The Heart & Blood Vessels

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Functions of Heart and blood Vessels

1. The heart is an essential pumping organ in the cardiovascular system where the **right heart** pumps **deoxygenated blood** (returned from body tissues) to the lungs for gas exchange, while the **left heart** pumps **oxygenated blood** (returned from the lungs) to tissue cells for sustaining cellular respiration.

2. Attached to the heart is blood vessels that transport blood in various circulation pathways:

   **Pulmonary blood vessels** transport blood between the heart and the lungs.

   **Systemic blood vessels** transport blood between the heart and body tissues.
Anatomy of The heart

1. Heart size is similar to a fist - about 14 cm long, 9 cm wide.
2. The heart is located in the pericardial cavity where its base is under the second pair of rib, and its apex is at the fifth pair of rib.
3. About 2/3 of its mass is to the left of the midline in the mediastinum.
4. **Pericardium**: membranous sacs that surround the heart and hold it in the mediastinum. It consists of an outer layer called **fibrous pericardium** (made of fibrous connective tissue) and an inner layer called **serous pericardium** (serous membrane). Serous pericardium is subdivided into a **parietal pericardium** (lining the wall of mediastinum) and a **visceral pericardium** (covering the surface of the heart). Between these two layers is a space called **pericardial cavity** which is filled with the pericardial fluid to reduce friction.
5. Heart wall

a) Three layers of tissues forming the walls of heart and creating the heart chambers and heart valves inside.

b) **Epicardium** is the outermost layer, and is the same as the visceral pericardium (the innermost tissue of pericardium).

c) **Myocardium** is the middle, and thickest layer; composed of cardiac muscle which contains specialized structures such as **intercalated disks** that allow this layer to function a unit.

d) **Endocardium** is the innermost layer, made of endothelial and connective tissues that not only forms the inner lining of the heart chambers, also forms the heart valves and extends outward to become the endothelium tissue of blood vessels. It also contains specialized nerve like muscle fibers called **purkinje fibers** to activate heart actions.
6. **Heart chambers**: hollow cavities within the heart for containing blood.

- Two smaller chambers called **atrium** are near the base, and two larger chambers called **ventricle** are close to the apex.
- **Right Atrium (RA)** after receiving deoxygenated blood from body tissues through the **superior** and **inferior vena cava**, pumps the blood into the **Right Ventricle (RV)** via the tight atrioventricular orifice.
• **RightVentricle (RV)** then pumps the blood to the lungs for gas exchange, through the pulmonary trunk and arteries.

• **Left Atrium (LA)** after receiving oxygenated blood from the lungs through the pulmonary veins, pumps the blood into the **Left Ventricle (LV)** via the left atria ventricular orifice.

• **LV** then pumps the blood to the body tissues for supplying oxygen to every body cell, through the aorta.

• **RA** and **LA** are separated by a central heart wall called interatrial septum, while **RV** and **LV** are separated by interventricular septum.

• **LV** has a thicker myocardium layer (for stronger contractions) and contains rough ridges called *trabeculae carnea* (for containing a larger blood volume in exercising conditions).
(e) Frontal section

- Aorta
- Left pulmonary artery
- Left atrium
- Left pulmonary veins
- Mitral (bicuspid) valve
- Aortic valve
- Pulmonary valve
- Left ventricle
- Papillary muscle
- Interventricular septum
- Epicardium
- Myocardium
- Endocardium
- Superior vena cava
- Right pulmonary artery
- Pulmonary trunk
- Right atrium
- Right pulmonary veins
- Fossa ovalis
- Pectinate muscles
- Tricuspid valve
- Right ventricle
- Chordae tendineae
- Trabeculae carneae
- Inferior vena cava
7. **Heart valves**: Extensions of endocardium for preventing back flow of blood into heart chambers.

- Two heart valves located between atria and ventricles are called **atrio-ventricular valves (AV valves)** which include the **tricuspid valve** between RA and RV, and **bicuspid valve (mitral valve)** between LA and LV.

- Two heart valves located at the exiting arteries are called **semilunar valves (SL valves)** which include the **pulmonic semilunar valve** at the base of pulmonary trunk, and the **aortic semilunar valve** at the base of aorta.

- Each AV valve consists of **cusps** (extensions of endocardium), **chordae tendineae**, and **papillary muscles** (the later two are designed to prevent eversion of the cusps into the atria).

- Each SL valve only consists of 3 half- moon shaped cusps extended directly from endocardium.
(e) Frontal section
(a) Anterior aspect (pericardium removed)
• Heart valves open and close in response to pressure changes in heart chambers - when the atria are full, AV valves open due to lesser pressure in ventricles; when the ventricles are full, AV valves close and SL valves open due to lesser pressure in atria and exiting arteries.

• AV valves prevent backflow into atria, while SL valves prevent backflow into ventricles.
8. Blood supply to cardiac muscle:

- Although the heart chambers contain blood almost constantly, none of this blood can supply oxygen and nutrients to the cardiac muscle in myocardium.

- **Coronary arteries** (from the first branching of aorta) supply oxygenated blood to the cardiac muscle.

- Two major branches of coronary arteries - anterior and posterior interventricular coronary arteries.

- Inside the myocardium, coronary arteries subdivide to become arterioles and capillaries, providing a constant supply of oxygen and nutrients to cardiac muscle cells.

- Deoxygenated blood from myocardium is drained by cardiac veins which dispose the blood into coronary sinus, and in turn returns the blood to RA.
Aorta

Left pulmonary artery

Left pulmonary veins

Auricle of left atrium

Left atrium

Great cardiac vein

Posterior vein of left ventricle

Left ventricle

Apex

Superior vena cava

Right pulmonary artery

Right pulmonary veins

Right atrium

Inferior vena cava

Coronary sinus

Right coronary artery (in coronary sulcus)

Posterior interventricular artery (in posterior interventricular sulcus)

Middle cardiac vein

Right ventricle

(d) Posterior surface view

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Nervous Control of heartbeat

- Cardiac cycles are mainly controlled by nerve impulse, while hormones only can influence the heart rate.

- Two mechanisms to regulate cardiac cycles: **intrinsic control** (consists of pacemakers and a conduction system) and **extrinsic control** (consists of sympathetic and parasympathetic nerves, and hormones, that influence the pacemakers and affect the heart rate).

- In **intrinsic control** of heartbeat, a group of modified cardiac muscle cells called the **sinoatrial node (SA node)** located in the back wall of RA, emits an impulse to initiate atrial systole (contraction) and to stimulate another group of cells between RA and RV, called the **atrio-ventricular node (AV node)**. The **AV node** now emits an impulse which travels along the **Bundle of His (interventricular bundle)** located in the interventricular septum. At the apex, the impulse is directed into another set of fibers in the ventricles called **Purkinje fibers**, which cause ventricular systole.
Intrinsic Control

1. The sinoatrial (SA) node (pacemaker) generates impulses.

2. The impulses pause (0.1 s) at the atrioventricular (AV) node.

3. The atrioventricular (AV) bundle connects the atria to the ventricles.

4. The bundle branches conduct the impulses through the interventricular septum.

5. The subendocardial conducting network depolarizes the contractile cells of both ventricles.

(a) Anatomy of the intrinsic conduction system showing the sequence of electrical excitation

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In extrinsic control, pressure receptors along the aorta and common carotid arteries detect changes in blood pressure and send nerve impulses to the cardiac centers in medulla oblongata, which in turn activates either sympathetic nerves (to increase heart rate and contractility) or parasympathetic nerves (to decrease heart rate and contractility). These nerves innervate the SA node, changing the basic rhythm in cardiac action. Hormones such as epinephrine and norepinephrine can also have the same stimulatory effect on the SA node.
Arrhythmias

• **Arrhythmias:** are abnormal heart action caused by the following factors:

**Bradycardia:** is slow heart rate (<60 beats/min) which is normal during sleep, but can be induced by low body temperature, parasympathetic stimulation, and certain drugs. It is indicated by a short PQ interval and a flat T wave on the ECG.

**Tachycardia:** is fast heart rate (> 100 beats/min) which is normal during exercising or excitement, but can be induced by high body temperature, sympathetic stimulation, drugs, heart diseases, anemia, or shock. It is indicated by a lack of P, Q, S, or T wave, with only high-frequency of upward and downward deflections on the ECG.

**Flutter:** is very high heart rate (>250 beats/min) which is usually pathological (e.g. bacterial infection or inflammation of myocardium). It is indicated by many small, unrecognized waves, then a big upward/downward wave on the ECG.
Fibrillation: is high but uncoordinated heart rate caused by regions of myocardium contracting and relaxing independently (lack of syncytum).

Atrial fibrillation: is not very serious if the ventricles are functioning normally.

Ventricular fibrillation: is usually fatal (the most common cause of sudden death) where blood cannot be pumped properly into the lungs and body tissues. It is indicated by extremely irregular waves on the ECG, and usually Q and S waves are absent.
Circulation pathways - Summary

- **Pulmonary circuit:** allows deoxygenated blood to be transported into the lungs for gas exchange, so that oxygenated blood can once again flows into the left heart.
  Deoxygenated blood from body tissues → superior & inferior vena cava → RA → tricuspid valve → RV → pulmonic SL valve → pulmonary arteries → lungs (gas exchange occurs) → oxygenated blood travels in pulmonary veins → LA → bicuspid valve → LV.

- **Coronary circuit:** allows oxygenated blood to be delivered to cardiac muscle cells in the heart wall, and its deoxygenated blood is drained back to the RA.
  Oxygenated blood in LV → aortic SL valve → aorta → coronary arteries → arterioles → capillaries in myocardium (gas exchange occurs) → deoxygenated blood travels into venules → cardiac veins → coronary sinus → RA.
• **Systemic circuit:** allows oxygenated blood from the left heart to be delivered to tissue cells through arteries and arterioles, and deoxygenated blood is transported back to the right heart through veins and venules.

Oxygenated blood in LV → aortic SL valve → aorta → arteries → arterioles → capillaries in tissues (gas exchange occurs) → deoxygenated blood travels in venules → veins → superior & inferior vena cava → RA.
1. Blood vessels are organs since they are composed of layers of tissue.
2. Blood vessels from closed system of tubes to transport blood to and from the heart: heart → arteries → arterioles → capillaries → venules → veins → heart.
Arteries

– Blood vessels that carry blood away from the heart to the lungs and tissues.

– Arterial wall consists of 3 layers of tissue – innermost tunica interna (made of smooth muscle), middle tunica media (made of smooth muscle), and outermost tunica externa (made of fibrous connective tissue).

– Tunica media layer contains elastic fibers, allowing arterial wall to be expandable.

– Arterioles are small arteries that deliver blood to the capillaries, and because of their small diameter, they play a key role in vasoconstriction and vasodilatation.

– Most arteries and arterioles carry oxygenated blood, except the pulmonary arteries where they transport deoxygenated blood from RV to the lungs.
**Artery**
- **Tunica intima**
  - Endothelium
  - Subendothelial layer
  - Internal elastic membrane
- **Tunica media**
  (smooth muscle and elastic fibers)
  - External elastic membrane
- **Tunica externa**
  (collagen fibers)
  - Vasa vasorum

**Vein**
- **Capillary network**
- **Capillary**
  - Basement membrane
  - Endothelial cells

**Valve**
- **Lumen**
Capillaries

Microscopic blood vessels that allow the exchange of nutrients and wastes between blood and tissues. This exchange is a filtration process enforced by **hydrostatic pressure** (created by water molecules in blood plasma) and **osmotic pressure** (created by plasma proteins, particularly albumin).

Capillary wall is composed of only a layer of squamous cells, forming the **endothelium** (which is actually an extension of the tunica interna layer form the arterioles and venules).

Most capillaries form extensive networks called capillary beds to increase surface area and have a more efficient exchange rate (small, ring – like smooth muscles form pre-capillary sphincters to control blood flow into capillary beds).
(a) Continuous capillary

Continuous capillaries are the least permeable and most common.

- Abundant in skin, muscles, lungs, and CNS.
- Often have associated pericytes.
- Pinocytotic vesicles ferry fluid across the endothelial cell.
- Brain capillary endothelial cells lack intercellular clefts and have tight junctions around their entire perimeter. (This is the structural basis of the blood brain barrier described in Chapter 12.)

(b) Fenestrated capillary

Fenestrated capillaries have large fenestrations (pores) that increase permeability.

- Occur in areas of active filtration (e.g., kidney) or absorption (e.g., small intestine), and areas of endocrine hormone secretion.
- Fenestrations are Swiss cheese–like holes that tunnel through endothelial cells.
- Fenestrations are usually covered by a very thin diaphragm made of extracellular glycoproteins. This diaphragm has little effect on solute and fluid movement.
- In some digestive tract organs, the number of fenestrations in capillaries increases during active absorption of nutrients.
(a) Sphincters open—blood flows through true capillaries.

(b) Sphincters closed—blood flows through metarteriole—thoroughfare channel and bypasses true capillaries.
Veins

• Blood vessels that carry blood to the heart, from the lungs and tissues.

• walls of veins also consist of the same 3 tissues as in arteries, except the tunica media is much thinner and has no elastic fibers.

• blood pressure in veins is extremely low, as a result valves formed by the tunica interna layer are necessary to prevent backflow. Because of this low pressure, low velocity blood flow in veins, they serve as the largest blood reservoir (containing 60-70% of total blood volume).

• Most veins carry deoxygenated blood, except the pulmonary veins where they transport oxygenated blood from the lungs to the LA.

• Venules are small veins that are formed by the union of several capillaries.
Blood Vessel disorders

- **Atherosclerosis** – accumulation of fat in the lumen of arteries; responsible for 50% of all deaths in U.S.; may lead to *ischemia* (blood deficiency to tissues), *necrosis* (tissue death), or *arteriosclerosis* (hardening of arteries which could cause bursting or cracking).

- **Aneurysm** – weakened artery wall and high blood pressure causes a pulsating sac in arteries; may lead to cracks in the arteries.

- **Phlebitis** – inflammation of veins.

- **Varicose veins** – abnormal and irregular dilations of superficial veins.
Circulatory pathways

a) pulmonary circuit: carry blood from the heart to the lungs and back to the heart.

- Heart → Pulmonary trunk → R+L Pulmonary arteries → Lobar arteries (3 in the R, 2 on the left) → arterioles → pulmonary capillaries → drain into → Pulmonary veins (2 from each lung) → left atrium.
(b) **Illustration.** The pulmonary arterial system is shown in blue to indicate that the blood it carries is oxygen-poor. The pulmonary venous drainage is shown in red to indicate that the blood it transports is oxygen-rich.
b) Systemic circuit: carries blood from the heart to all parts of the body and back again.

- **Aorta**: largest artery in the body, arches over the heart to the left and descends just out, and to the left of the vertebral column.
<table>
<thead>
<tr>
<th>Portion of aorta</th>
<th>Major bunch</th>
<th>Region or organ supplied</th>
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<td>Ascending aorta</td>
<td>Right + left coronary a. Brachiocephalic artery</td>
<td>Heart</td>
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<tr>
<td>Arch of aorta</td>
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<td>R. upper limb &amp; R. side of head</td>
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<td></td>
<td>Left common carotid a.</td>
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<td>Thoracic aorta (descending aorta)</td>
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<td>Mediastinal a.</td>
<td>Mediastinum</td>
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<td>Post. intercostal a.</td>
<td>Thoracic wall</td>
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Abdominal aorta:
- Celiac artery
- Phrenic artery
- Sup. Mesenteric a.
- Suprarenal artery
- Renal a.
- Gonodal a.
- Inf. Mesenteric
- Lumbar a.
- Middle sacral a.
- Common iliac a.

Organs of upper digestive tract
- Diaphragm
- Portions of small & large intestine
- Adrenal gland
- Kidney
- Ovary or testis
- Lower portion of large intestine
- Post. abdominal wall
- Sacrum & coccyx
- Lower abdominal wall, pelvic organs and lower limbs
(a) Schematic flowchart.
(b) The celiac trunk and its major branches. The left half of the liver has been removed.
(c) Major branches of the abdominal aorta.
(d) Distribution of the superior and inferior mesenteric arteries. The transverse colon has been pulled superiorly.
Brachiocephalic artery:
1. R. Subclavian artery
   a) R. Axillary artery
   b) R. Vertebral artery
2. R. Common carotid artery (R. side of head and neck)
   a) R. internal carotid artery (major brain supplier).
   b) R. external carotid a. supplies head, jaw, and face.
• Note: R. Subclavian and R. Common carotid arteries are branches of Brachiocephalic a. while Left subclavian and Left common carotid directly arise from the arch of aorta.
Arteries of Neck, Head, and Brain

- Subclavian a. → Vertebral arteries → Basilar artery (pons, mid brain, cerebellum) → post. cerebral arteries (form an arterial circle) → Circle of Willis (communicates with internal carotid artery).

- Other branches of subclavian are Thryocervical and Costocervical arteries.
(d) Major arteries serving the brain (inferior view, right side of cerebellum and part of right temporal lobe removed)
Arteries to the Shoulder & Upper Limb

- Axillary a. → brachial artery which forms:
  - deep brachial a.
  - Radial a.
  - Ulnar a.
- radial & ulnar arteries join to form the palmar arches which forms:
  - metacarpals
  - digitals
(a) Schematic flowchart

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Arteries to Thoracic Wall

- **Subclavian a. → internal thoracic a.** (upper 6 ribs) → 2 ant. Intercostal a. (upper 6 ribs).
- **Thoracic aorta**
  a) post. Intercostal a. (3rd to 11th ribs).
  b) phrenic a. (diaphragm).
Arteries to the pelvis & Lower Limb

Abdominal aorta → common iliac arteries

• Common iliac arteries form:
  a) Internal iliac a. (supplies pelvic muscles, visceral structures, gluteal muscles, and ext. genitalia).

• popliteal artery form:
  a) ant. tibial a. → dorsalis pedis a.
  b) post. tibial a. supplies calf muscles & form:
     – peroneal a. (lat. peroneal muscle of leg)
     – medial plantar a.
     – lateral plantar a. → digital arteries
Common iliac artery
Internal iliac artery
Superior gluteal artery
External iliac artery
Deep artery of thigh
Lateral circumflex femoral artery
Medial circumflex femoral artery
 Obturator artery
Femoral artery
Adductor hiatus
Popliteal artery

Anterior tibial artery
Posterior tibial artery
Fibular artery
Dorsalis pedis artery
Arcuate artery
Dorsal metatarsal arteries

(b) Anterior view

Popliteal artery
Anterior tibial artery

Posterior tibial artery
Fibular artery
Lateral plantar artery
Medial plantar artery
Dorsalis pedis artery (from top of foot)
Plantar arch

(c) Posterior view

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Veins of The Head & Neck

- External Jugular Veins (drain face, scalp and superficial areas of neck) and Internal jugular veins (drain the brain, deep areas of face and neck) empty into the → Subclavian veins → Brachiocephalic veins → Superior vena cava → R. atrium.

- Note: there are 2 brachiocephalic veins but only 1 brachiocephalic artery.
Deep Veins of Upper Limb & Shoulder

- Palmar venous arches drains into the radial and ulnar veins → brachial veins → axillary veins → subclavian veins → brachio cephalic veins.
Superficial Veins of the Upper Limb & Shoulder

- Dorsal venous arches drains into 3 veins:
  a) cephalic vein
  b) basilic vein
  c) median antebrachial vein

- cephalic vein travels upward and joins the axillary vein. It also connects to the basilic vein via the median cubital vein.

Median antebrachial vein → basilic vein → brachial vein → axillary vein → subclavian vein.
Veins from the abdominal viscera

- R + L gastric veins (stomach), superior mesentric vein (small intestine & upper colon), splenic vein (spleen, pancreas), and inferior mesentric vein (lower colon & rectum) empty into Hepatic portal vein → hepatic portal system → liver → hepatic veins → interior vena cava.
(b) Tributaries of the inferior vena cava. Venous drainage of abdominal organs not drained by the hepatic portal vein.

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(c) The hepatic portal circulation.
Deep Veins From The Lower Limb & Pelvis

- Medial & lateral plantar veins form the posterior tibial vein.
- Dorsalis pedis vein form the anterior tibial vein.

Anterior & posterior tibial veins → popliteal vein → femoral vein → external iliac vein which unites with internal iliac vein → common iliac vein → Inferior vena cava.
Common iliac vein
Internal iliac vein
External iliac vein
Inguinal ligament
Femoral vein
Great saphenous vein (superficial)

Popliteal vein
Small saphenous vein
Fibular vein
Anterior tibial vein
Dorsalis pedis vein
Dorsal venous arch
Dorsal metatarsal veins

Great saphenous vein
Popliteal vein
Anterior tibial vein
Fibular vein
Small saphenous vein (superficial)
Posterior tibial vein
Plantar veins
Deep plantar arch
Digital veins

(b) Anterior view
(c) Posterior view

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Superficial veins from the lower Limb

- Dorsal venous arch drain into the great & small saphenous veins.
- Great saphenous vein which is the longest vein of the body drain into the femoral vein.
- Small saphenous vein drain into the popliteal vein.
(a) Schematic flowchart of the anterior and posterior veins

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Major veins of the systemic circulation
(b) Illustration, anterior view. The vessels of the pulmonary circulation are not shown.
Clinical Terms

Heart palpitation: unusually strong, irregular and fast heart beat so that the person becomes aware of it.

Congestive heart failure: inability of the ventricle to pump adequate blood to cells.

Thrombophlebitis: formation of blood clot in a vein in response to inflammation of the venous wall.

Hypertension: high blood pressure.

Atherosclerosis: characterized by deposition of cholesterol – lipid – calcium in arterial wall.

Mitral valve prolapse: valve disorder due to malfunction of papillary muscles or defect in chordae tendineae.

Aneurysm: balloon-like out pocketing of an artery that may cause rupture of that artery.