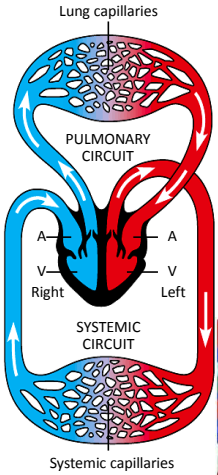
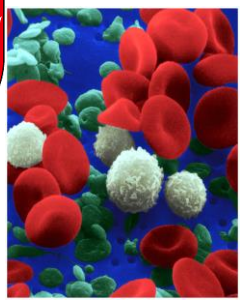


Transport System in Mammals



Fundamental Biology

1

Objectives

After this lecture, you should be able to:

- Explain the need for transport systems in multicellular animals in terms of size and surface area to volume ratios;
- Describe the mammalian circulatory system as a closed double circulation
- Explain the relationship between the structure and function of arteries, veins and capillaries
- Describe the structure of red blood cells, phagocytes and lymphocytes and explain the differences between blood, tissue fluid and lymph
- Describe and explain the significance of the increase in the red blood cell count of humans at high altitude

2

Transport system in mammals

- **The importance of transport system:**

- Circulate oxygen, carbon dioxide, nutrition, hormone any many metabolites (including enzymes) in the body
- Homeostasis: maintaining body temperature, pH
- Facilitating immune system

Two classification of transport system in mammals:

1. **Artery system**: bring the oxygen-rich blood and metabolism products to the body
2. **Vein system**: carry the carbondioxide-rich blood and metabolism waste to the heart

Exception (vice versa): vein from pulmonary and artery to pulmonary

The cardiovascular pathway

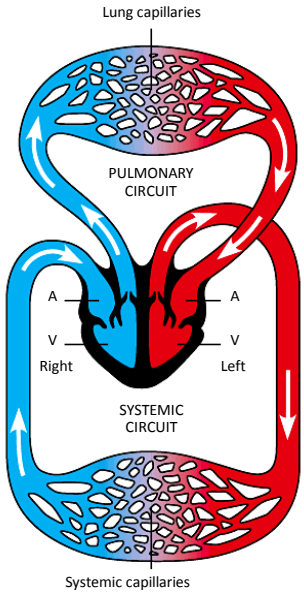
Includes two circuits:

➢**The pulmonary circuit**: circulates the blood through the lungs

Blood from all regions of the body →right atrium→ right ventricle → pulmonary trunk, pulmonary arteries (CO2→ O2)→ pulmonary venules→ pulmonary veins → left atrium

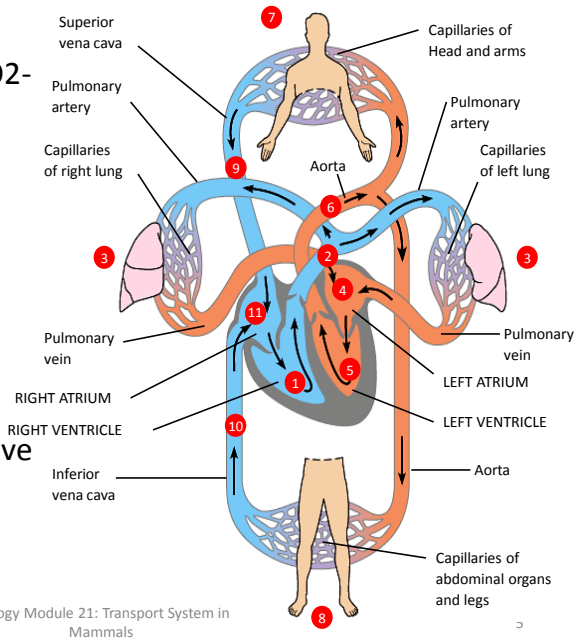
➢**The systemic circuit**: serves the needs of body tissues

Blood from superior and inferior vena cava →right atrium → lungs → left ventricle → aorta → organs and major body regions → superior/ inferior vena cava → right atrium



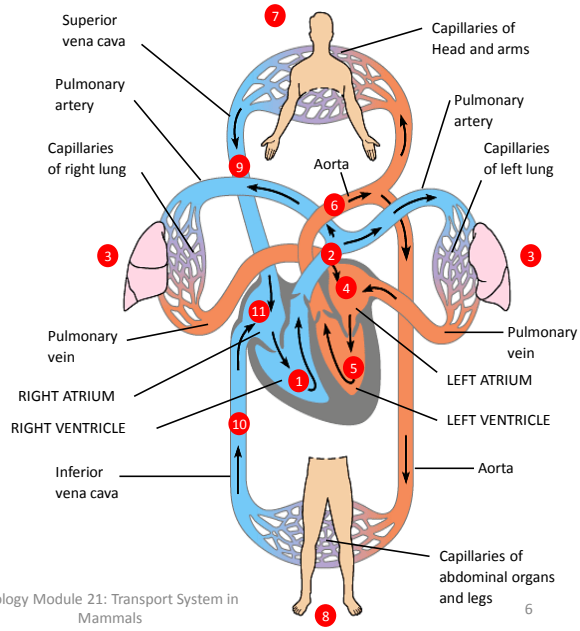
Passage of blood through the heart

- The superior vena cava and inferior vena cava (O2-poor blood) → enter the right atrium
- The right atrium sends blood through an atrioventricular valve (tricuspid) → right ventricle
- The right ventricle sends blood through the pulmonary semilunar valve → pulmonary trunk → divides into two pulmonary arteries → lungs

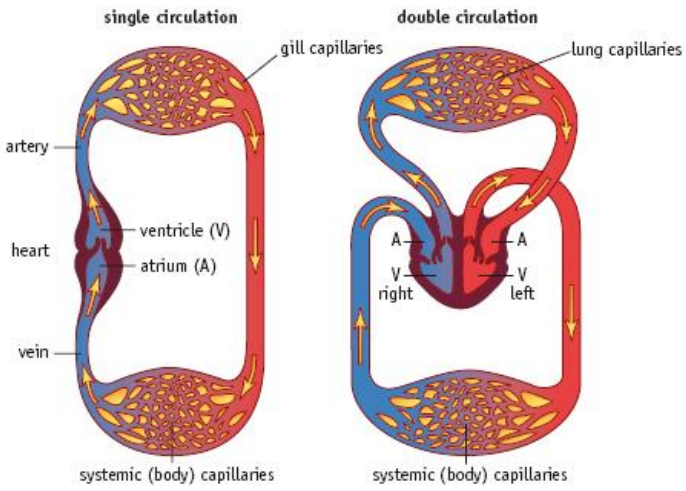


Four pulmonary veins (O2-rich blood) → enter left atrium. The left atrium sends blood through an atrio ventricular valve (bicuspid)→ left ventricle

Left ventricle sends blood through the aortic semilunar valve → into the aorta → to the body proper



Single circulation and double circulation



Fish have **a single circulation.**

Birds and mammals have a **double Circulation.**

Single circulatory systems

Animals with a closed circulatory system have either single circulation or double circulation. Single circulation is found, for example, in fish:

- The heart pumps deoxygenated blood to the gills → here gaseous exchange takes place;
- there is diffusion of carbon dioxide from the blood into the water that surrounds the gills, and diffusion of oxygen from this water into the blood

Closed circulatory systems

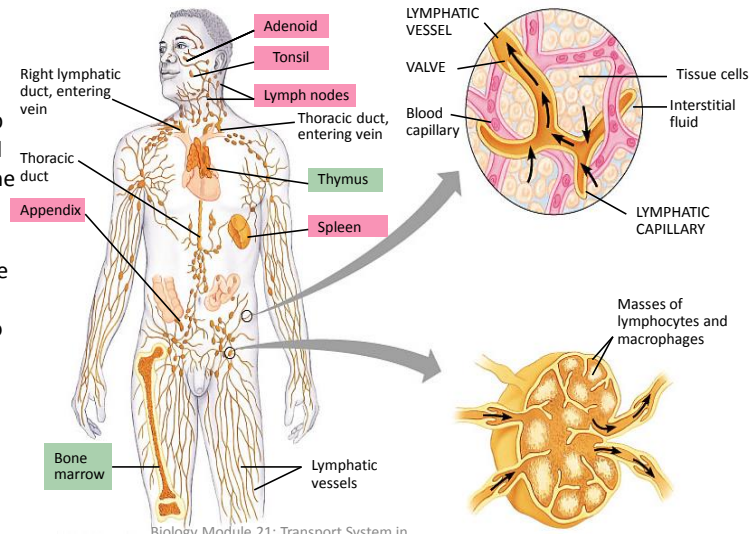
Many animals, including all vertebrates, have a closed circulatory system in which the blood is enclosed within tubes. This generates higher blood pressures as the blood is forced along fairly narrow channels instead of flowing into large cavities. This means the blood travels faster and so the blood system is more efficient at delivering substances around the body:

• The blood leaves the heart under pressure and flows along **arteries and then arterioles (small arteries) to capillaries.**
• There are extremely large numbers of capillaries. These come into close contact with most of the cells in the body, where substances are exchanged between blood and cells.
• After passing along the capillaries, the blood returns to the heart by means of **venules (small veins) and then veins.**
• Valves ensure that blood flows only in one direction.
Animals with closed circulatory systems are generally larger in size, and often more active than those with open system

Transport system: the lymphatic system

- The lymphatic system consists of lymphatic vessel and lymphatic organs
- Function:

1. Lymphatic capillaries take up excess tissue fluid and return it to the blood stream
2. Lacteals receives lipoproteins at the intestinal villi and transport them to the blood stream
3. Lymphatic system helps defend the body against disease



Cardiovascular disorders

•Hypertension

Hypertension is present when the systolic blood pressure is 140 or greater or diastolic blood pressure is 90 or greater. For medical treatment → the diastolic pressure that is emphasized

•Atherosclerosis

An accumulation of soft masses of fatty materials, particularly cholesterol, beneath the inner linings of arteries → plaque → interfere the blood flow→ diet low in saturated fat & cholesterol and rich in fruit and vegetables

• **Stroke, heart attack and aneurysm**

Associated with hypertension and atherosclerosis

➢**Stroke**: a cerebrovascular accident (CVA)→ small cranial arteriole bursts or is blocked by an embolus

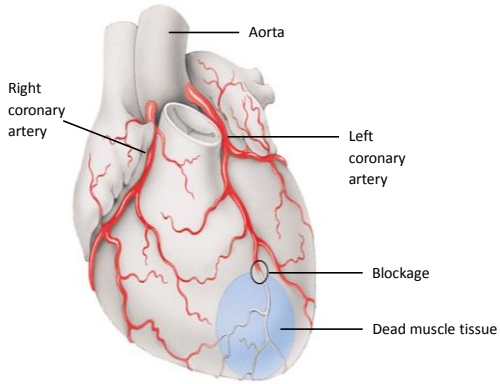
➢**Heart attack**: a myocardial infarction (MI)→ occurs when a portion of heart muscle dies due to a lack of oxygen. If a coronary artery become partially blocked→ angina pectoris

➢**An aneurism**: is a ballooning of a blood vessel, most often the abdominal artery or the arteries leading to the brain

➢the coronary arteries (the first branches off aorta): serves the heart muscle itself

➢The hepatic portal system: associated with the liver

Blood passes from capillaries of the intestinal villi → venul → hepatic portal vein→ leaves the liver → enters the inferior vena cava



High blood pressure

- Elevated blood pressure, known as **hypertension, is considered to be one of the most** common factors in the development of cardiovascular disease. High blood pressure increases the likelihood of atherosclerosis occurring.
- Blood pressure is a measure of the hydrostatic force of the blood against the walls of a blood vessel. You should remember that blood pressure is higher in arteries and capillaries than in veins. The pressure in an artery is highest during the phase of the cardiac cycle when the ventricles have contracted and forced blood into the arteries.
- This is the **systolic pressure. Pressure is at its lowest in the artery when the ventricles are** relaxed. This is the **diastolic pressure.**

Figure 1.24 Nowadays blood pressure monitors can give digital readouts.

Measuring blood pressure

- A **sphygmomanometer is a traditional device used to measure blood pressure. It** consists of an inflatable cuff that is wrapped around the upper arm, and a manometer or gauge that measures pressure (Figure 1.24). When the cuff is inflated the blood flow through the artery in the upper arm is stopped. As the pressure in the cuff is released the blood starts to flow through the artery. This flow of blood can be heard using a stethoscope positioned on the artery below the cuff . A pressure reading is taken when the blood first starts to spurt through the artery that has been closed. This is the *systolic pressure.*
- *A second reading is taken when the pressure* falls to the point where no sound can be heard in the artery. This is the *diastolic pressure.*
- The SI units (International System of Units) for pressure are kilopascals, but in medical practice it is traditional to use millimetres of mercury, mmHg. (The numbers refer to the number of millimetres the pressure will raise a column of mercury

What determines your blood pressure?

- Contact between blood and the walls of the blood vessels causes friction, and this impedes the flow of blood. This is called peripheral resistance. The arterioles and capillaries offer a greater total surface area, resisting flow more, slowing the blood down and causing the blood pressure to fall. Notice in Figure 1.25 that the greatest drop in pressure occurs in the arterioles.
- The fluctuations in pressure in the arteries are caused by contraction and relaxation of the heart. As blood is expelled from the heart, pressure is higher. During diastole, elastic recoil of the blood vessels maintains the pressure and keep the blood flowing

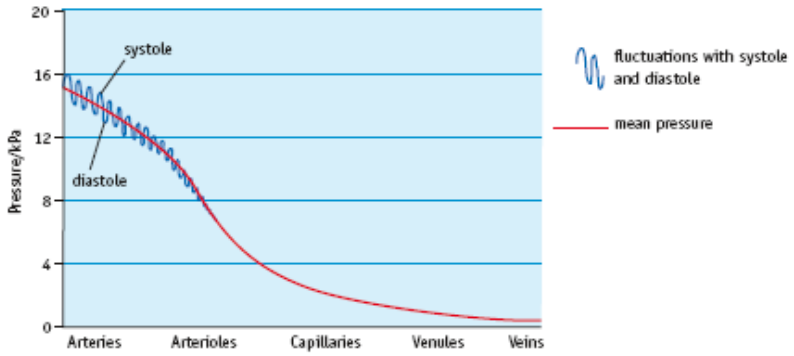
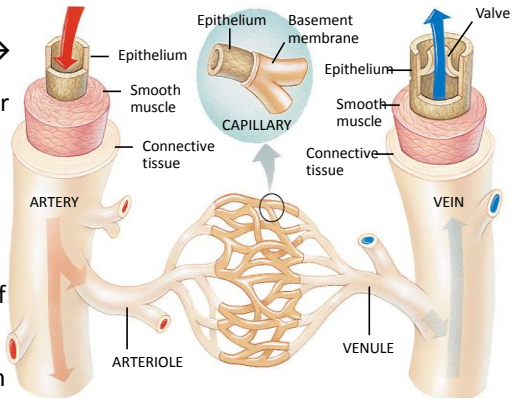


Figure 1.25 Blood pressure in the circulatory system. As peripheral resistance increases with greater total surface area, the flow of blood slows causing pressure to fall

- If the smooth muscles in the walls of an artery or an arteriole contract, the vessels constrict, increasing resistance. In turn, your blood pressure is raised. If the smooth muscles relax, the lumen is dilated, so peripheral resistance is reduced and blood pressure falls. Any factor that causes arteries or arterioles to constrict can lead to elevated blood pressure. Such factors include natural loss of elasticity with age, release of hormones such as adrenaline, or a high-salt diet. In turn high blood pressure can lead to atherosclerosis.
- One sign of high blood pressure is **oedema, fluid building up in tissues and causing** swelling. Oedema may also be associated with kidney or liver disease, or with restricted body movement.
- At the arterial end of a capillary, blood is under pressure. This forces fluid and small molecules normally found in plasma out through the capillary walls into the intercellular spaces, forming **tissue fluid (also called interstitial fluid) (Figure 1.26).**
- The capillary walls prevent blood cells and larger plasma proteins from passing through, so these stay inside the capillaries.
- If blood pressure rises above normal, more fluid may be forced out of the capillaries. In such circumstances, fluid accumulates within the tissues causing oedema.

The blood vessels: structure and function

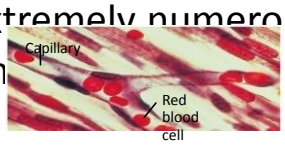
- **The arteries**: carry blood away from the heart to the capillaries
  - The arterial wall has 3 layers: inner → simple squamous and connective tissue with elastic fibers; middle layer → elastic fibers and smooth muscle; outer layer → both elastic and collagen fibers
  - **Arteriols** → constricted or dilated affects blood pressure
- **The veins**: return the blood from the capillaries to the heart. About 70% of blood is in the veins
  - **Venuls:** small veins that drain blood from capillaries and then join to form a vein
  - Have 3 layers: (= arteries), but less smooth muscle and connective tissue→ thinner →can expand to greater extent
  - Have valves (especially veins of the lower extremities): blood flows only toward heart when open and prevent backwards flow when closed



The capillaries: permit exchange of material with the tissue → relative constancy of tissue fluid. Capillary beds →present in all regions of the body

Blood vessels: structure and functions

Capillaries are small and extremely numerous: estimated 6,300 square n



Artery and vein have different structure:
Artery → thick wall
Vein → thin wall

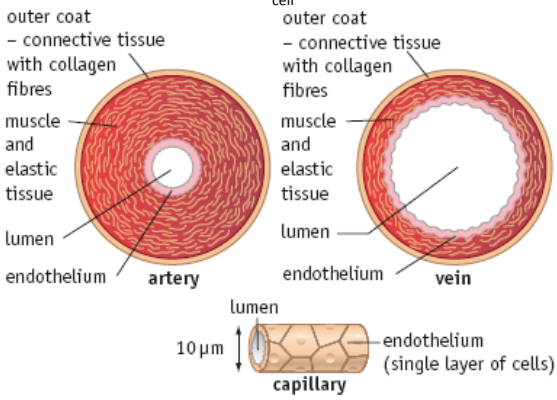


Diagram of an artery, a vein and a capillary.
The endothelium that lines the blood vessels is made up of epithelial cells

Arteries and veins can easily be distinguished, as shown in figure below.
The walls of both vessels contain **collagen, a tough fibrous protein, which makes them strong** and durable. They also contain elastic fibres, which allows them to stretch and recoil. Smooth muscle cells in the walls allow them to constrict and dilate. The key differences between the arteries and veins are listed below.

Arteries:
- narrow lumen
- thicker walls
- more collagen, elastic fibres and smooth muscle
- no valves

Veins:
- wide lumen
- thinner walls
- less collagen, elastic fibres and smooth muscle
- valves

Photomicrograph of an artery (left) and vein (right) surrounded by connective tissue

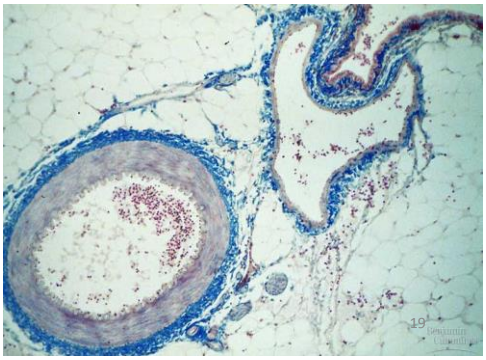
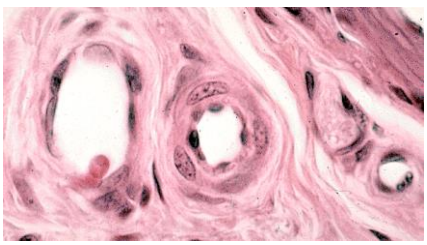


Table 1. Relative permeability of capillaries in a muscle to different substances

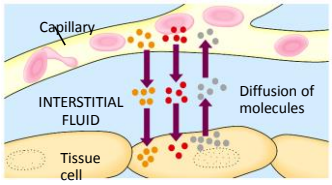


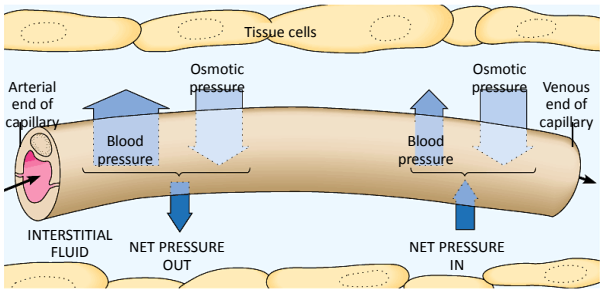
Substance	Relative molecular mass	Permeability
water	18	1.00
Sodium ions	23	0.96
urea	60	0.8
glucose	180	0.6
haemoglobin	68 000	0.01
albumin	69 000	0.000 01

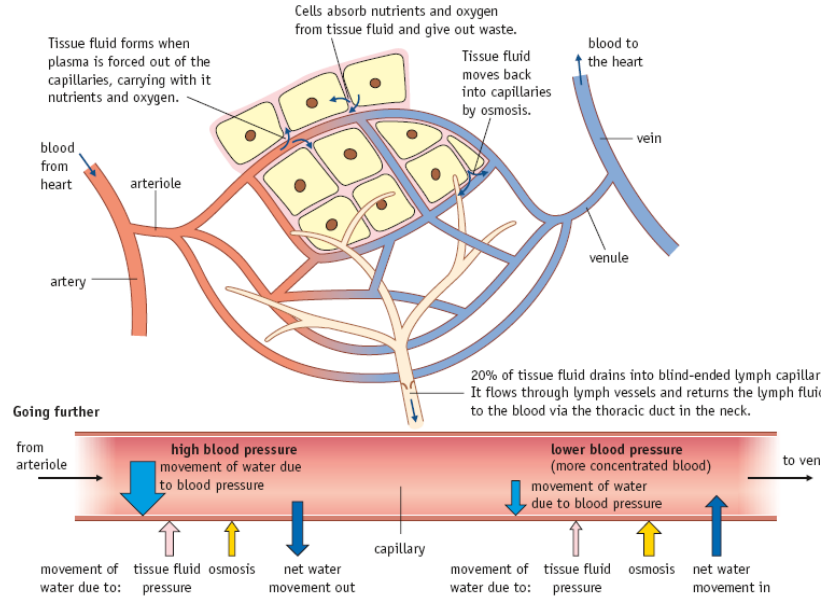
Blood capillaries

Water and other small molecules can cross trough the cells of capillary Wall. Three processes influence capillary exchange:

1. Blood pressure: created by the pumping of heart, is the pressure against a vessel's wall
2. Diffusion
3. Osmotic pressure: is force caused by a difference in solute concentration on either side of the membrane→ osmotic pressure of blood pulls water into and retains water inside capillary







Notice how the net movement in is less than the movement out.
The excess fluid formed is drained away through the lymphatic system.

Lymphatic capillaries

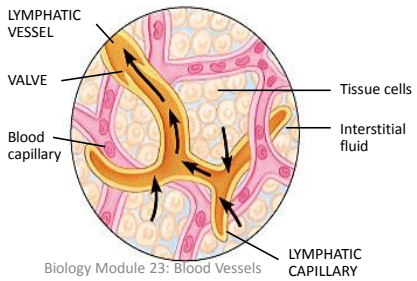
In the end, about 85% of the water that left a capillary at the arterial ends returns to it at the venous end →retrieving fluid by means of osmotic pressure is not completely effective → excess: enters lymphatic capillaries

• has more valves: prevent the backward flow

•Lymphatic capillaries → lymphatic ducts → cardiovascular veins

•Lymph: the fluid carried by lymphatic vessels has the same composition as tissue fluid (absorb excess fluid at he blood capillaries)

Edema: swelling that occurs when tissue fluid is not collected by the lymphatic capillaries



Blood Pressure in the blood vessels

• **Arterial end of capillary**

Bright red in color→ RBC brings O2.

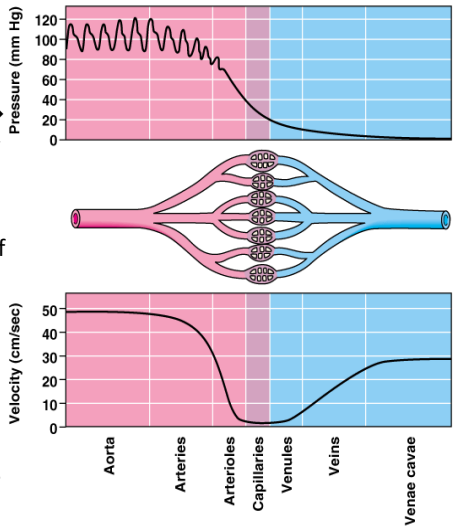
At the arterial end of capillary: blood pressure (an outward force) 30 mmHg, is higher than osmotic pressure (an inward force) 21 mmHg → water and other small molecules exit a capillary at its arterial end → creates tissue fluid

• **Midsection of capillary**

As the result of metabolism, tissue cells give off CO2 and other wastes. Because tissue fluid is always the area greater concentration for waste materials → diffuse into a capillary

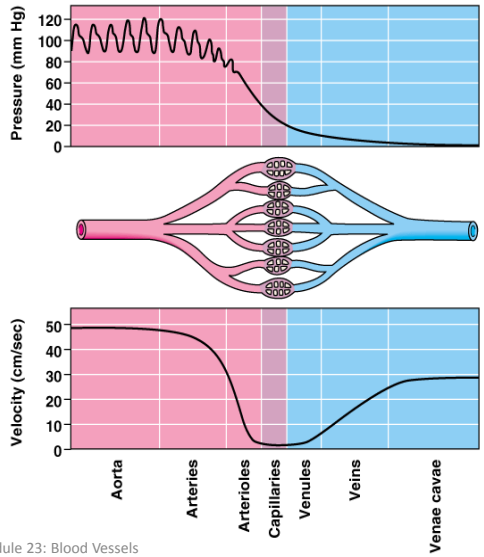
• **Venous end of capillary**

At the venous end, blood pressure is much reduced to only 15 mmHg → water tends to enter a capillary → hemoglobin has given up its O2 and taken hydrogen ions → reduced hemoglobin: deep maroon in color



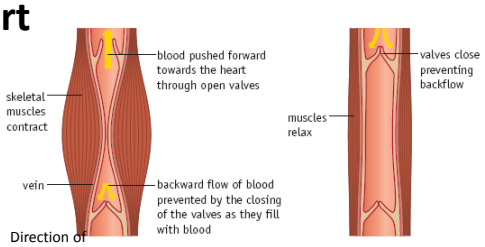
Blood Pressure in the blood vessels

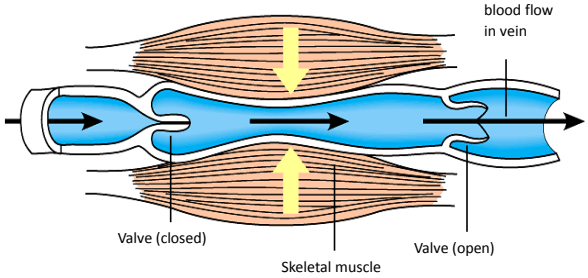
- Blood flow in capillaries: moves slowly through the capillaries → the slow progress allows time for the exchange of substances between blood and the surrounding tissues
- **Pressure is highest in the arteries**
- It drops to **zero** by the time the blood reaches **the veins → blood pressure is minimal in venules and veins**
  (20 – 0 mm Hg)



Three factors keep blood moving back to the heart

- skeletal muscle contraction,
- the presence of valves in veins
- respiratory movements





- **Fainting**: bloods collects in the limbs, depriving the brain of needed blood flow and oxygen → horizontal position aids in getting blood to the head

Movement of blood in the blood vessels

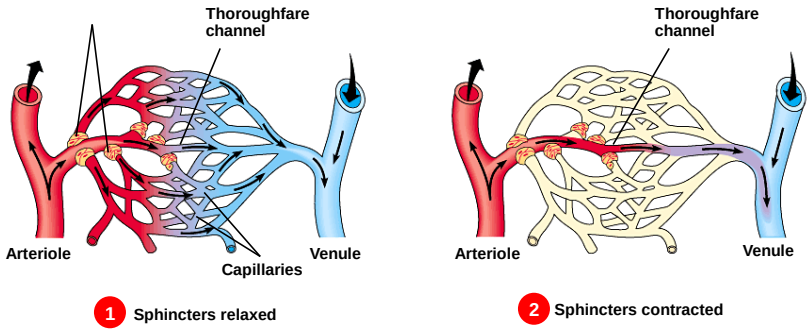
How does blood move through the vessels?

Every time the heart contracts (**systole), blood is forced into arteries and their elastic** walls stretch to accommodate the blood.

During **diastole (relaxation of the heart), the** elasticity of the artery walls causes them to recoil behind the blood, helping to push the blood forward. The blood moves along the length of the artery as each section in series stretches and recoils in this way.

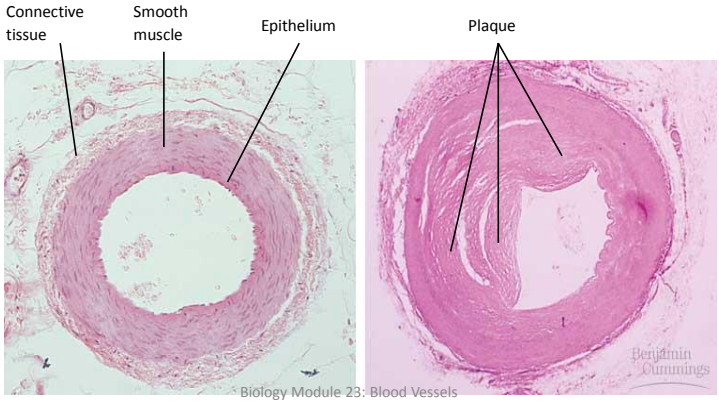
The pulsing flow of blood through the arteries can be felt anywhere an artery passes over a bone close to the skin. The blood is under the low pressure in the veins →difficult to be felt.

- Muscular constriction of arterioles and precapillary sphincters controls the flow through capillaries



Atherosclerosis

An accumulation of soft masses of fatty materials, particularly cholesterol, beneath the inner linings of arteries → plaque → interfere the blood flow→ diet low in saturated fat & cholesterol and rich in fruit and vegetables



Problems in blood vessels: Aneurysms

- If part of an artery has narrowed and become less flexible, blood can build up behind it.
- The artery bulges as it fills with blood and an **aneurysm forms. An atherosclerotic aneurysm** of the aorta is shown in next Figure

- What will eventually happen as the bulge enlarges and the walls of the aorta are stretched thin?

Aortic aneurysms are likely to rupture when they reach about 6–7 cm in diameter → The resulting blood loss and shock can be fatal. The bulge can often be felt in a physical examination or seen with ultrasound examination and it may be possible to surgically replace the damaged artery with a section of artificial artery.

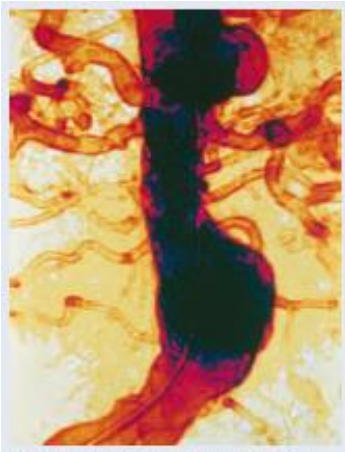


Figure 1.19 An aneurysm in the aorta below the kidneys. If an aneurysm ruptures it can be fatal.

Problems in blood vessels

Dissolving blood clot:

- Tissue plasminogen activator (t-PA): converts plasminogen→ plasmin (an enzymes that dissolves blood clot)
- Aspirin: reduces stickiness of platelets

Coronary bypass operations

- A segment from another blood vessel→ stitches one end to the aorta and other end to a coronary artery past the point of obstruction
- Gene therapy: VEGF (vascular endothelial growth factor)→ to grow new blood vessel

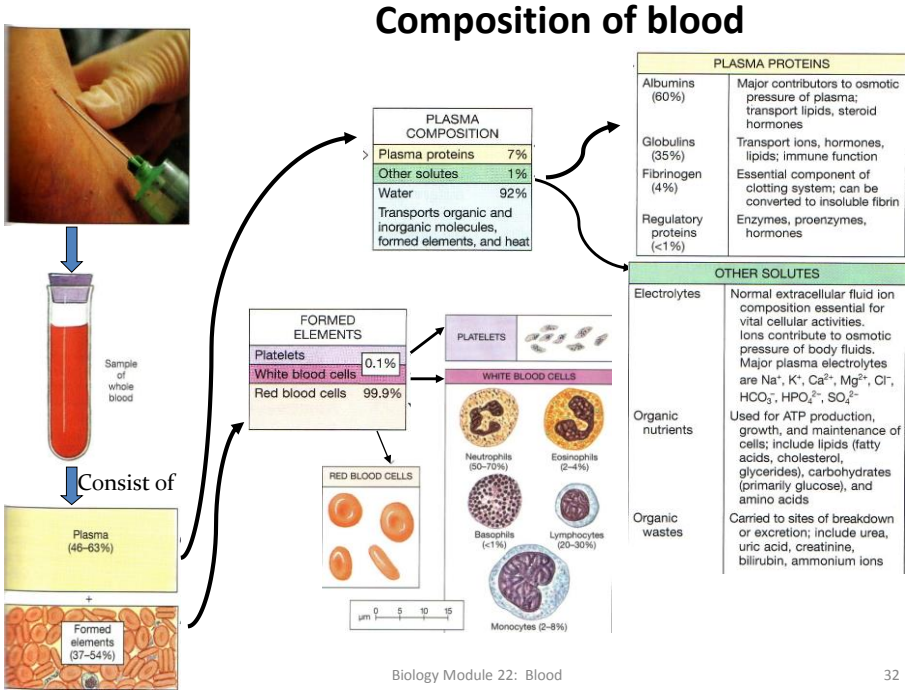
Clearing clogged arteries

- In angioplasty ,heart transplants and other treatments
- Congestive heart failure→ the heart is no longer able to pump blood adequately→ blood backs up in the heart and lungs

Dilated and inflamed veins

- Varicose veins: develops when the valves of veins become weak and ineffective due to the backwards pressure of blood
- Hemorrhoids: varicose veins in the rectum
- Phlebitis : inflammation of a vein

Composition of blood



Blood

Composition:

- 45% formed elements: red blood cells, white blood cells and platelets
- 55% plasma: a variety of inorganic and organic molecules dissolved in water

Function:

1. Transport: oxygen (lungs), nutrients (digestive track); hormone → from all parts of the body, exchange with: carbon dioxide, waste
2. Defense: defends the body against invasion of pathogens, blood clotting
3. Regulation: regulate body temperature, body salts/ water balance, body pH

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- **Plasma**

The liquid portion of blood:

- 92% is water,
- 8% consists of various salts/ ions and organic molecules. Salts→ maintain the pH; Organic molecules: glucose, amino acids→ nutrients; urea→ nitrogenous waste; large organic molecules→ hormones, plasma proteins
- The plasma leaks out through the gaps between the cells in the walls of capillaries, and seeps into the spaces between the cells of the tissues → as **tissue fluid**

- **Plasma proteins**
  - 100 mL plasma contains 7.6 g protein
  - Large size and globular shapes protein plasma blood
  - Three primary plasma proteins :
    - Albumins → 60% of plasma proteins, regulate osmotic pressure of plasma
    - Globulins → antibodies
    - Fibrinogen → blood clotting

Blood plasma and tissue fluid

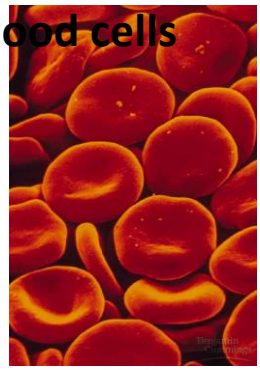
Table 1. The relative permeability of capillaries in muscle to different substance

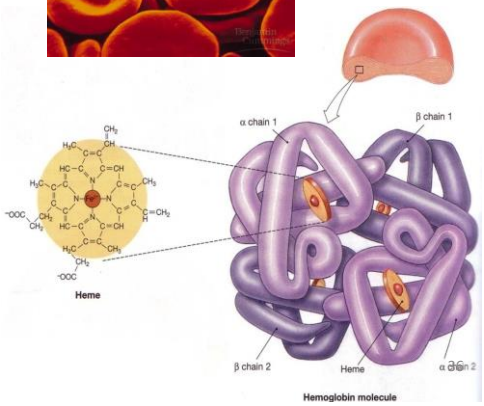
Substance	Relative molecular mass	Permeability
Water	18	1.00
Sodium ions	23	0.96
Urea	60	0.8
Glucose	180	0.6
Haemoglobin	68000	0.01
Albumin	69000	0.00001

Lymph:
About 90% of the fluid that leaks from capillaries eventually seeps back into them. The remaining 10% is collected up and returned to the blood system by means of series of tubes → lymph vessels or lymphatics

The red blood cells

- Red blood cells (erythrocytes): are small, biconcave disk that lack of nucleus when mature
- Great quantity: 4 – 6 million per mm^3 of whole blood
- Contains hemoglobin → transport O_2 , red color
- Oxygen combines loosely with iron

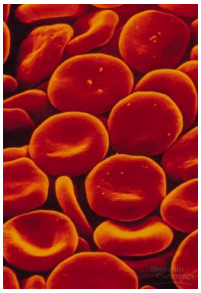




The life cycle of red blood cells

Production of RBC (= erythropoiesis)

- In red bone marrow cells
- RBC lives only 120 days → 2 million RBC are destroyed/ min
- Erythropoietin → speeds up maturation



Destruction of RBC

- Old and damaged RBC are destroyed in liver and spleen

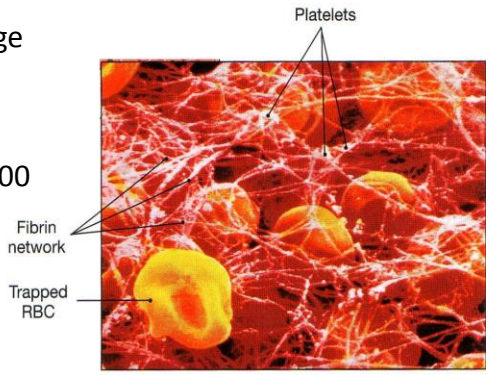
- RBC→ hemoglobin → globin + amino acids
- Heme → bile pigments (billirubin and biliverdin)

Hemolysis: rupturing RBC

Blood clotting

Platelets (thrombocytes) result from fragmentation of certain large cells, megakaryocytes.

- Produced at a rate 200 billion a day
- Blood contains 150,000 – 300,000 per mm3
- Involved in blood clotting/ coagulation



(b) A blood clot

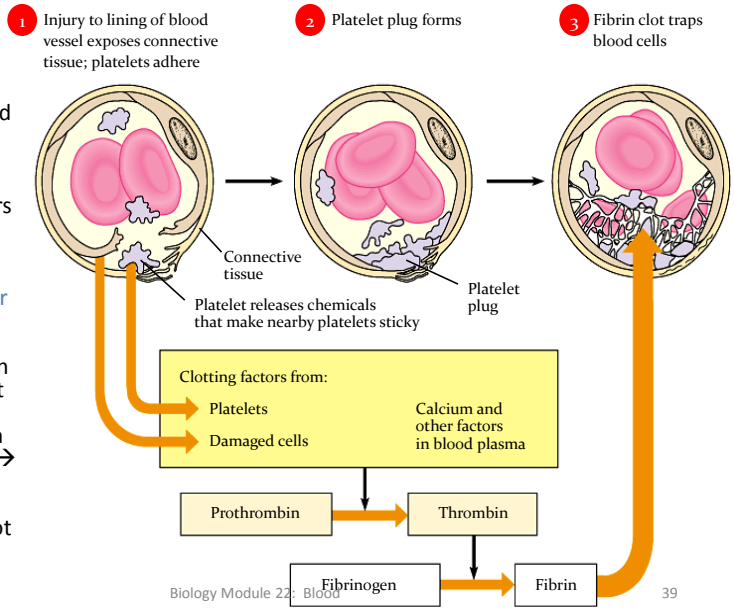
Hemophilia

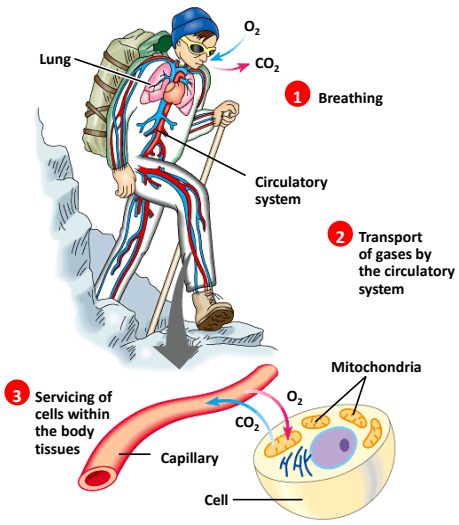
Inherited clotting disorder due to a deficiency clotting factor

Blood clotting

Stages of blood clotting:

Break occurs in blood vessel →damaged tissue releases tissue thromboplastin (blood clotting factor)→ initiates a series of reactions involving several clotting factors and Calcium ions (Ca2+)→ lead to production prothrombin activator → converts prothrombin to thrombin → thrombin act as an enzyme that severs 2 short amino acid chains from each fibrinogen molecule → forming threads of fibrin→ provide framework for the clot





The higher the altitude, the thinner concentration of oxygen is, the lower air pressure is

↓

Hemoglobin in red blood cells carry the oxygen

↓

Sufficient red blood cells number is important in carrying oxygen in high altitude

The partial pressure of oxygen in the atmosphere is just over 20kPa and the partial pressure of oxygen in the alveolus in the lungs is about 13 kPa. If a person climb up a mountain to a height of 6500 m, the air pressure is much less. The partial pressure of oxygen in the air is only about 10 kPa, and in the lungs about 5.3 kPa.

Abnormal hemoglobin

- Inherited disorders :
  - **Thallassemia :**
    - Inability to produce adequate amounts of alpha and beta chains of Hb
    - Rate of RBC production is slowed and the mature RBC are fragile and short lived.
    - Should undergo periodically transfusions
  - **Sickle cell anemia**
    - Mutation the amino acid sequence of the beta chains of Hb molecule.
    - Blood contain abundant oxygen → Hb mol and RBC appear normal
    - Defective Hb bound oxygen → the adjacent Hb molecules interact and the cells become stiff and curved → RBC fragile and easily damaged

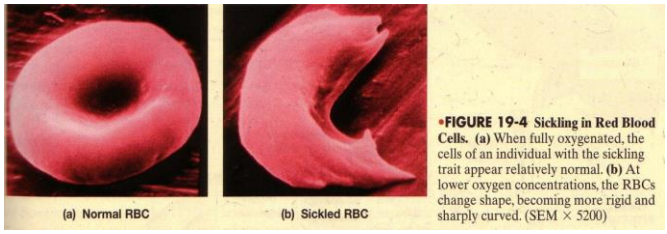


FIGURE 19-4 Sickling in Red Blood Cells. (a) When fully oxygenated, the cells of an individual with the sickling trait appear relatively normal. **(b)** At lower oxygen concentrations, the RBCs change shape, becoming more rigid and sharply curved. (SEM × 5200)

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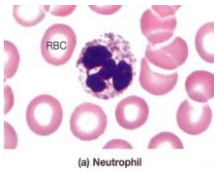
The white blood cells (leucocytes)

- Larger than RBC, have a nucleus, lack hemoglobin, translucent
- 5,000 – 11,000 per mm3
- Found in tissue fluid and lymph (fluid within lymphatic vessels)
- Fight infection (homeostasis, immunity)
- Derived from stem cells in the red bone marrow
- CSFs (Colony-stimulating Factors): proteins that help regulate the production of WBC
- Types of WBC: granular and agranular → have granules in the cytoplasm surrounding nucleus. Granules: enzymes and proteins → helps WBC defend the body

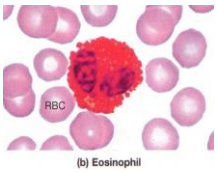
The white blood cells (leucocytes)

Granular leucocytes:

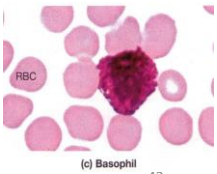
- Neutropils: most abundant, have multilobed nucleus joined by nuclear threads (polymorphonuclear). Engulf the pathogen during phagocytosis



- Eosinophils: have bilobed nucleus, take up eosin→ red color. Increase the number in parasitic worm infection and allergic reaction

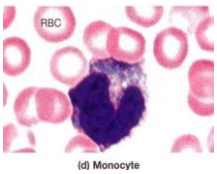


- Basophils: have U-shaped or lobed nucleus, take up basic stain→ dark blue color. Together with mast cells→ release histamine associated with allergic reactions

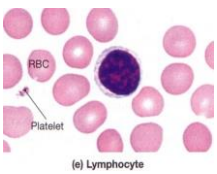


Agranular leucocytes

- Monocytes: the largest of WBC. After taking up residence in tissue→ differentiate into larger macrophages. Macrophages phagocytes pathogen, old cells, and cellular debris, stimulate other lymphocytes to defend the body



- Lymphocytes: 2 types: B lymphocytes and T lymphocytes.
  - B lymphocytes: producing antibodies→ combine with antigen to destroy target pathogen
  - T lymphocytes: directly destroy any cell that has foreign antigen



Leukemia

A type of cancer, an abnormally large number of immature WBC that fill red bone marrow & prevent RBC development

Blood typing

ABO system

- The presence or absence of type A and type B antigens on RBC→ determines a person's blood type. Blood type A: has A antigen in the RBC; blood type B: has B antigen in the RBC
- 4 types of blood: A, B, AB and O
- The presence of anti-A or anti-B in plasma→ can cause agglutination → followed by hemolysis → death

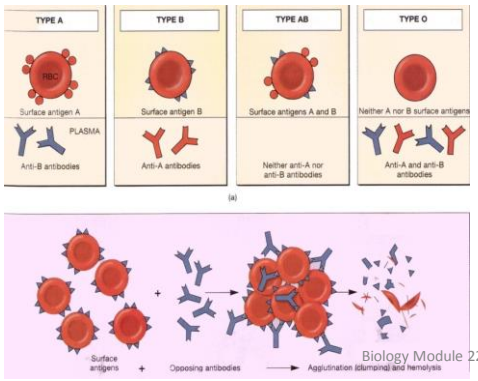


TABLE 19-2 Differences in Blood Group Distribution

Population	Percentage with Each Blood Type				
	O	A	B	AB	Rh^+
U.S. (average)	46	40	10	4	85
African American	49	27	20	4	95
Caucasian	45	40	11	4	85
Chinese American	42	27	25	6	100
Filipino American	44	22	29	6	100
Hawaiian	46	46	5	3	100
Japanese American	31	39	21	10	100
Korean American	32	28	30	10	100
Native North American	79	16	4	<1	100
Native South American	100	0	0	0	100
Australian Aborigine	44	56	0	0	100

Rhesus (Rh) system

- 85% of US population has this antigen (Rh+)
- Rh- individuals normally do not have antibodies to the Rh factor, but they make it when exposed to the Rh factor
- Hemolytic disease of the newborn

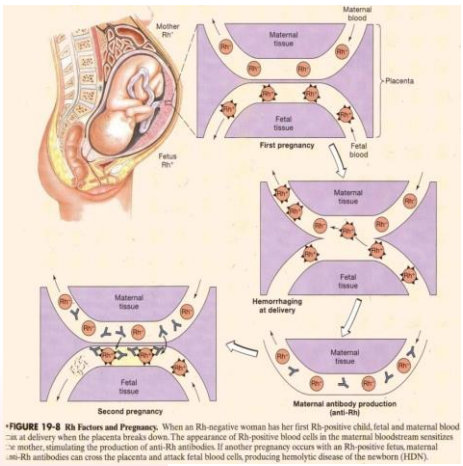
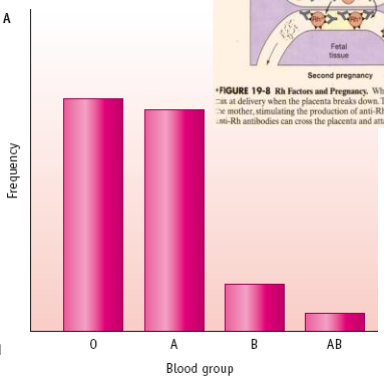


FIGURE 19-8 Rh Factors and Pregnancy. When an Rh-negative woman has her first Rh-positive child, fetal and maternal blood mix at delivery when the placenta breaks down. The appearance of Rh-positive blood cells in the maternal bloodstream sensitizes the mother, stimulating the production of anti-Rh antibodies. If another pregnancy occurs with an Rh-positive fetus, maternal anti-Rh antibodies can cross the placenta and attack fetal blood cells, producing hemolytic disease of the newborn (HDN).



Rh problem and the frequency of blood group in the world