Learning objectives
1. Describe the functional components of the cardiovascular system (blood, blood vessels and heart).
2. Describe the four heart chambers, their relations to each other and the great vessels, and the function division of the heart into right and left sides.
3. Explain the series arrangement of the systemic and pulmonary circulations.
4. Describe the resting distribution of the systemic blood volume, pressure, flow and velocity.
5. Describe how the distribution of systemic blood flow may be altered to suit different physiological conditions.
6. Explain the fundamental haemodynamic relationship between blood flow, blood pressure and vascular resistance.
7. Describe the overall structure and function of the coronary circulation.

Pericardium
- Fibroserous membrane that covers the heart and the proximal ends of its great vessels.
- Closed sac composed of two layers:
  - Fibrous pericardium – tough external layer continuous with central tendon of the diaphragm.
  - Serous pericardium – consists of two layers.
    - Parietal layer – lines internal surface of fibrous pericardium.
    - Visceral layer – lines external surface of heart; continuous with parietal layer.
- Pericardial fluid
  - Within pericardial cavity, the potential space between parietal and visceral layers.
  - 15-50ml.
- Anchors the heart
  - Anteriorly attached by ligaments to posterior surface of sternum.
  - Posteriorly bound by loose connective tissue to structures in posterior mediastinum.
  - Continuous superiorly with adventitia of great vessels of heart and with cervical fascia.
  - Continuous inferiorly with central tendon of diaphragm.

Pathologies of the pericardium
- Acute pericarditis – viral, post-myocardial infarction, uraemic (pertaining to kidney failure).
- Bacterial – tuberculosis, fungal or malignant.
- Pericardial effusions: Abnormal accumulation of fluid in pericardial cavity → intrapericardial pressure → sufficient pressure to affect heart function → cardiac tamponade.
- Constrictive pericarditis: Occurs when a thickened fibrotic pericardium impedes normal diastolic filling.

Chambers
- Atria (primers)
  - Continuously filled by veins.
  - Low pressure, thin walled.
- Ventricles (pumps)
  - Thick walled.
- Right side – pulmonary circulation.
- Left side – systemic circulation.
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Valves
- Function passively to ensure unidirectional flow.
- Atrio-ventricular (AV) valves
  - Greater force exerted on AV valves than on semilunar valves → supported by tendinous cords.
  - Tricuspid valve – right side, 3 cusps.
  - Mitral valve – left side, 2 cusps.
- Semilunar valves
  - Not supported by tendinous cords.
  - Pulmonary valve – right side
  - Aortic valve – left side.

Heart valve problems
- Aortic valve / mitral stenosis: Abnormal narrowing of aortic/mitral valve opening.
- Regurgitation / insufficiency: Valve does not close properly, allowing blood to leak in wrong direction. Mitral regurgitation most common.
- Diseases: Inflammation, rheumatic fever, change in structure with age, congenital.

Blood
- About 7% of body weight (5 litres).
- Red blood cells (erythrocytes) – responsible for oxygen transport.
- White blood cells (leukocytes) – immune cells.
- Platelets – cell fragments involved in clotting.
- Plasma
  - 93% water.
  - Dissolved substances – respiratory gases, electrolytes, proteins, nutrients, wastes, hormones.
- Haematocrit (Ht): Fraction of blood volume occupied by red blood cells.
  - Approximately 46% in men and 38% in women.

Functions of circulatory system
- Transport essential nutrients – oxygen, glucose, amino acids, water.
- Removal of waste products – carbon dioxide, urea.
- Homeostasis
- Coordinate body functions – chemical messengers (hormones).
- Defence mechanisms – leukocytes.
- Heat transfer
- Reproduction – penile erection.

Components of circulation
- 3 circulatory systems – pulmonary, systemic and coronary.
- Blood flows from heart → arteries → arterioles → capillaries → venules → veins → heart.
- Arteries: Transport oxygenated blood under high pressure.
- Arterioles: Act as control conduits through which blood is released into capillaries.
- Capillaries: Exchange fluids, nutrients and wastes within tissues.
- Venules: Collect blood.
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- Veins: Transport deoxygenated blood back to the heart. Act as blood reservoir.

Blood flow in cardiovascular system
- Systemic and pulmonary systems are in series.
- Systemic circulation is a parallel circuit.
- Distribution of cardiac output of the left ventricle (at rest)

Heart rate (HR)
- Normal: approx. 70/min
  - Can be as low as 40/min for athletes.
- Maximum heart rate ≈ 220 – age
- Cardiac cycle – events from the beginning of one heartbeat to the beginning of the next.
  - Systole – contraction phase; “heartbeat”.
  - Diastole – relaxation phase.
- Stroke volume (SV) – volume of blood ejected from one ventricle during each systole.
  - L/beat.
  - Normal resting stroke volume is 70 ml/beat.
- Cardiac output (CO) = SV × HR
  - Normal resting cardiac output is 5 L/min.

Intra-systemic distribution of blood volume varies according to physiological need.
- Distribution of systemic blood flow – rest vs. exercise.
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Pressure across circulatory system.

Blood velocity distribution
- Inversely proportional to cross-sectional area.
- Large total cross-sectional area of capillaries → lowest velocity in capillaries → allows blood-tissue diffusion and exchange.
  - 0.3 – 1.0 mm/s.
  - Blood dwell time = 1 – 3 sec.

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>CSA (cm²)</th>
<th>Velocity (mm/sec)</th>
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</thead>
<tbody>
<tr>
<td>Aorta</td>
<td>2.5</td>
<td>333</td>
</tr>
<tr>
<td>Small arteries</td>
<td>20</td>
<td>42</td>
</tr>
<tr>
<td>Arterioles</td>
<td>40</td>
<td>21</td>
</tr>
<tr>
<td>Capillaries</td>
<td>2500</td>
<td>0.3</td>
</tr>
<tr>
<td>Venules</td>
<td>250</td>
<td>3.3</td>
</tr>
<tr>
<td>Small veins</td>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>Veineae cavae</td>
<td>8</td>
<td>104</td>
</tr>
</tbody>
</table>

Guyton’s 3 basic principles – basic theory of circulatory function
1. **The rate of blood flow to each tissue is almost always precisely controlled in relation to the tissue need.**
   - Active tissue can need 20-30 times increased blood flow than resting tissue, but heart can only increase output to 4-7 times → not possible to increase blood flow everywhere → microvessels monitor tissue needs → dilate or constrict to control local blood flow.
   - Nervous control of circulation from CNS also helps control tissue blood flow.
2. **Cardiac output is controlled mainly by the sum of all local tissue flows.**
   - Blood flow through tissues return to heart → heart responds to increased inflow by pumping it back to arteries.
   - Heart also often needs special nerve signals to pump required amounts of blood flow.
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3. **In general, arterial pressure is controlled independently of either local blood flow control or cardiac output control.**

   - Blood pressure falls significantly below the normal level of about 100mmHg → nervous reflexes return blood pressure toward normal:
     - Increase force of heart pumping.
     - Contraction of large venous reservoirs.
     - Generalized constriction of most arterioles → more blood in large arteries → increase arterial pressure.
   - Over prolonged periods, kidneys secrete hormones to regulate blood volume.

Basic haemodynamics

- **Flow (F):** Quantity of blood that passes a given point in the circulation in a given period of time.
- ml/min, L/min, etc.
- **Blood pressure (BP):** Force exerted by the blood against any unit area of vessel wall.
- **mmHg**
- **Resistance to blood flow (R)**
  - Cannot be measured directly
  - Calculated from measurements of blood flow and pressure difference between two points in the vessel.
  - Peripheral resistance unit (PRU): If the pressure difference between two points is 1 mmHg and the flow is 1 ml/sec, the resistance is said to be 1 PRU.

<table>
<thead>
<tr>
<th></th>
<th>Systemic</th>
<th>Pulmonary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CO (ml/sec)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Arterio-venous pressure</td>
<td>100</td>
<td>14</td>
</tr>
<tr>
<td>difference (mmHg)</td>
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<td></td>
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<tr>
<td>Total peripheral / pulmonary</td>
<td>1</td>
<td>0.14</td>
</tr>
<tr>
<td>vascular resistance (PRU)</td>
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</tr>
</tbody>
</table>

Interrelations between pressure, flow and resistance

- **Ohm’s law:** \( flow = \frac{pressure\ difference}{resistance} \)
  - Resistance is due to friction.
- \( CO = HR \times SV \)
- **Mean arterial pressure = CO × total peripheral resistance**

Types of flow

- **Laminar flow** – streamlined, silent, efficient.
- **Turbulent flow** – blood flows crosswise as well as along vessel → greater resistance → inefficient and noisy.
  - Often seen in large vessels at high velocities and at branch points.
  - Noise increases if obstruction present due to increased turbulence – clinically diagnostic tool.

Factors that determine resistance to flow.

- **Length of tube (constant in body).**
  - Resistance is directly proportional to the length of the tube.
  - **Tubes in series:** \( R_{total} = R_1 + R_2 + R_3 + \ldots \).
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- Tubes in parallel: \( \frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \).
- Same flow but shorter distance in pulmonary circulation → lower pressure.

- Radius of tube (variable).
  - Conductance: A measure of the blood flow through a vessel for a given pressure difference. 
    \( \text{ml/sec mmHg} \).
  - Conductance \( \propto \text{diameter}^4 \).
  - \( C = \frac{1}{R} \) smaller diameter → higher resistance to flow.

- Viscosity of fluid (relatively constant).
  - Haematocrit – percentage of blood that is cellular.
  - Blood viscosity is largely dependent on Ht.
  - ↑Ht → ↑viscosity → ↑resistance

Coronary circulation – arteries
- Left coronary artery – supplies anterior and left lateral portions of left ventricle.
- Right coronary artery – supplies right ventricle and posterior part of left ventricle.
- Small arterial branches penetrate from epicardium into myocardium.
- High capillary density.
  - 10 – 20× of that in skeletal muscle.
  - High oxygen extraction.

Coronary circulation – coronary venous return
- Coronary sinus – main vein of the heart.
  - Blood from left ventricle drains into right atrium through coronary sinus.
  - ~75% of coronary blood flow.
- Anterior cardiac veins
  - Drains blood from right ventricle into right atrium.
- Thebesian veins
  - Small amount of coronary venous blood flows back to heart through minute thebesian veins, into all chambers.

Coronary circulation – control of blood flow
- Systole → cardiac muscle contracts → obstruct blood flow through coronary capillaries.
  - ~75% of coronary blood flow through capillaries of left ventricle occurs during diastole.
  - Contraction of right ventricular muscle << left ventricular muscle → inverse phasic changes of blood flow through capillaries of right ventricle only partial in contrast to left ventricle.
• Humoral control – local muscle metabolism is primary controller of coronary flow.
• Nervous control – stimulation of autonomic nerves to heart can affect coronary blood flow directly or indirectly.
  – Indirect effects mostly opposite to direct effects and play more important role in control of coronary blood flow.
    → Sympathetic stimulation → release adrenaline and NA → ↑heart rate, ↑heart contractility,
       ↑rate of metabolism of heart → local blood flow regulatory mechanisms dilate coronary vessels.
    → Vagal stimulation → release Ach → ↓heart rate, ↓heart contractility → ↓cardiac oxygen consumption → constrict coronary arteries.
  – Direct effects
    → ACh released by parasympathetic stimulation of vagal has a direct effect to dilate the coronary arteries.
    → Adrenaline and NA released by sympathetic stimulation can have vasoconstrictor or vasodilator effects depending on type of receptors (α or β) on vessel walls.