Hemodynamics
Hemodynamics...

- The study of the movement of blood and of the forces concerned.
Physical Characteristics of Circulation
Functional parts of the circulation...

- **Arteries:**
  - Transport blood.
  - Strong vascular wall.
  - Rapid flow of blood.

- **Arterioles:**
  - Control valves.
  - Strong muscular wall.
Capillaries:
- Exchange fluid, nutrients, electrolytes & other substances.
- Very thin wall.

Venules:
- Collect blood from capillaries.
- Coalesce into larger veins.
Veins:

- Transport blood from tissues back to heart.
- Major reservoir of blood.
- Thin muscular wall.
- Low pressure.
Volumes of blood in different parts of circulation

- Large venous networks (liver, bone marrow, skin): 21%
- Systemic venous system: 64%
- Large veins: 18%
- Pulmonary circuit: 8%
- Pulmonary arteries: 2%
- Pulmonary capillaries: 2%
- Pulmonary veins: 4%
- Heart: 7%
- Aorta: 2%
- Elastic arteries: 4%
- Muscular arteries: 5%
- Arterioles: 2%
- Systemic capillaries: 7%
- Systemic arterial system: 7%
Cross sectional areas & velocities of blood flow

<table>
<thead>
<tr>
<th>Vessel Type</th>
<th>cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aorta</td>
<td>2.5</td>
</tr>
<tr>
<td>Small arteries</td>
<td>20</td>
</tr>
<tr>
<td>Arterioles</td>
<td>40</td>
</tr>
<tr>
<td>Capillaries</td>
<td>2500</td>
</tr>
<tr>
<td>Venules</td>
<td>250</td>
</tr>
<tr>
<td>Small veins</td>
<td>80</td>
</tr>
<tr>
<td>Venae Cavae</td>
<td>8</td>
</tr>
</tbody>
</table>
Velocity of blood flow is inversely proportional to cross sectional area.

Under resting conditions:
- 33 cm/sec in aorta.
- 0.3 mm/sec in capillaries.
Pressure in various portions of circulation

**Systemic circulation**
High pressure

**Pulmonary circulation**
Low pressure

- Left Heart
- Arteries
- Arterioles
- Sphincters
- Capillaries
- Venules
- Veins
- Right Heart
- Pulmonary artery
- Arterioles
- Capillaries
- Venules

Pressure values:
- 120 mmHg
- 80 mmHg
- 40 mmHg
- 25 mmHg
- 0 mmHg

100 mmHg
Biophysical consideration: interrelationships among pressure, flow and resistance
RELATIONS AMONG P, R & Q

1) Pressure gradient.
2) Vascular resistance.
Cont...

- Ohm’s law:
Blood flow

› Quantity of blood that passes a given point in the circulation in a given period.

› 5000 ml/min
Parabolic velocity profile during laminar flow
Critical velocity:

- Laminar flow occurs up to a certain critical velocity.
- At or above this critical velocity, flow is turbulent.
Turbulent flow:

- Blood flow in all directions and continually mixing with the vessel.

Reynold’s number:

- The measure of the tendency for turbulence to occur.
Reynold’s Number

Reynold’s Number = \( \frac{\rho v D}{u} \)

- \( \rho \) is the weight-density of the fluid
- \( u \) is the dynamic viscosity of the fluid
- \( v \) is the velocity of the fluid flow
- \( D \) is the diameter of the tube
If $Re < 2000 \rightarrow$ flow is not turbulent.
If $Re > 3000 \rightarrow$ turbulence is almost always present.
Conditions where turbulent flow may occur

- When rate of blood flow becomes too great.
- Obstruction in a vessel.
- Sharp turn.
- Viscosity of blood is low.
Measuring blood flow

- Electromagnetic flowmeter.
- Ultrasonic Doppler flowmeter
Electromagnetic flowmeter
Blood pressure

- The force exerted by the blood against any unit area of the vessel wall.

- Measured in:
  - mmHg (using mercury manometer).
  - Cm H2o.

1 mmHg = 1.36 cm H2o
Methods for measuring blood pressure

- Mercury manometer.
- High fidelity method.
Mercury manometer
High fidelity method: electronic pressure transducers
Resistance

- The impediment to blood flow in a vessel.
- Can’t be measured.
- Instead calculated from measurement of blood flow & pressure difference.
Unit of resistance: peripheral resistance unit.
Total peripheral resistance & total pulmonary resistance

\[ R = \frac{100 \text{ mmHg}}{100 \text{ ml/sec}} = 1 \text{ PRU} \]

\[ R = \frac{14 \text{ mmHg}}{100 \text{ ml/sec}} = 0.14 \text{ PRU} \]

Strong constriction \(\rightarrow\) 4 PRU
Strong dilation \(\rightarrow\) 0.2 PRU

Mean Rt arterial P = 16 mmHg
Mean Lt atrial P = 2 mmHg
• **Conductance**: a measure of blood flow through a vessel for a given change in pressure.
• ml/ sec/ mmHg.
• The reciprocal of resistance.

\[
\text{conductance} = \frac{1}{\text{resistance}}
\]
Conductance of a vessel increases in proportion to the fourth power of the diameter.
Poiseuille’s law:

\[ Q = \frac{\pi \Delta P r^4}{8Hl} \]

Note: Q is directly proportional to the forth power of radius, demonstrating that diameter of a blood vessel plays the greatest role.
Importance of forth power law in determining arteriolar resistance

- Arteriolar respond to nervous signals or local tissue signals.
- Turning off blood flow or increase flow.
Effect of blood hematocrit & viscosity on vascular R & Q

- Viscosity: the friction developed between RBCs as they slide over each other during flow of blood.

- An important factor in Poiseuill’s law.
Greater viscosity
Greater resistance to flow
The less the flow
Hematocrit

- The percentage of blood volume occupied by erythrocytes as they are packed down in a centrifuged blood sample.
Effect of hematocrit on blood viscosity
Effects of pressure on vascular resistance & tissue Q
Vascular Distensibility & Function of the Arterial & Venous System
Vascular distensibility

\[
\text{vascular distensibility} = \frac{\text{increase in volume}}{\text{increase in pressure} \times \text{original volume}}
\]

• Normally expressed as the fractional increase in volume for each mmHg rise in pressure.
• When a vessel being distensible it means it can swell out by pressure from within.
Distensibility = 0.1 per mmHG or 10%/ mmHg
Difference in distensibility between arteries & veins

- Walls of arteries are thicker than veins.
- Veins are 8 x as distensible as arteries.
Vascular compliance

- The total quantity of blood that can be stored in a given portion of the circulation for each mmHg rise in pressure.
- It’s a measure of how easily the structure can be stretched.
Compliance = distensibility x volume

e.g: veins are 24x more compliant than arteries
(8x as distensible $\times$ 3x as great volume) = 24
Compliance and distensibility are quite different

Highly distensible vessel/ slight volume

Less compliance •

Less distensible vessel/ large volume

More compliance •
Volume-pressure curve of the arterial and venous circulation
Delayed compliance (stress-relaxation) of vessels
Arterial pressure palpation

Diagram showing:
- Slow rise to peak
- Sharp incisura
- Exponential diastolic decline (may be distorted by reflected wave)
- Sharp upstroke

Y-axis: Pressure (mm Hg)
X-axis: Seconds
Factors affecting pulse pressure:

- Stroke volume.
- Compliance of arterial tree.
Less compliance

Greater rise in pressure for a given stroke volume of blood pumped into the arteries
Damping of pressure pulse
The cause of damping of pressure pulse

Resistance to blood movement in vessels

Compliance of the vessels
Clinical methods for measuring blood pressure

- Auscultatory method (sphygmomanometer)
Auscultatory method

Sphygmomanometer

Sounds heard
Normal arterial blood pressure
Veins and their function
Central venous pressure (CVP)

- Venous pressure as measured at Rt atrium.
- Measured by means of a catheter.
CVP and right atrial pressure

- Anything that affects Rt atrial pressure usually affects venous pressure everywhere in the body.
Regulation of Rt atrial pressure

Ability of the Ht to pump blood out of Rt atrium

Tendency for blood to flow from peripheral vessels back to Rt atrium
Normal Rt atrial pressure = 0 mmHg
Can rise to 20-30 mmHg (abnormal conditions).
Can fall to -3 to -5 mmHg.
Measurement of venous & Rt atrial pressure

- Venous pressure
  - By inserting a syringe needle

- Rt atrial pressure
  - Inserting a catheter through veins into Rt atrium
Venous resistance and peripheral venous pressure
Peripheral small veins: 4-7 mmHg > Rt atrial pressure

Atmospheric pressure collapse in neck
Rib collapse
Axillary collapse
Intrathoracic pressure = -4 mm
Abdominal pressure collapse
Effect of high atrial pressure on peripheral venous pressure

- when Rt atrial pressure increase above 0 mmHg.
- When Rt atrial pressure > 4-6 mmHg.
Hydrostatic pressure and venous pressure
• 1 mmHg = 13.6 mm H2O

Hydrostatic pressure affects arterial pressure!!
Venous valves and venous pump: their effect on venous pressure
• Importance of valves.
• Arrangement of valves.
• Effect of movement of the legs.
Specific blood reservoirs
1. Spleen
2. Liver
3. Large abdominal veins
4. Venous plexus beneath the skin
5. To lesser extent heart and lungs