 10 - 100 capillaries / bed
  - Vascular short
  - True capillaries

* Sphincters control blood flow through capillary bed

Terminals

Postcapillary

Sphincters

Venous

Venules

D: 20.0 μm
T: 1.0 μm

Vascular shunt a) Vascular shunt
b) True capillaries

Precapillary

Precapillary sphincters

Venous sinuses

Specialized, flattened veins composed only of endothelium; supported by surrounding tissues

Veins: Major groups:

1) Venules
   - Formed where capillaries unite
   - Extremely porous

2) Veins (capacitance vessels)
   - Large lumen; “volume” sink
   - Low pressure environment

Capillaries: Blood Vessel Anatomy: Cardiovascular System – Vessels

Cardiovascular System – Vessels

Heart

Vascular anastomoses

Regions where vessels unite, forming interconnections

Arteriovenous anastomosis

Arterial anastomoses provide alternative channels for blood to reach locations

Joints

Abdominal organs

Brain

Retina, spleen, & kidney have limited collateral circulation

Heart

Vein blocks are common; vein blockages rarely lead to tissue death

Great saphenous vein harvest

Marieb & Hoehn (Human Anatomy and Physiology, 8th ed.) – Figure 19.2

Pathophysiology: Cardiovascular System – Vessels

Atherosclerosis:

Formation of atheromas (small, patchy thickenings) on wall of vessel; intrude into lumen

1) Endothelium injured
   - Infection / hypertension

2) Lipids accumulate / oxidize
   - LDLs collect on tunica intima

Foam cells:
Macrophages engorged with LDLs; form fatty streaks

- 3) Fibrous plaque forms:
   - Collagen / elastic fibers
   - Deposited around dying or dead foam cells

4) Plaque becomes unstable
   - Calcium collects in plaque
   - Vessel constricts; arterial wall frays / liberates ( = thrombus)

Outcomes:

- Myocardial infarctions
- Strokes
- Aneurysms

Angioplasty / Stent
Bypass surgery

Statins:

Cholesterol-lowering drugs

Link

Angioplasty / Stent
Bypass surgery

Infection / hypertension

Myocardial infarctions

Strokes

Aneurysms

Hemodynamics: Cardiovascular System – Vessels

Blood Flow:

Volume of blood flowing past a point per given time (ml / min)

The velocity of blood flow is not related to proximity of heart, but depends on the diameter and cross-sectional area of blood vessels

\[ v = \frac{Q}{A} \]

\( v \) = Velocity (cm / sec)
\( Q \) = Flow (ml / sec)
\( A \) = Cross-sectional area (cm²)

Costanzo (Physiology, 4th ed.) – Figure 10.4

Relative tissue makeup

Endothelial cell
Elastic tissue
Smooth muscle
Fibrous tissue

D: 20.0 μm
T: 1.0 μm
To stay alive, blood must be kept moving...

Blood Flow: Volume of blood flowing past a point per given time (vol/min)

The velocity of blood flow is not related to proximity of heart, but depends on the diameter and cross-sectional area of blood vessels.

Blood velocity is highest in the aorta and lowest in the capillaries.

\[ v = \frac{Q}{A} \]

Hemodynamics:
Cardiovascular System – Vessels

A man has a cardiac output of 5.5 L/min. The diameter of his aorta is estimated to be 20 mm, and the total cross-sectional area of his systemic capillaries is estimated to be 2500 cm².

What is the velocity of blood flow in the aorta relative to the velocity of blood flow in the capillaries?

\[ v_{\text{capillaries}} = \frac{5.5 \text{ L/min}}{2500 \text{ cm}^2} \]
\[ v_{\text{aorta}} = \frac{5500 \text{ cm}^3}{3.14 \text{ cm}^2} \]

\[ v_{\text{capillaries}} = 2.2 \text{ cm/min} \]
\[ v_{\text{aorta}} = 1752 \text{ cm/min} \]

Blood Pressure:
Force per unit area on wall of vessel (mm Hg)

Blood Flow (Q) = Difference in blood pressure (ΔP)

Blood Flow through a blood vessel or a series of blood vessels is determined by blood pressure and peripheral resistance.

Peripheral Resistance: Amount of friction blood encounters passing through vessels (mm Hg/mL/min)

1. Blood flow is inversely proportional to resistance encountered in the system.

\[ \text{Blood Flow (Q)} = \frac{1}{\text{Peripheral resistance (R)}} \]

The major mechanism for changing blood flow in the cardiovascular system is by changing the resistance of blood vessels, particularly the arterioles.

\[ Q = \frac{\Delta P}{R} \]
\[ R = \frac{\Delta P}{Q} \]

A man has a renal blood flow of 500 mL/min. The renal arterial pressure is 100 mm Hg and the renal venous pressure is 10 mm Hg.

What is the vascular resistance of the kidney for this man?

\[ R = \frac{100 \text{ mm Hg} - 10 \text{ mm Hg}}{500 \text{ mL/min}} \]
\[ R = 0.18 \text{ mm Hg/mL/min} \]
Hemodynamics:
The factors that determine the resistance of a blood vessel to blood flow are expressed by Poiseuille’s law:

\[ R = \frac{8L}{\pi r^4} \]

1) Blood viscosity  2) Vessel Length  3) Vessel Diameter

- \( \uparrow \) viscosity \( \rightarrow \) resistance
- \( \uparrow \) length \( \rightarrow \) resistance
- \( \uparrow \) diameter \( \rightarrow \) resistance

Hemodynamics:
The total resistance associated with a set of blood vessels also depends on whether the vessels are arranged in series or in parallel:

A) Series resistance:
Sequential arrangement (e.g., pathway within single organ):

- Artery
- Arteriole
- Capillary
- Venule
- Vein

Arterial resistance is the greatest which equals the area with the greatest decrease in pressure.

The total resistance is equal to the sum of the individual resistances.

B) Parallel resistance:
Simultaneous arrangement (e.g., pathway among various circulations):

- Adding a new resistance to the circuit causes total resistance to decrease.
- Increasing the resistance in one circuit causes total resistance to increase.

The total resistance is less than any of the individual resistances.

Hemodynamics:
Ideally, blood flow in the cardiovascular system is streamlined:

1) Laminar Flow: Characterized by parabolic velocity profile
   - Flow is 0 velocity at wall, maximal at center
   - Layers of fluid slide past one another
   - Viscosity: Measure of the resistance to sliding between adjacent layers
   - Blood - 4x more viscous than water

2) Turbulent Flow: Blood moves in directions not aligned with axis of blood flow
   - More pressure required to propel blood
   - Noisy (stethoscope)

Reynolds Number:
Indicator of whether flow will be laminar or turbulent

\[ R = \frac{\rho v D}{\eta} \]

Factors affecting Reynolds Number:
1) Viscosity (\( \uparrow \) viscosity \( \rightarrow \) Reynolds number)
2) Velocity (\( \uparrow \) velocity \( \rightarrow \) Reynolds number)

Hemodynamics:
The capacitance of a blood vessel describes the volume of blood a vessel can hold at a given pressure:

\[ \text{Compliance} = \frac{\text{Volume (mL)}}{\text{Pressure (mmHg)}} \]

Compliance is high in veins (large blood volumes @ low pressure)
Compliance is low in arteries (low blood volumes @ high pressure)

Total blood volume = Unstressed volume + Stressed volume
Changes in compliance of the veins cause redistribution of blood between arteries and veins
- Venous constriction
To stay alive, blood must be kept moving...

Hemodynamics:

As noted earlier, blood pressure is not equal throughout system

Pressure remains high:
- High elastic recoil of artery walls
- Pressure reservoir

Pathophysiology:

Several pathologic conditions alter the arterial pressure curve in a predictable way

Arteriosclerosis:

↓ compliance = ↑ systolic pressure

Systolic pressure:
Pressure from ventricular contraction
Diastolic pressure:
Pressure from ventricular relaxation

Dicrotic notch:
Brief period following closure of aortic valve where pressure drops due to retrograde flow

Energy consumed to overcome friction forces

Blood return assisted by:
- Large lumen (↓ resistance)
- Valves
- Muscular pumps
Blood Pressure Regulation:

Mean arterial pressure ($P_a$) is the driving force for blood flow and must be maintained at a high, constant level.

Blood Flow ($Q$) = \[
\frac{\text{Difference in blood pressure (\Delta P)}}{\text{Peripheral resistance (R)}}
\]

Mean Arterial Pressure ($P_a$) = Cardiac Output ($Q$) \times Peripheral Resistance ($R$)

Factors Affecting Blood Pressure:

Blood Volume

Mean Arterial Pressure ($P_a$) = Cardiac Output ($Q$) \times Peripheral Resistance ($R$)

$P_a$ is regulated by two major systems that work via negative feedback to maintain ~ 100 mm Hg

Baroreceptor mechanisms are fast, neurally mediated reflexes that attempt to keep $P_a$ constant via changes in cardiac output and vessel diameter

Baroreceptors:

- Mechanoreceptors: respond to stretch
- Carotid sinus: increase / decrease in $P_a$
- Aortic arch: increase / decrease in $P_a$

while sensitive to absolute level of pressure, they are most sensitive rates of changes in pressure.

System 1

Vasodilatory Maneuver: Expiring against a closed glottis, used to test integrity of baroreceptor reflex

Renin-angiotensin II aldosterone system is a slow, hormonally mediated response to keep $P_a$ constant via changes in blood volume.
**Blood Pressure Regulation:**

**Renin-angiotensin II aldosterone** system is a slow, hormonally mediated response to keep $P_c$ constant via changes in blood volume.

**Microcirculation:**

![Image of microcirculation](Image)

- **Functions of the arterioles, capillaries, lymphatic vessels, and veins**
  - Exchange across capillary wall
  - $O_2$ / $CO_2$
  - Fluids
  - Solutes
  - Simple diffusion drives exchange of gases and solutes
  - Fluid transfer across membrane occurs via osmosis
  - Hydrostatic pressure
  - Osmotic pressure
  - Starling forces

**Cardiovascular System – Vessels**

- **Blood Volume**
- **Blood Pressure**
- **Vessels**
- **Arterioles**
- **Capillaries**
- **Venules**

**Additional mechanisms aid in regulating mean arterial pressure**

A) Peripheral chemoreceptors (carotid bodies / aortic arch)
- Respond to $P_{car}$ with vasoconstriction and increased heart rate

B) Central chemoreceptors (medulla oblongata)
- Respond to primarily to $P_{VEN}$ and $J_{PCO_2}$

Brain becomes ischemic
- Increased sympathetic outflow
- Intense arteriolar vasoconstriction in peripheral capillary beds

C) Antidiuretic hormone (ADH) (posterior pituitary)
- Responds to an $\downarrow$ serum osmolality and $a$ in blood pressure
- Triggers vasodilation

**Cardiovascular System – Vessels**

- **Fluid movement across a capillary wall is driven by the Starling pressures across the wall**

$$J_v = K_f \left( (P_i - P_c) - (\eta_i - \eta_c) \right)$$

- **$J_v$** = Fluid movement (mL/min)
- **$K_f$** = Hydraulic conductance (mL/min/mm Hg)
- **$P_i$** = Capillary hydrostatic pressure (mm Hg)
- **$P_c$** = Interstitial hydrostatic pressure (mm Hg)
- **$\eta_i$** = Capillary osmotic pressure (mm Hg)
- **$\eta_c$** = Interstitial osmotic pressure (mm Hg)

**Direction of fluid movement ($J_v$) may be into or out of capillary**

**Filtration** = Net fluid movement is out of capillary and into interstitial fluid (number)

**Absorption** = Net fluid movement is into capillary and out of interstitial fluid (number)

**In a skeletal muscle of an individual, the following Starling pressures were measured:**

- $P_c = 30$ mm Hg
- $P_i = 1$ mm Hg
- $\eta_i = 26$ mm Hg
- $\eta_c = 3$ mm Hg

**What is the direction and magnitude of fluid movement across this capillary?**

$$J_v = K_f \left( (P_i - P_c) - (\eta_i - \eta_c) \right)$$

- $J_v = 0.5 \left( (30 - 1) - (26 - 3) \right)$
- $J_v = 0.5 \left( 29 - 23 \right)$
- $J_v = 0.5 \left( 6 \right)$

**$J_v = 3$ mL/min** (filtration)
Flow of Lymph:

**Microcirculation:**
Fluid movement across a capillary wall is not equal along the length of a capillary.

- **Arterial end:**
  - $P_i = 35$
  - $\tau_i = 26$
  - $J_a = 0.5 \text{ mL/min}$ (net filtration)
  - $J_a = 1 \text{ mL/min}$

- **Venous end:**
  - $P_i = 0$
  - $\tau_i = 1$

What happens to the fluid not returned to the capillary?

**Flow of Lymph:**

Lymphatic vessels:
- Collecting Vessels
- Lymphatic trunks
- Lymphatic ducts
- One-way valves (intake)

Lymphoid system:
- Produce / maintain / distribute lymphocytes
- Distributes hormones / nutrients / waste products
- Lymphatics
- Lymph nodes
- Cisterna chyli
  - Chamber that collects lymph from abdomen, pelvis, and lower limbs

Cardiovascular System - Vessels

**Microcirculation:**
- Thoracic Duct:
  - Begins inferior to diaphragm
  - Empties into left subclavian vein

- Right Lymphatic Duct:
  - Empties into right subclavian vein

**Pathophysiology:**

Edema (swelling) results from an increase in interstitial fluid volume.

- $J_e = \frac{K_c (P_i - P) - C_i J_c}{\Delta X}$

**Causes:**
1. **Increased capillary hydrostatic pressure**
   - Arteriole dilation
   - Deep vein thrombosis
   - Heart failure
2. **Decreased capillary osmotic pressure**
   - Severe liver failure (AIDS, protein synthesis)
   - Protein malnutrition
3. **Increased hydraulic conductance**
   - Increased capillary permeability
   - Severe burn
   - Inflammation (leaky vessels)

4. **Impaired lymphatic drainage**
   - Prolonged standing
   - Removal / irradiation of lymph nodes
   - Parasitic infection

**Special Circulations:**

Blood flow is variable between one organ and another, depending on the overall demands of each organ system.

Blood flow to specific organs can increase or decrease depending on metabolic demands

Changes in blood flow to an individual organ are achieved by altering arteriolar resistance

**Local control:**

A) **Autoregulation**
- Maintenance of constant blood flow in face of changing arterial pressure

\[ Q = \frac{\Delta P}{R} \]

**Myogenic Hypothesis:**
When vascular smooth muscle is stretched, it contracts

- \[ \Delta P = \uparrow\text{ BP} \]
- \[ \uparrow\text{ BP} = \uparrow\text{ smooth muscle stretch} = \text{vasoconstriction} \]

- \[ \downarrow\text{ BP} = \downarrow\text{ smooth muscle stretch} = \text{vasodilation} \]

**ALTERNATIVELY**

- \[ \downarrow\text{ BP} = \uparrow\text{ smooth muscle stretch} = \text{vasodilation} \]
The mechanisms that regulate blood flow are categorized as **local** (intrinsic) control and **neural / hormonal** (extrinsic) control.

1) **Local control**:
   - **B) Active hyperemia**
     - Blood flow to an organ is proportional to its metabolic activity.
   - **C) Reactive hyperemia** (Repayment of oxygen 'debt')
     - Blood flow to an organ is increased in response to a period of decreased blood flow.

**Metabolic Hypothesis**:
- Oxygen delivery to a tissue is matched to oxygen consumption by altering arteriole resistance.

- Tissues
- CO₂
- H⁺
- K⁺
- Lactate

- Fluid
- Back to resting.

Blood flow to an organ is proportional to its metabolic activity.
- Blood flow to an organ is increased in response to a period of decreased blood flow.

Local controls are most important mechanism for regulating coronary, cerebral, skeletal muscle, pulmonary, and renal circulation.

2) **Neuronal / Hormonal controls**:
   - **A) Neuronal**
     - Sympathetic innervation of vascular smooth muscle.
   - **B) Hormonal**

- Histamine
  - arteriodilator; vasoconstrictor
  - \( T_P = \) local edema

- Serotonin
  - local vasoconstriction

- Prostaglandins
  - local vasodilators / vasoconstrictors

- Bradykinin
  - arteriodilator; vasoconstrictor
  - \( T_P = \) local edema

Pathophysiology:

**Circulatory shock** refers to any condition in which the blood vessels are inadequately filled.

- **A) Hypovolemic Shock**
  - Large-scale blood loss
  - Acute hemorrhage
  - Severe vomiting / diarrhea
  - Extensive burns
- **B) Vascular Shock**
  - Abnormal expansion of vascular beds due to extreme vasodilation
  - Anaphylaxis (allergies)
  - Failure of ANS regulation
  - Septicemia (bacteria)
- **C) Cardiogenic Shock**
  - Heart malfunctions
  - Myocardial infarction