Chapter 8

Circulation & Immunity

Goals for This Chapter

1. Identify the major structures of the circulatory system
2. Describe the structure and function of blood vessels
3. Describe the action of the heart and the circulation of blood through the body
4. Investigate heart rate and blood pressure

5. Identify disorders of the circulatory system
6. Investigate the relationship between blood pressure, heart rate, and exercise
7. Describe the main components of blood
8. Explain the role of blood in regulating blood temperature

9. Explain the role of the circulatory system in the exchange of matter and energy
10. Identify blood disorders and the technologies used to treat them
11. Describe and explain the function of the lymphatic system
12. Identify and list the cellular and non-cellular components of the immune system
13. Describe the role of cellular and non-cellular components of the immune system

Section 8.1 – Structures of the Circulatory System

Main Functions of the Circulatory System

- Oxygen and nutrients are transported to our cells, and waste must be removed by the circulatory system
- Our internal temperature is also regulated by our circulatory system
- Our circulatory system also protects us from blood loss due to injury and infections

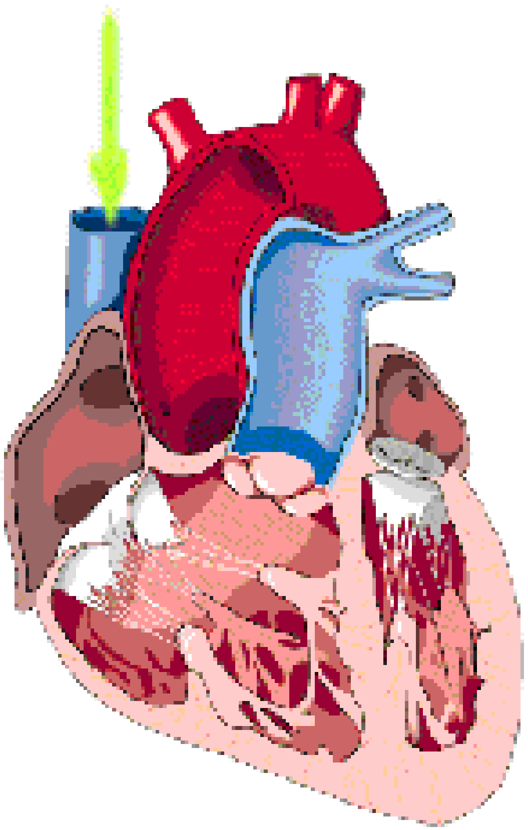
William Harvey

- Early theories suggested that blood ebbed and flowed like a tide
- William Harvey suggested that the heart pumped blood through the body
- He determined that the body's blood volume is circulated over and over through the body

The Heart

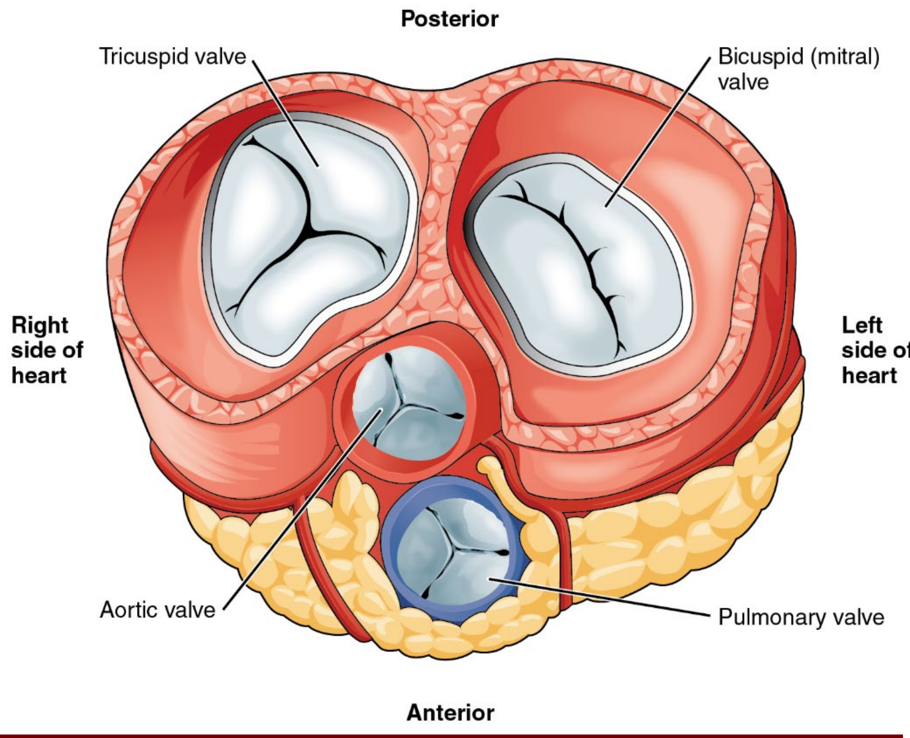
- The heart is a muscular structure about the size of the human fist
- It is surrounded by a fluid-filled membrane called the pericardium

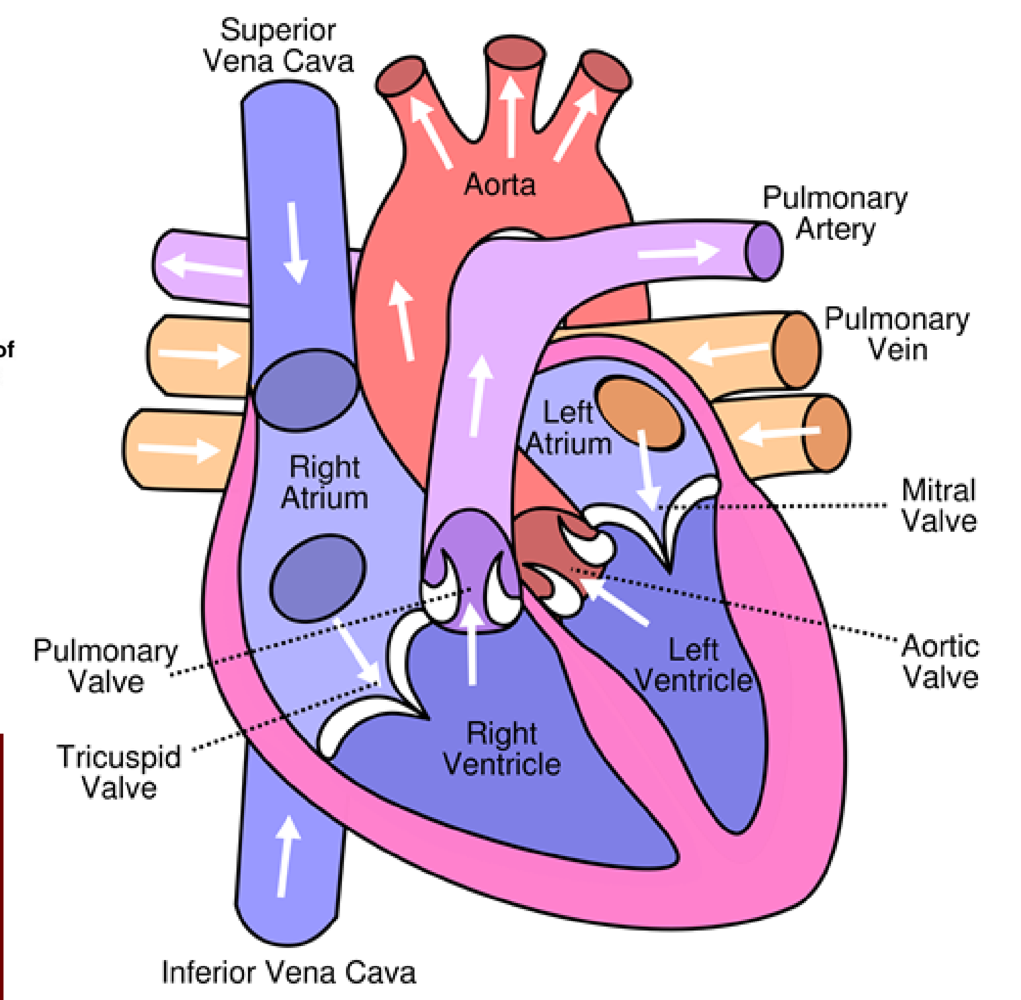
Circulation Within The Heart



- Right Atrium
- Tricuspid Valve
- Right Ventricle
- Pulmonic Valve
- Pulmonary Arteries
- Pulmonic Veins
- Left Atrium
- Mitral Valve
- Left Ventricle
- Aortic Valve
- Aorta

Anatomy of the Heart





Anatomy of the Heart

- Blood comes back to the heart through the Vena Cava (Inferior & Superior) and enters the Right Atrium.
- When the atrium contracts, it pushes blood down through the Right AV (atrio-ventricular) valve, aka the tricuspid valve.
- The blood now enters the Right Ventricle. When the ventricle contracts, blood is pushed through the pulmonary semi-lunar valve and into the pulmonary artery (going to the lungs).

Anatomy Continued

- When deoxygenated blood is exchanged for oxygenated blood at the lungs, it returns to the heart via the pulmonary veins.
- Blood enters the Left Atrium now. When it contracts, blood is forced through the Left AV (atrio-ventricular) valve, aka the mitral valve into the Left Ventricle.
- When the ventricle contracts, blood is pumped through the aortic semi-lunar valve and out through the aorta to the rest of the body.
- NOTE: valves have **chordae tendinae** to prevent back-flow of blood through the heart.

- The superior vena cava brings in blood from the head, and the inferior vena cava brings in blood from the rest of the body
- Oxygenated blood from the lungs enters the left atrium from the pulmonary veins
- The pulmonary arteries send deoxygenated blood from the right ventricle to the lungs
- The aorta carries oxygenated blood from the left side of the heart to the rest of the body

- Coronary arteries run along the muscle tissue on the surface of the heart, bringing oxygen and nutrients to the muscle
- If these arteries become blocked, then the muscle will slowly die
- The heart, unlike other organs, will not slow down if there are not enough nutrients or oxygen to support it

Coronary Bypass Surgery

- In this surgery, grafted veins are used to provide a route through which blood may travel around the blocked vessels

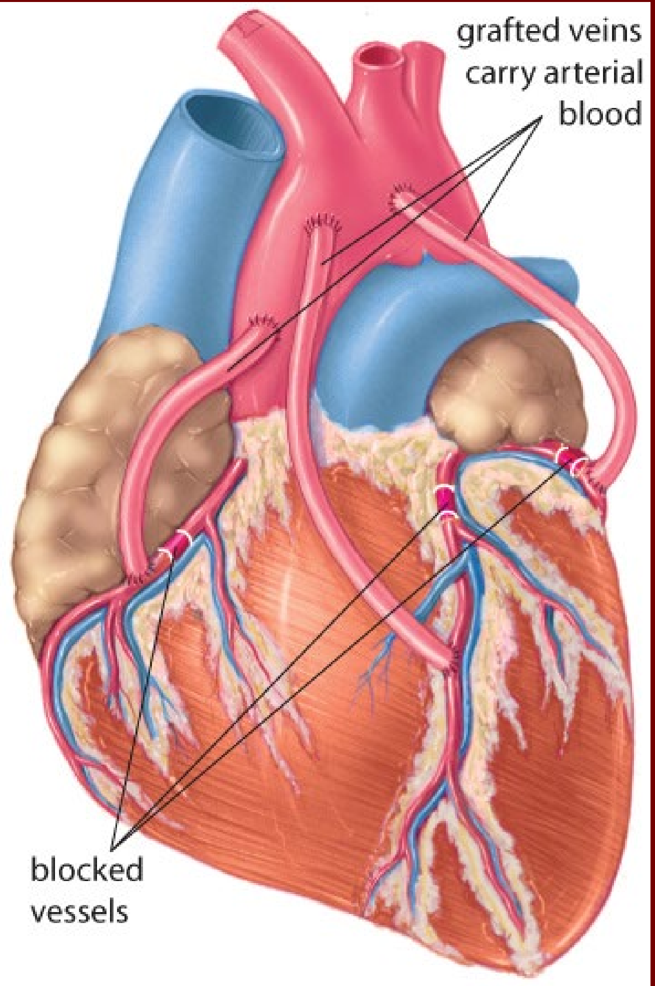


Figure 8.13 Coronary bypass operation: this heart shows a triple bypass, meaning that three new pathways were constructed to avoid blockages in three separate blood vessels.

Major Arteries and Veins of the Body

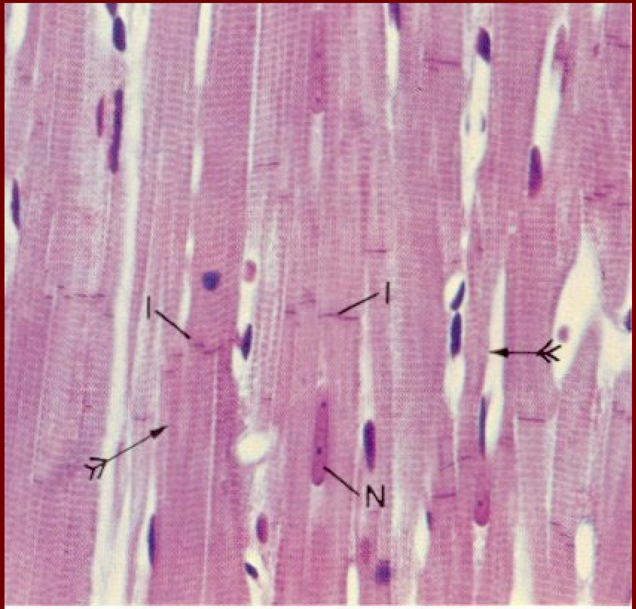
- Arteries:
  - Aorta: biggest artery in the body; pumps blood to head, torso, and lower body.
  - Carotid artery: branches off from the aorta and goes to the brain.
  - Coronary artery: provides blood to the heart itself
  - Femoral artery: provides blood to the lower extremities
  - Hepatic artery: provides blood to the liver
  - Renal artery: provides blood to the kidneys

Major Blood Vessels Cont.

- Veins:
  - Vena Cava: biggest vein in the body; separated into 2 parts. Inferior VC comes from the body and Superior VC comes from the head
  - Jugular: vein coming down the neck from the brain
  - Coronary: vein taking blood from heart to VC
  - Femoral: carrying blood from lower body to heart (IVC)
  - Hepatic: carrying blood from liver
  - Renal: carrying blood from kidneys

Setting The Heart's Tempo

- The muscle of the heart is unlike other muscles in the body
- The muscle cells of the heart are branched
- These muscle tissues, known as myogenic muscle will beat without nerve stimulation



Cardiac Muscle, H&E (Med)
I = Intercalated discs
N = Nuclei
Arrows = Cross trabeculae

- The tempo of the heart is set by the sinoatrial (SA) node and the atrioventricular (AV) node
- These node acts as a pacemaker, ensuring that all of the muscle beats at the same rhythm
- Surgeons that perform open-heart surgery must be very careful not to cut any of the nerves running from the SA node or the AV node

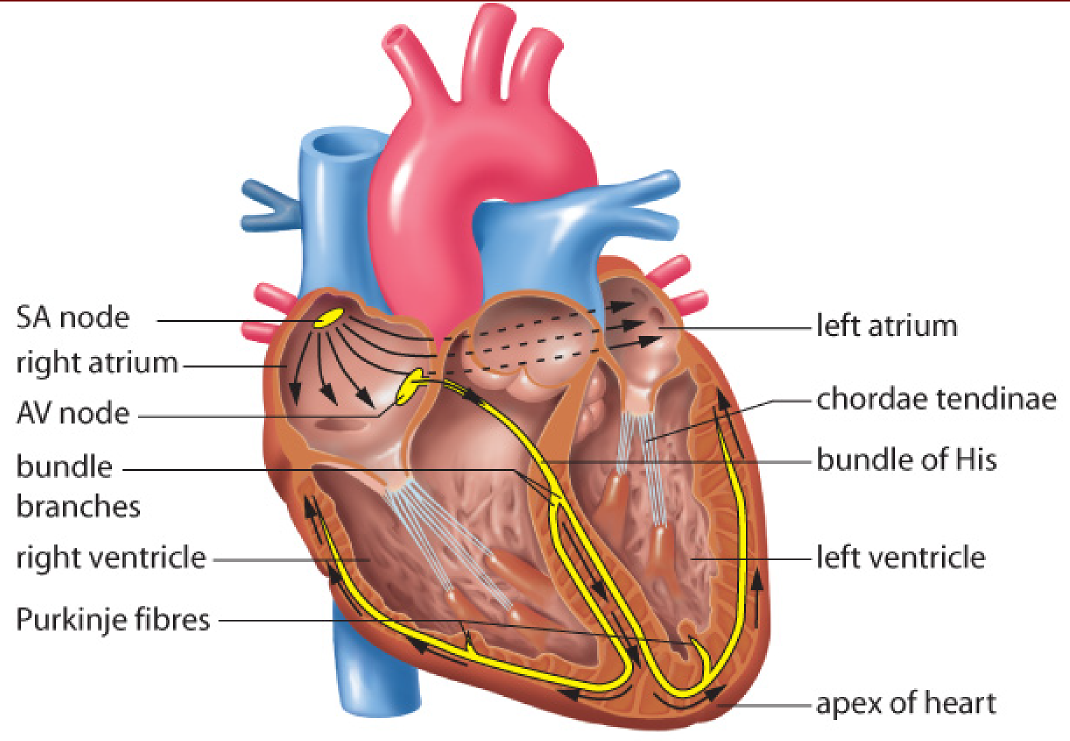


Figure 8.7 The SA node sends out an electrical stimulus that causes the atria to contract. When this stimulus reaches the AV node, it is passed through the bundle of His and the Purkinje fibres. The stimulus causes the ventricles to contract, starting from the apex and then upward, which forces blood toward the pulmonary artery and aorta. The chordae tendinae are strong, fibrous strings that prevent the valves in the heart from inverting when the heart contracts.

Electrocardiograms

- The electrical activity in the heart can be measured using an electrocardiogram (ECG)
- In a healthy heart rhythm, there are three waves:
- ECG Demo Game

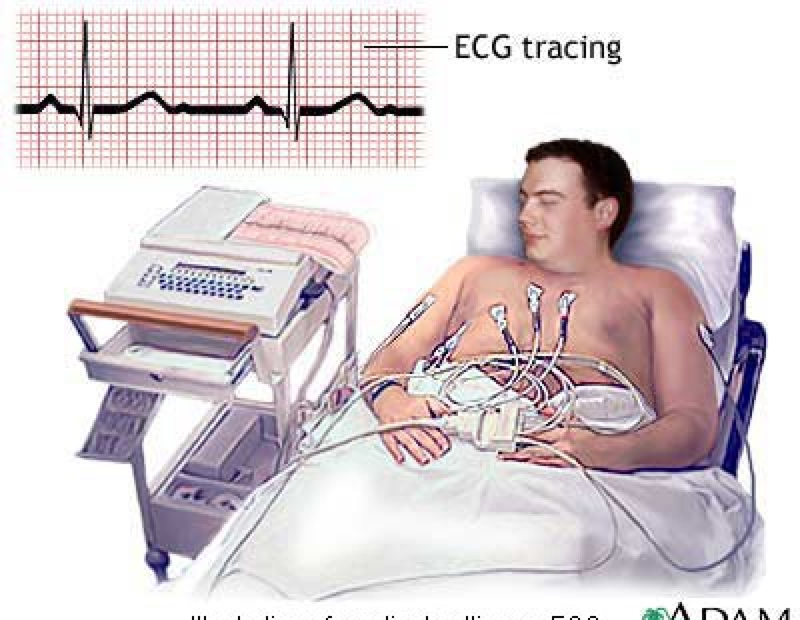


Illustration of a patient getting an ECG.

- A P wave indicates contraction of the atria
- A large spike, known as the QRS wave records ventricular contraction
- The final T wave indicates recovery of the ventricles
- Dead heart tissue will create an ECG with abnormal peaks and lines

Heart Sounds

- The familiar sounds of a heartbeat are due to the opening and closing of valves
- As the ventricles contract, blood is forced up the sides of the ventricle and the AV valve closes, producing a “lubb” sound
- As the ventricles relax, blood pressure decreases and the semilunar valves close, causing the “dubb” sound

- If a valve does not close completely, then a murmur is detected
- This murmur is the sound of blood rushing backwards through a valve, and creates a gurgling sound

Cardiac Output

- Cardiac output refers to the amount of blood that flows from each side of the heart per minute
- Two factors affect cardiac output:

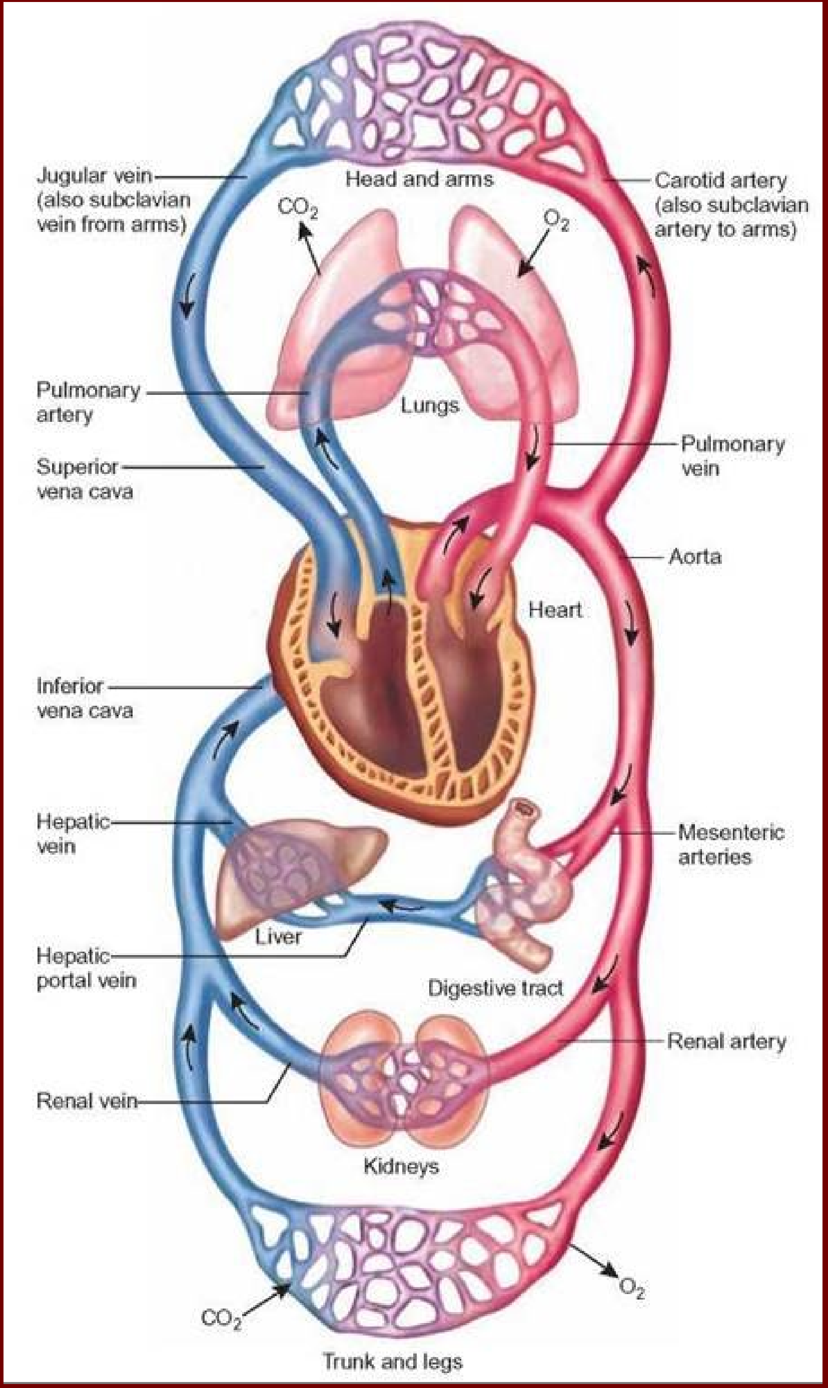
1. Stroke Volume – the amount of blood pumped by each beat of the heart
2. Heart Rate – the number of times the heart beats per minute

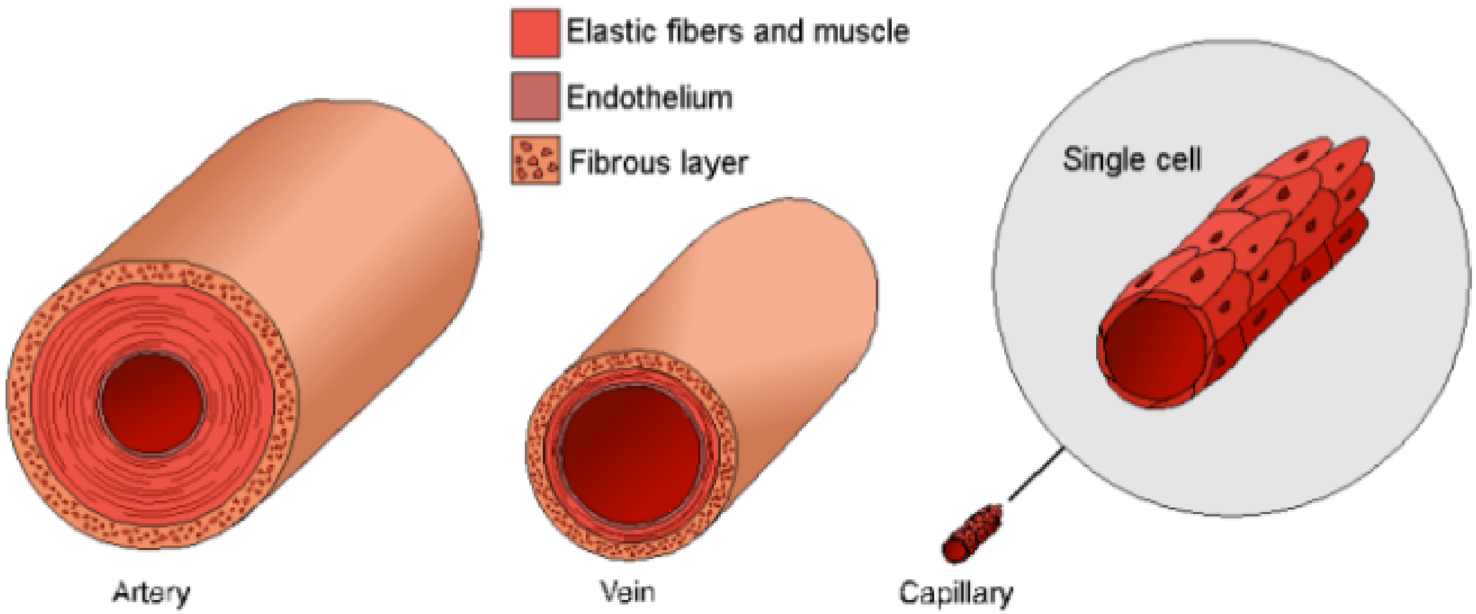
Ex: Calculating Cardiac Output

- Tom’s heart has a stroke volume of 50 mL and a heartrate of 100 beats per minute. Calculate his cardiac output.

- In general, the average person will have a cardiac output of about 5L per minute
- People with lower resting heart rates have a more muscular heart and can pump a greater volume with each beat

- Vessels that carry blood to and from the lungs form the pulmonary circulatory system
- Vessels that carry blood to and from the body's other tissues form the systemic circulatory system





Arteries take blood away from the heart (arteries=away)

Have thick muscular layer that expand and contract to push blood along.
Expansion of arteries is pulse

Veins take blood to the heart

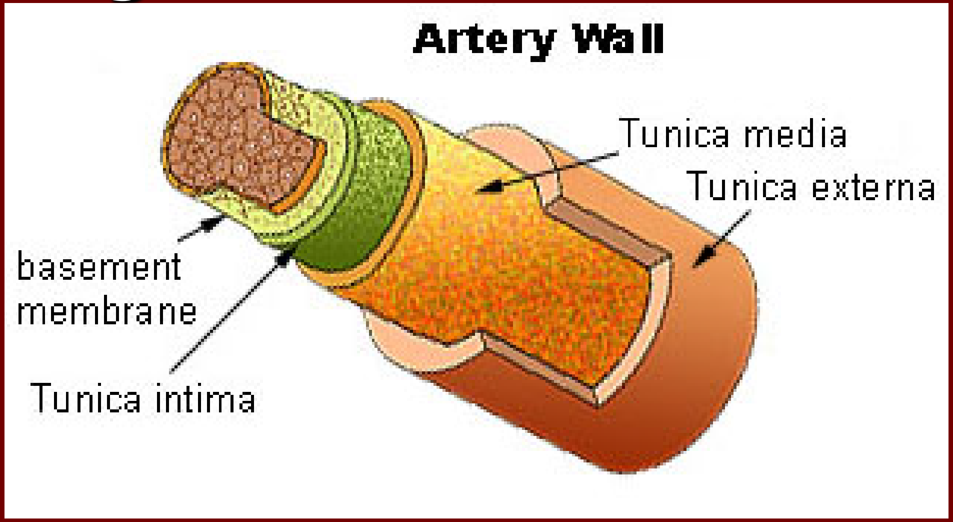
Thinner
Have valves to stop blood from going backwards

Capillaries are the smallest blood vessel. They are so small that only one blood cell can fit through at one time.They connect the veins and arteries.

Function: - where diffusion of nutrients and gases occurs

Blood Vessels

- Arteries are vessels that carry high-pressure blood away from the heart
- The pulse you feel is created by changes in the diameter of the vessel when blood flows through it



- Sometimes, an artery wall will become weak and bulge (known as an aneurysm)
- If this is not attended to, the artery will burst
- This can lead to a stroke if it occurs in the brain

- If a person’s diet contains too much fat, it will build up in the arteries
- The fat encourages a fibrous growth of calcium and other minerals to deposit on its surface (this is known as plaque)
- The fat and plaque can partially (or in extreme cases almost completely) block the passage of blood

- This condition is known as atherosclerosis
- This leads to very high blood pressure
- Around the deposit, blood can clot
- This will reduce the amount of oxygen and nutrients from reaching the tissues
- If this occurs in the vessels supplying heart muscle, the patient will have a heart attack
- If this occurs in the vessels supplying the nervous tissue of the brain, it results in a stroke

Treatment of Atherosclerosis

- Angioplasty may be used to treat this condition

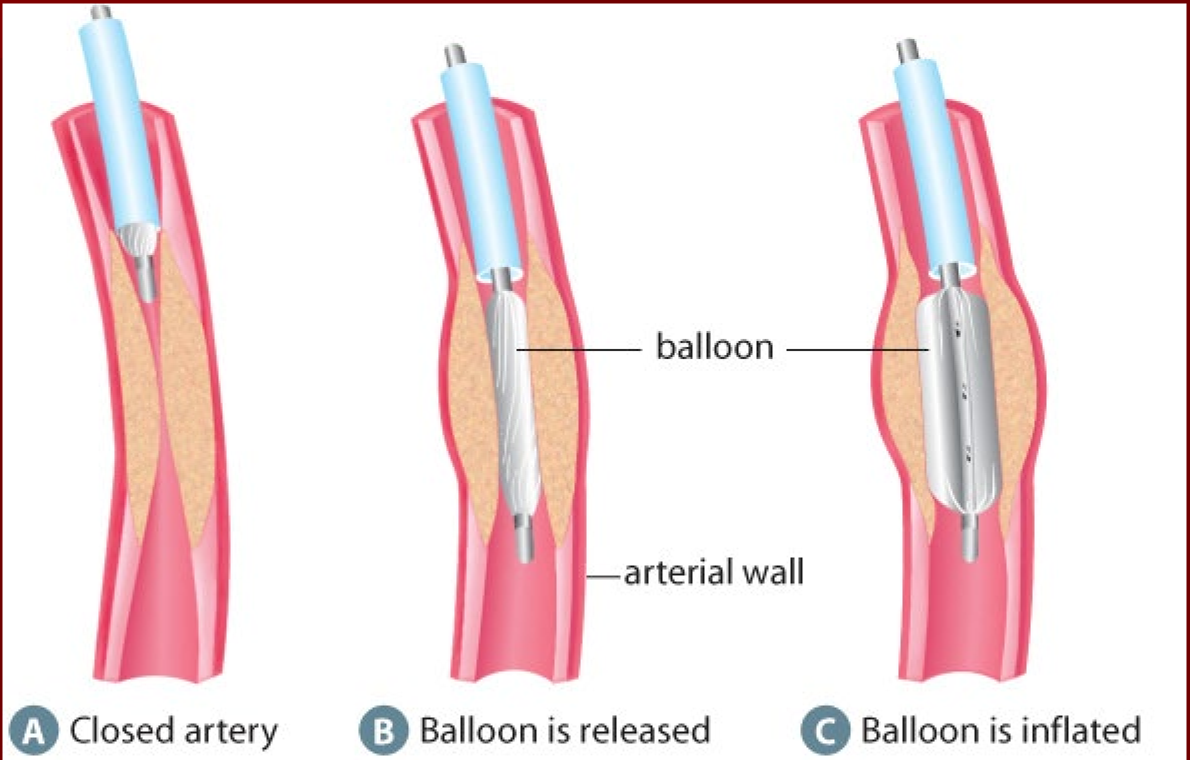
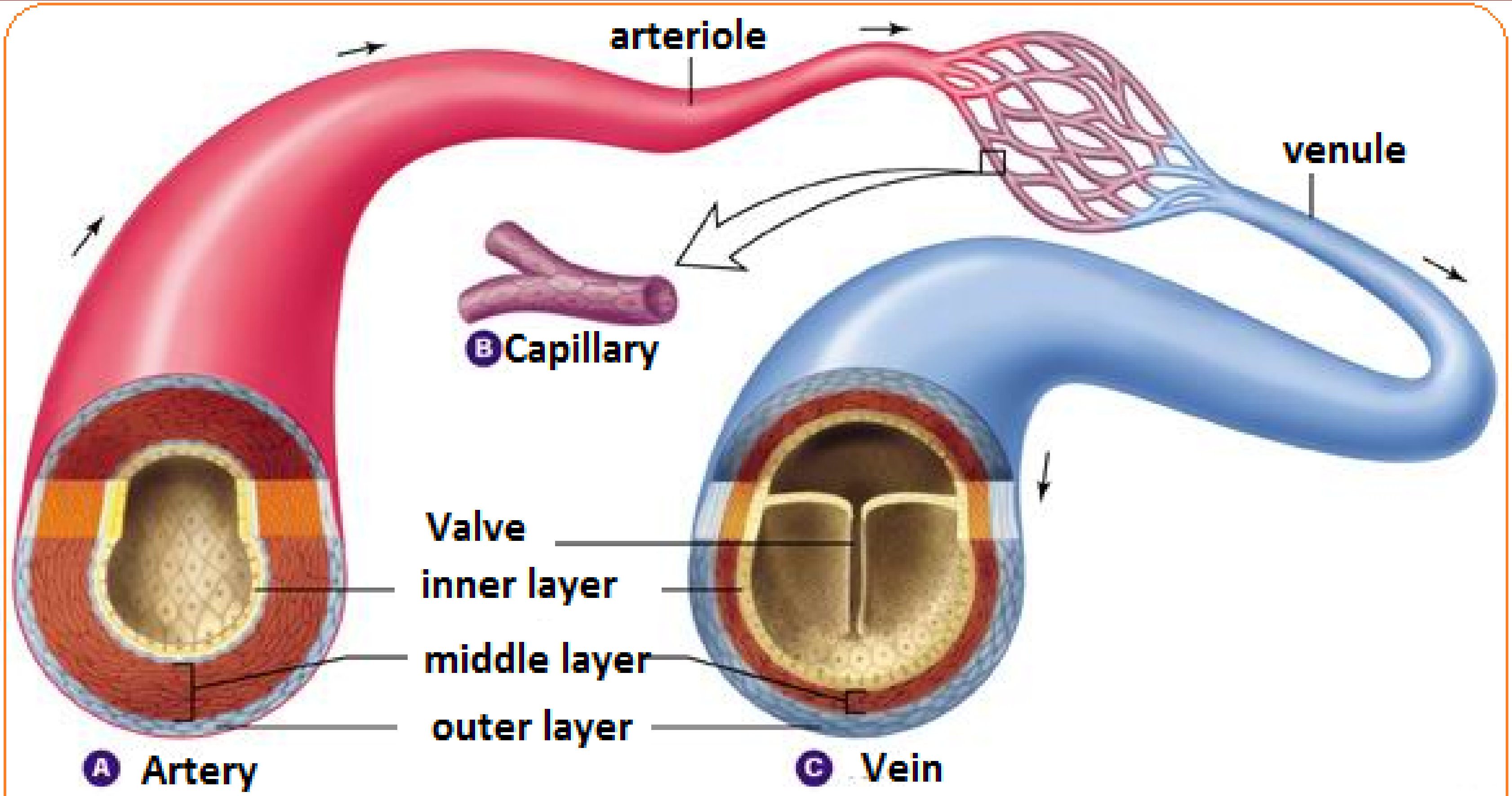


Figure 8.12 An angioplasty: The balloon is inflated to open up the blockage in the artery.

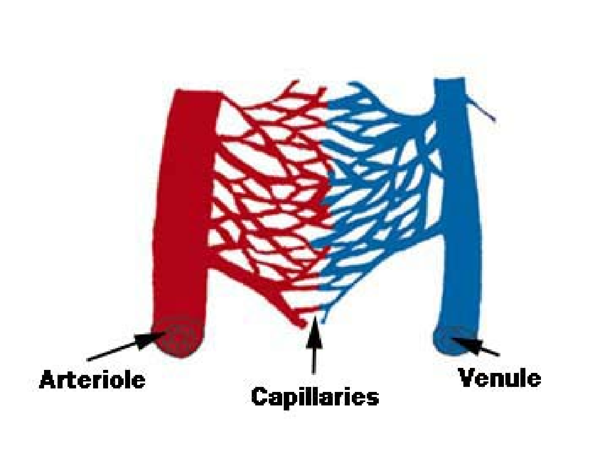
- From the arteries, the blood enters smaller vessels called arterioles
- The diameter of the arterioles is controlled by the sympathetic nervous system
- The arterioles can adjust their diameter to restrict blood flow (vasoconstriction) or to increase blood flow (vasodilation)

Blood Vessels

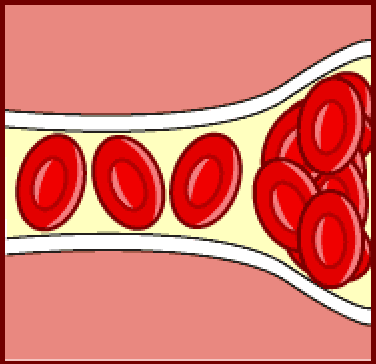


At any given moment, about 30% of the blood in your systemic circulation will be found in the arteries, 5% in the capillaries and 65% in the vein.

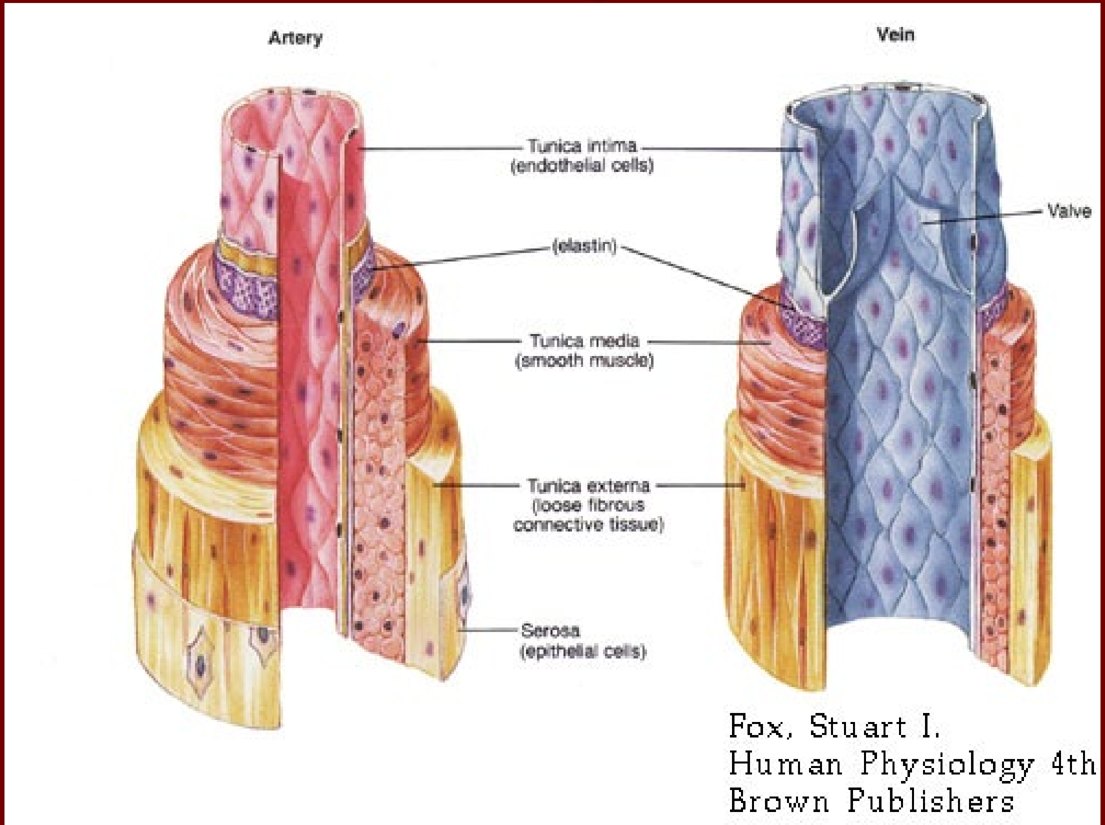
- From the arterioles, the blood flows into the capillaries
- Unlike other blood vessels, capillaries are only one layer of cells thick
- As well, blood cells must move through these capillaries single-file
- The thin walls of the capillaries facilitate diffusion of nutrients and gases (and waste) to and from the neighboring tissue



- However, capillaries are easily damaged
- When capillaries are broken, the blood leaves the capillary and enters the interstitial spaces between the cells and creates a bruise

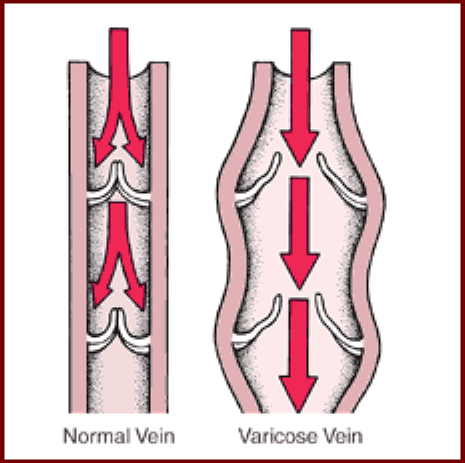


- The capillaries enlarge and turn into venules and veins
- However, unlike the arteries, the blood in the veins is not under high pressure
- So, how does blood get back to the heart?



- William Harvey discovered that veins have tiny valves that prevent blood from flowing in the wrong direction
- As well, the skeletal muscles help to push the blood back to the heart as they contract and increase pressure in the veins
- As much as 50% of your blood can be found in the veins (they act as a blood reservoir)

- As people get older, the veins lose their elasticity
- Over time, the blood can pool in the vein and damage the valves
- This causes the blood to pool at the extremities, causing bulges in the hands and feet (known as varicose veins)



Blood Pressure

- Blood pressure is measured using a sphygmomanometer
- This device fills with air and closes off blood flow in the brachial artery of the arm

- The pressure is slowly released until a low-pitched sound can be heard
- At this point, the systolic blood pressure is taken (this is the pressure produced by contraction of the ventricles)
- The pressure is released until the sound disappears
- This is when the diastolic blood pressure is taken (the pressure produced when the ventricles are relaxed)

- The highest blood pressures are found in the aorta because it is nearest to the heart
- Blood pressure drops rapidly as the blood enters the capillaries and slows
- Blood pressure is regulated by cardiac output and the diameter of the arteries and arterioles
- Dilation and constriction of the arterioles can depend on the presence of certain chemicals

Factors Affecting Arteriolar Resistance

Epinephrine	Arteriolar constriction, except to heart, muscles and skin
Sympathetic Nerves	Arteriolar constriction, except to skeletal and cardiac muscle
Acid Accumulation	Arteriolar dilation
CO_2 Accumulation	Arteriolar dilation
Lactic Acid Accumulation	Arteriolar dilation

8.2 – Blood and Circulation

- Blood is considered a connective tissue because it links all cells and organs in the body
- Blood consists of a fluid portion and a solid portion

Plasma – The Fluid Component

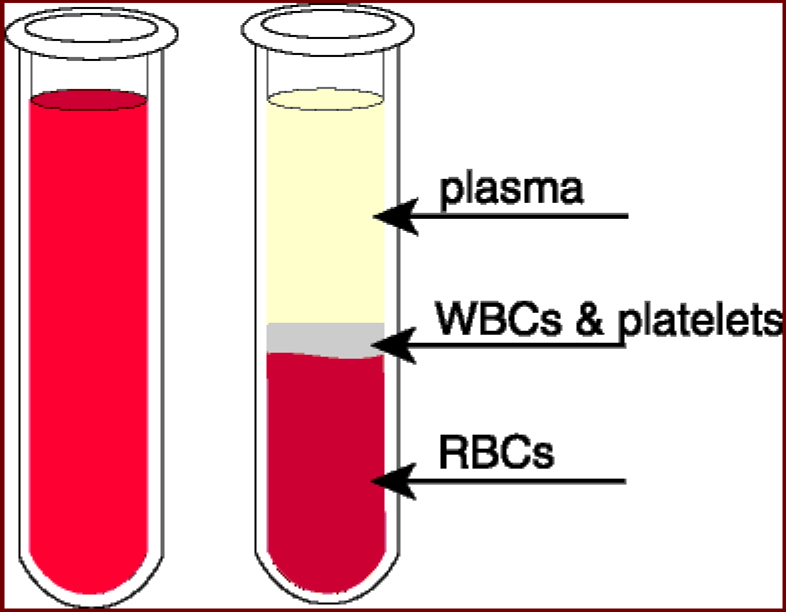
- 55% of blood volume is plasma (fluids, proteins, glucose, gases, wastes and vitamins and minerals)
- Blood proteins come in 3 types:

1. Albumins – serve to maintain osmotic balance
2. Globulins – act as part of immune response
3. Fibrinogen – helps with blood clotting

The Other 45%...

- There are several cell types that make up the remaining volume of blood:

1. Erythrocytes
2. Leukocytes
3. Platelets

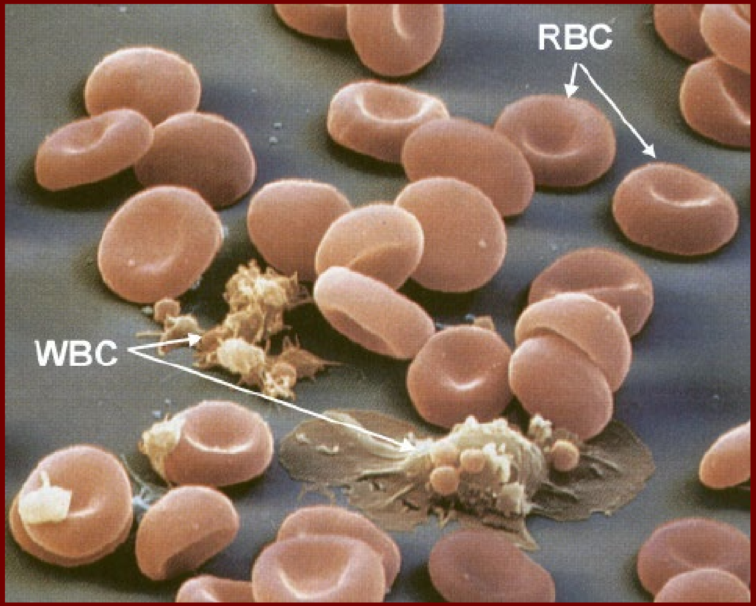


Erythrocytes

- Erythrocytes are red blood cells
- They are specially designed to carry oxygen
- Red blood cells lack a nucleus and have a "biconcave" shape
- This allows them to have a much greater surface area (for O_2 absorption) than a spherical cell
- However, without a nucleus, red blood cells cannot divide
- Contain hemoglobin (heme = iron containing) to increase O_2 absorption by 70x

Leukocytes

- These are also known as white blood cells
- These cells are responsible for immune system responses
- There are a number of different leukocyte types

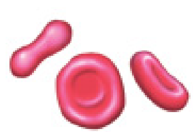
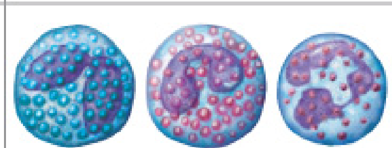
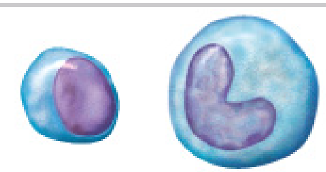


Platelets

- Platelets are formed from stem cell cytoplasm and have irregular shapes
- The platelets float through blood vessels and catch on broken vessel walls
- This causes a tear in the platelet, which initiates blood clotting

Cell Types

Table 8.2 The Cellular Components of Blood

Point of Comparison	Red blood cells	White blood cells		Platelets
		Granulocytes and monocytes	Lymphocytes	
Origin	red bone marrow	red bone marrow	thymus, red bone marrow	red bone marrow, lungs
Cells present per mm^3 of blood (approximate)	5 500 000 (male) 4 500 000 (female)	6000	2000	250 000
Relative size	small (8 μm diameter)	largest (up to 25 μm)	large (10 μm)	smallest (2 μm)
Function	to carry oxygen and carbon dioxide to and from cells	to engulf foreign particles	to play a role in the formation of antibodies (defence function)	to play a role in the clotting of blood (defence function)
Life span	120 days	a few hours to a few days	unknown	2–8 days
Appearance				

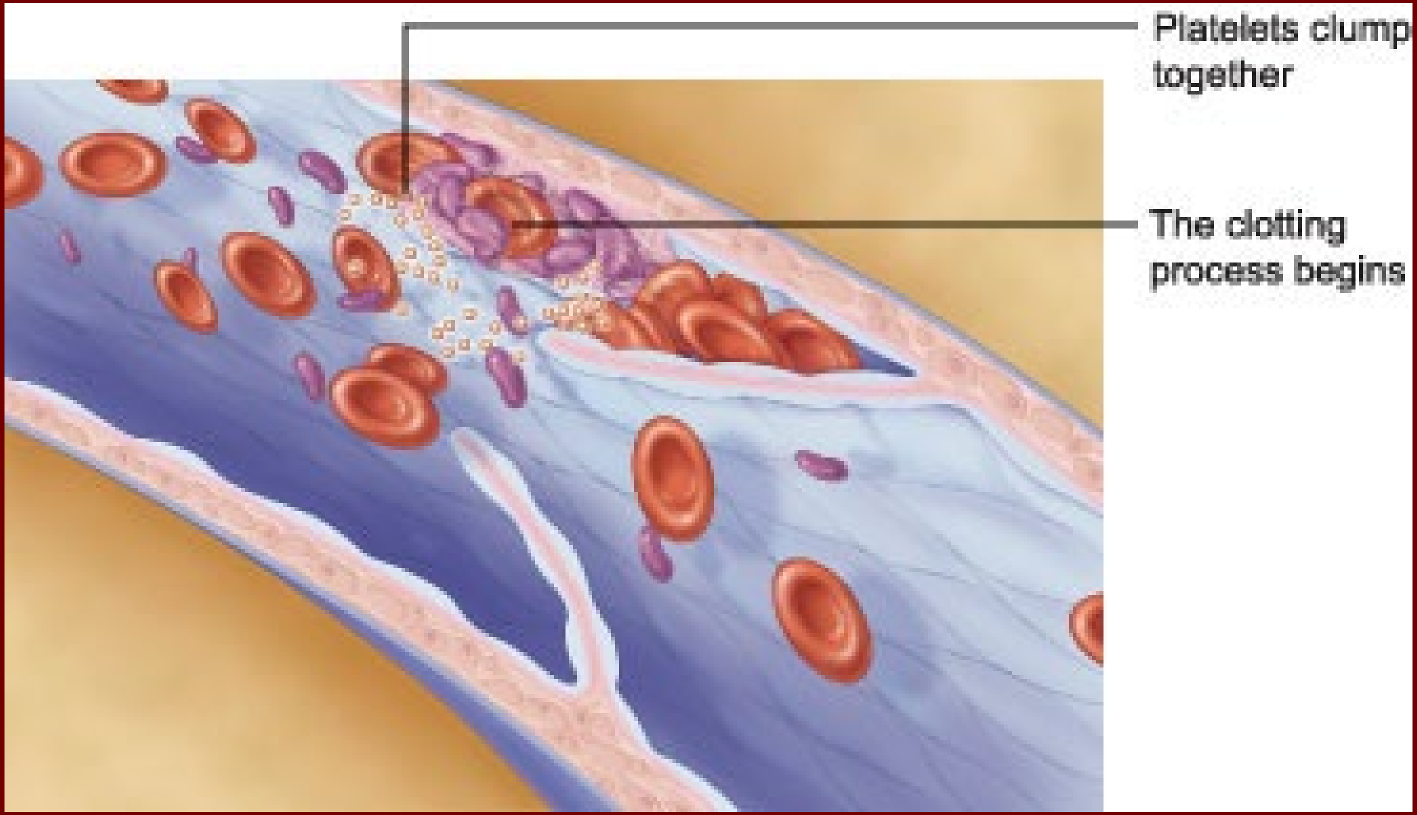
Blood Clotting

- Clotting maintains homeostasis by preventing massive blood loss
- This occurs in a series of steps

Clotting Process

1. When platelets burst on contact with a break in a vessel wall, they release compounds that combine with other blood components to form a protein known as *thromboplastin*
2. Thromboplastin and calcium ions activate a blood protein known as prothrombin
3. Prothrombin is converted to an enzyme known as thrombin, which splits up a fibrinogen molecule
4. Fibrinogen is converted into fibrin threads, which wrap around the damaged area, sealing it

Visual Representation of a Clot:



The Functions of Blood

1. Transport:
   - Oxygen, carbon dioxide, nutrients, waste
   - Function of RBC’s (erythrocytes)
2. Immune Response:
   - Engulf foreign pathogens, produce antibodies, puncture membranes of foreign cells, remember foreign pathogens for future encounters
   - Function of WBC’s (leukocytes)
3. Blood Clotting:
   - Wrapping protein around injured areas to prevent blood loss
   - Function of platelets

Homeostatic Regulation

- Blood also helps regulate our body temperature. The water inside blood plasma carries a lot of energy (due to high specific heat capacity)
- Through vasodilation or vasoconstriction of blood vessels, more or less blood can be moved to or from an area of the body, thus heating it up or cooling it down

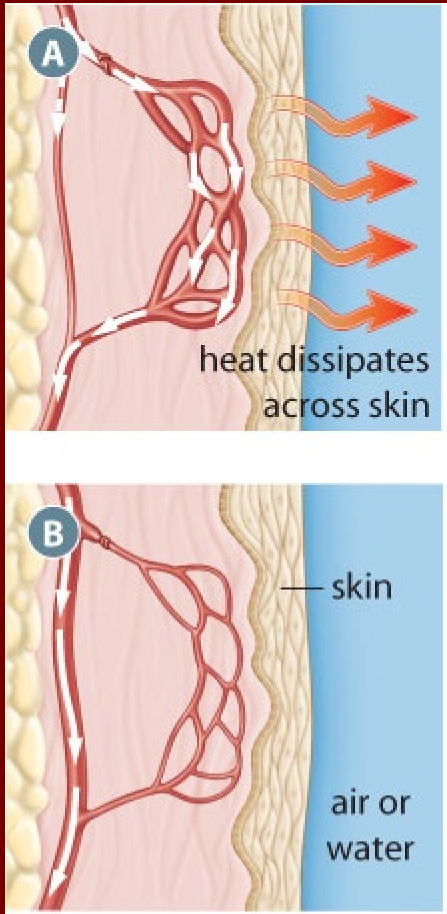


Figure 8.19 Vasodilation (A) and vasoconstriction (B)

Temperature Regulation

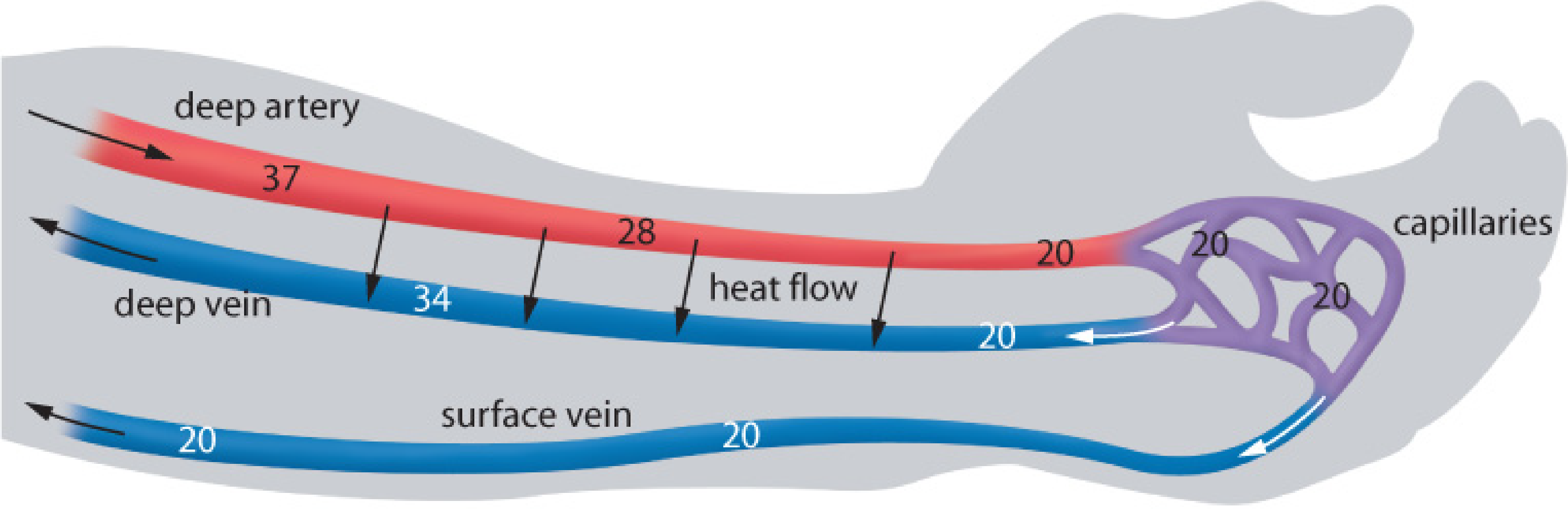


Figure 8.20 The countercurrent heat exchange mechanism between the blood vessels in the human arm: The deep vein and artery are adjacent to one another, so heat is exchanged from one to the other. As a result, arterial blood is cooled as it nears the hand, and venous blood is warmed as it leaves the hand and returns to the body core. When heat conservation is important, more blood returns to the heart through the deep vein. In higher-temperature conditions, when heat conservation is not a concern, more blood returns through the surface vein. Numerals indicate the temperature of the blood in degrees Celsius.

Circulation and the Action of Capillaries

- The combined surface area of the capillaries covers about 6300 m^2
- It is throughout this huge surface that we exchange materials between our blood and our cells

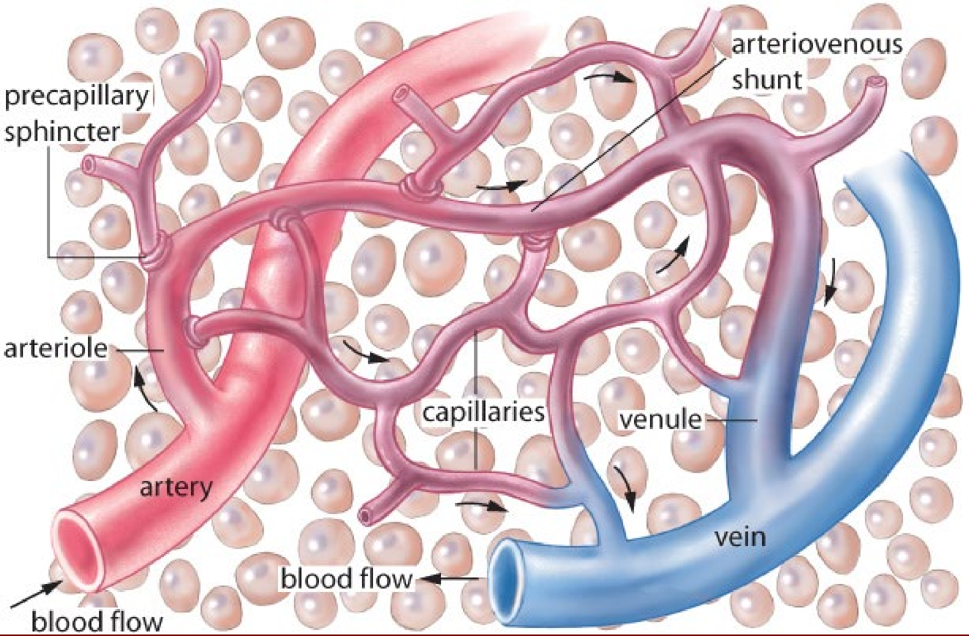


Figure 8.21 Anatomy of a capillary bed: The cells that make up living tissues are a distance of one to three cell-widths from a capillary. Why must cells lie so closely to capillaries?

Capillary Exchange

- Cells are surrounded by interstitial fluid, which is also known as extracellular fluid or tissue fluid
- Materials such as oxygen and nutrients have a low concentration in the interstitial fluid, but high concentrations in the blood
- Likewise, waste products have a high concentration in the interstitial fluid, but low concentrations in the blood

- Blood moves slowly through the capillaries, which increases the time over which diffusion may occur

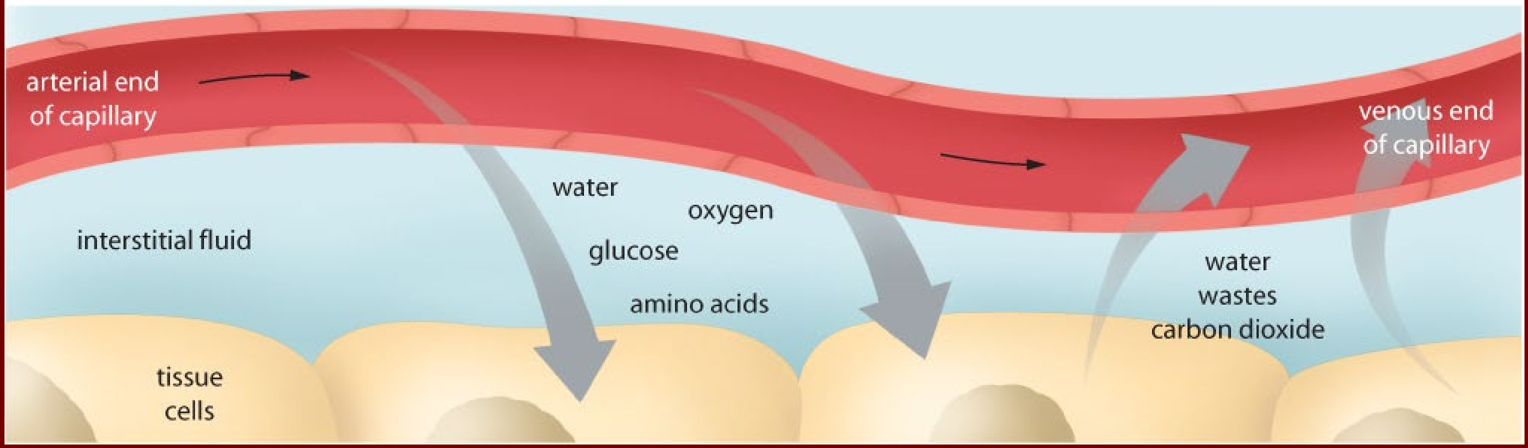


Figure 8.22 The exchange of materials between the blood in a capillary and the fluid surrounding the individual cells in the body takes place across the wall of the capillary.

Blood Disorders

1. Hemophilia
   - Genetic disorder that can result in fewer numbers of platelets or clotting proteins. This can lead to massive blood loss if the person experiences a cut or internal hemorrhaging.
2. Leukemia
   - Cancer of the leukocytes (WBC's). This can result from tumor growth in lymph nodes or bone marrow.
3. Anemia
   - Deficiency in hemoglobin or iron - leads to low O_2 transport and thus lethargy (low energy)

8.3 – The Lymphatic System & Immunity

- The lymphatic system is a network of vessels, glands, and nodes spread throughout the body

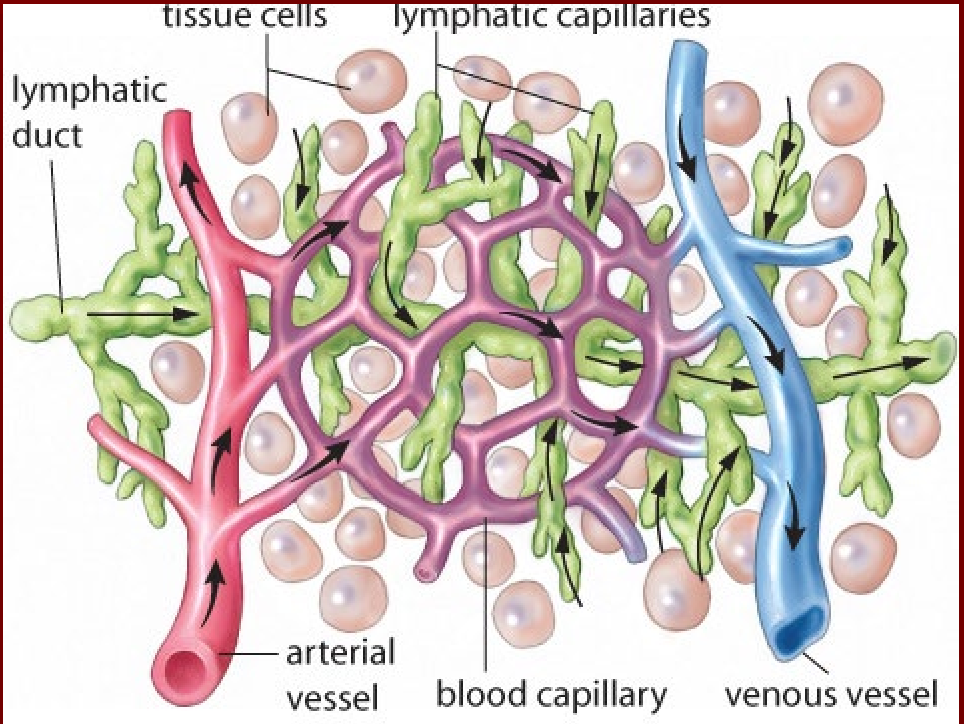


Figure 8.24 Lymph vessels are closely associated with the capillaries of the cardiovascular system. Fluid that escapes from the cardiovascular capillaries forms part of the interstitial fluid. Some of this fluid is collected in the lymphatic capillaries and eventually returned to the blood.

The Lymphatic System

- The lymphatic system connects to our circulatory system at the subclavian veins
- Lymph works with white blood cells to protect the body from infection (lymphocytes mature in the lymph nodes)
- The lymph nodes also contain macrophages which trap and destroy bacteria

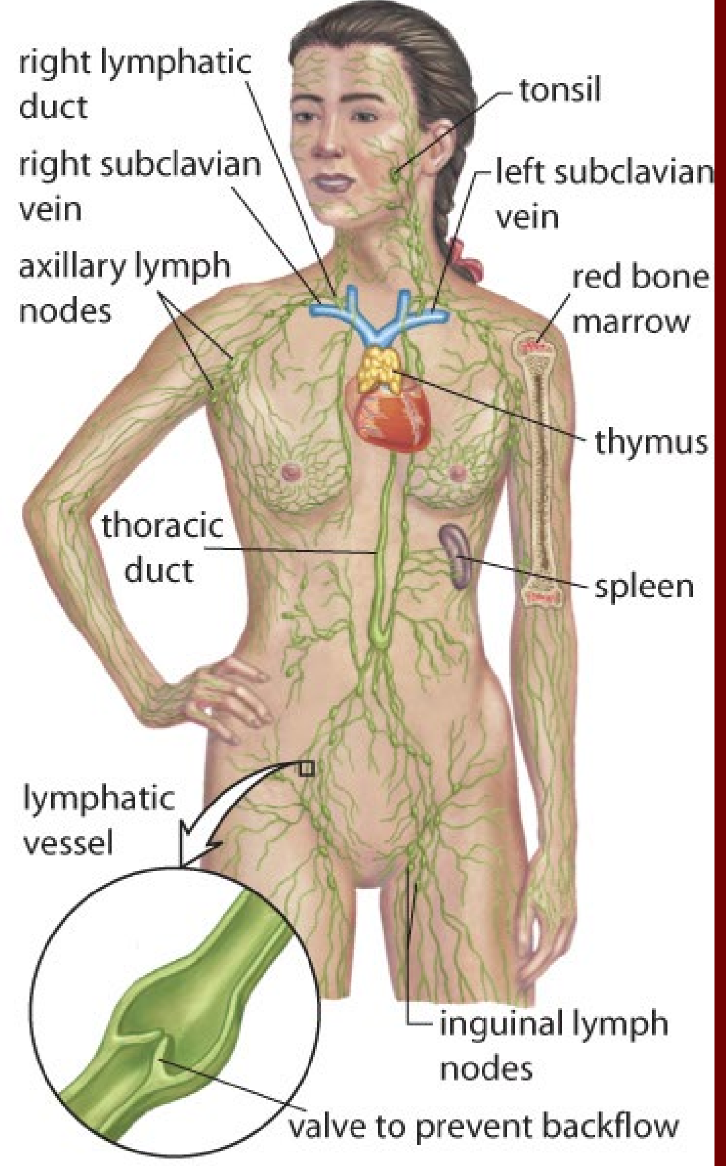


Figure 8.25 The human lymphatic system is spread throughout the body. Its largest vessels are in the region of the abdomen and thoracic cavity.

The Human Defense System

- The first line of defense for the body is to prevent organisms from entering
- The skin and mucus that line the respiratory passages serve to keep out most microbes
- Stomach acids, oils in the skin and enzymes in tears also break down bacteria

Two Types of Leukocytes

1. Granulocytes
   – contain conspicuous granules (specks) in their cytoplasm. There are 3 main kinds:
     a) Eosinophils – aid in allergic reactions by engulfing foreign pathogens
     b) Neutophils – also aids by phagocytosis of foreign pathogens
     c) Basophils – release histamine (inflammatory) to keep allergens at site of infection (tissues become inflamed)

Types of Leukocytes Con't.

2. Agranulocytes

– do not contain granules. These are usually made in bone marrow but stored/matured in lymph nodes. There are 2 different categories:

a) Monocytes

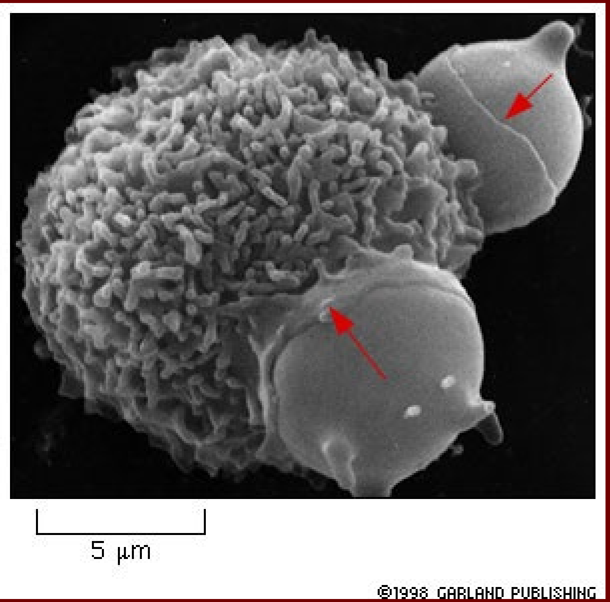
- include macrophages that engulf or perform phagocytosis on foreign pathogens (usually first on the scene)

b) Lymphocytes

- specialized cells to fight, kill, or remember pathogens
- also make antibodies to fight infections

Non-Specific Defenses

- This is also known as cell-mediated immunity
- Neutrophils, monocytes, and macrophages all kill bacteria by engulfing them



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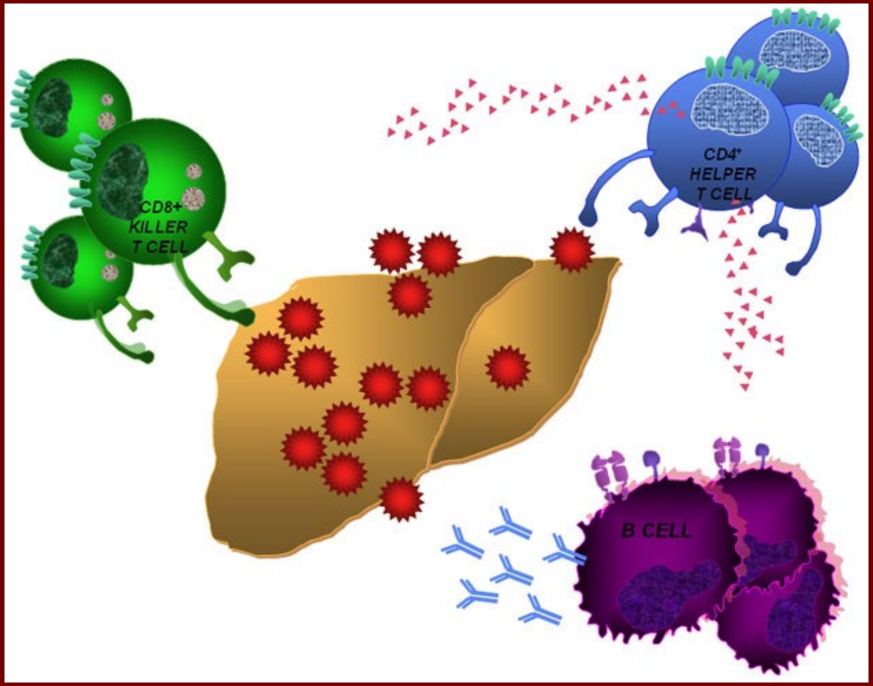
Specific Defenses (Antibody-Mediated Immunity)

- Antibodies are proteins that recognize foreign substances and either neutralize or destroy them
- Lymphocytes are primarily responsible for this immune response

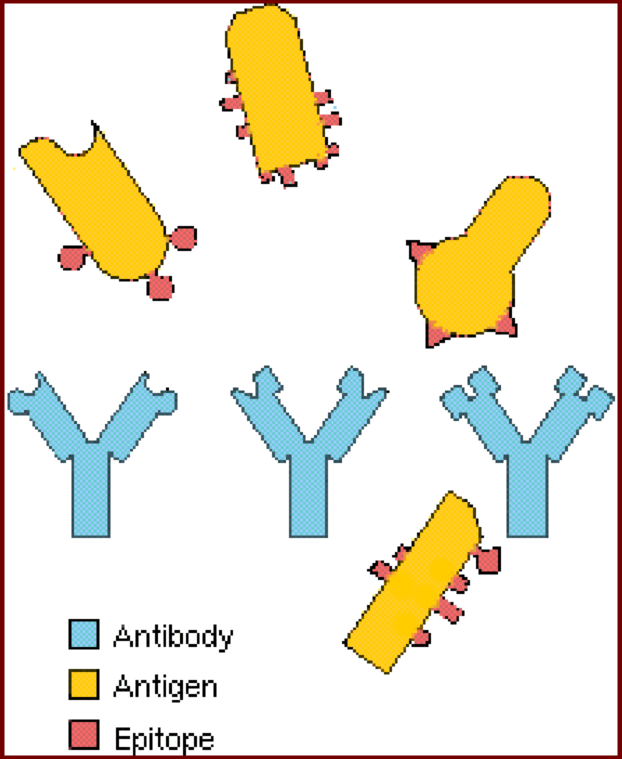
T and B cells (Lymphocytes)

- T cells are produced in the thymus gland and signal an attack from foreign invaders
- B cells produce the Y-shaped antibodies



Antigens and Antibodies

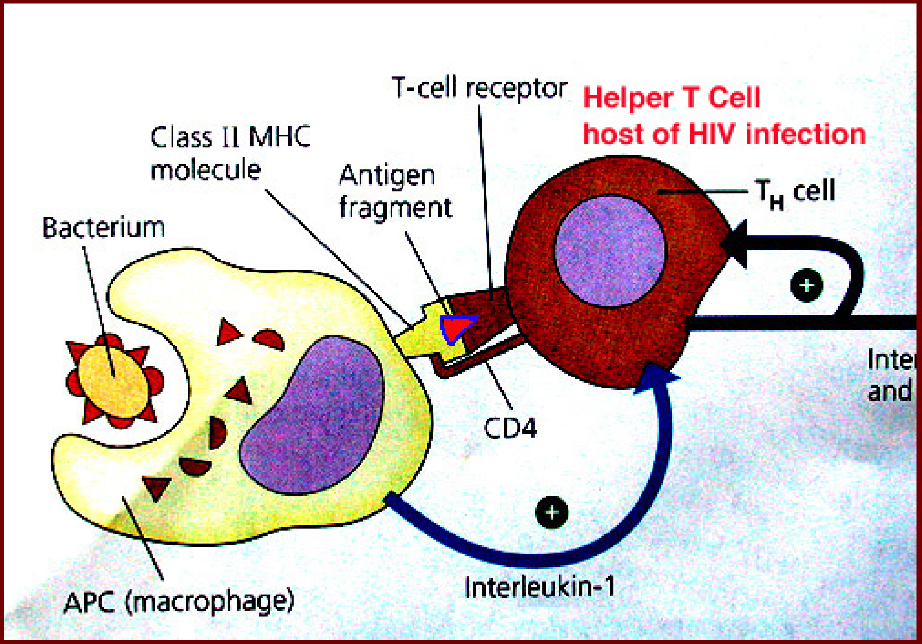
- Antibodies are Y-shaped proteins
- An antibody attaches to specific antigens because they have similar shapes
- Often the antigen-antibody complex makes the invader more visible to wandering macrophages, which engulf the bacteria



- Antibodies can bind to toxins, changing their shape and preventing them from entering cells
- Antibodies also work in the same manner on viruses
- However, viruses quickly mutate and prevent the same antibodies from working for very long
- HIV can actually “hide” inside the T cells that are supposed to signal its presence

Recognizing Antigens

- When an invader is destroyed by a macrophage, its antigens go to the macrophage surface
- The macrophage then couples with helper T cells, which read the antigen shape and release lymphokine



- This chemical causes B cells to divide and start to produce antibodies
- The helper T cells also activate killer T cells
- The killer T cells destroy invading cells and body cells that are infected by viruses by puncturing their cell membranes
- Killer T cells can also destroy cancer cells if they have antigens that are different from normal body cells

- Once an infection is fought off, suppressor T cells signal the immune system to shut down
- Phagocytes clean up any dead or injured B and T cells that remain
- Finally, memory T cells produce copies of the invader antigens so that they can be more easily identified in the future

Blood Types

- Early blood transfusion experiments often led to the death of the patient
- It wasn't until the 20th century that doctors realized that there were different blood groups
- The glycoproteins on the surface of blood cells can differ from one person to another

Blood Groups – How They Work

- individuals with an A blood type have the "A" version of the glycoprotein on the cell, while those with B blood types have the "B" version of the glycoprotein
- individuals with AB blood types have both markers, while type O individuals do not have any markers

ABO Antigens and Antibodies

Blood Type	Antigen Present	Antibodies in Plasma
A	A	b
B	B	a
AB	A and B	none
O	None	a and b

Blood Typing Demo

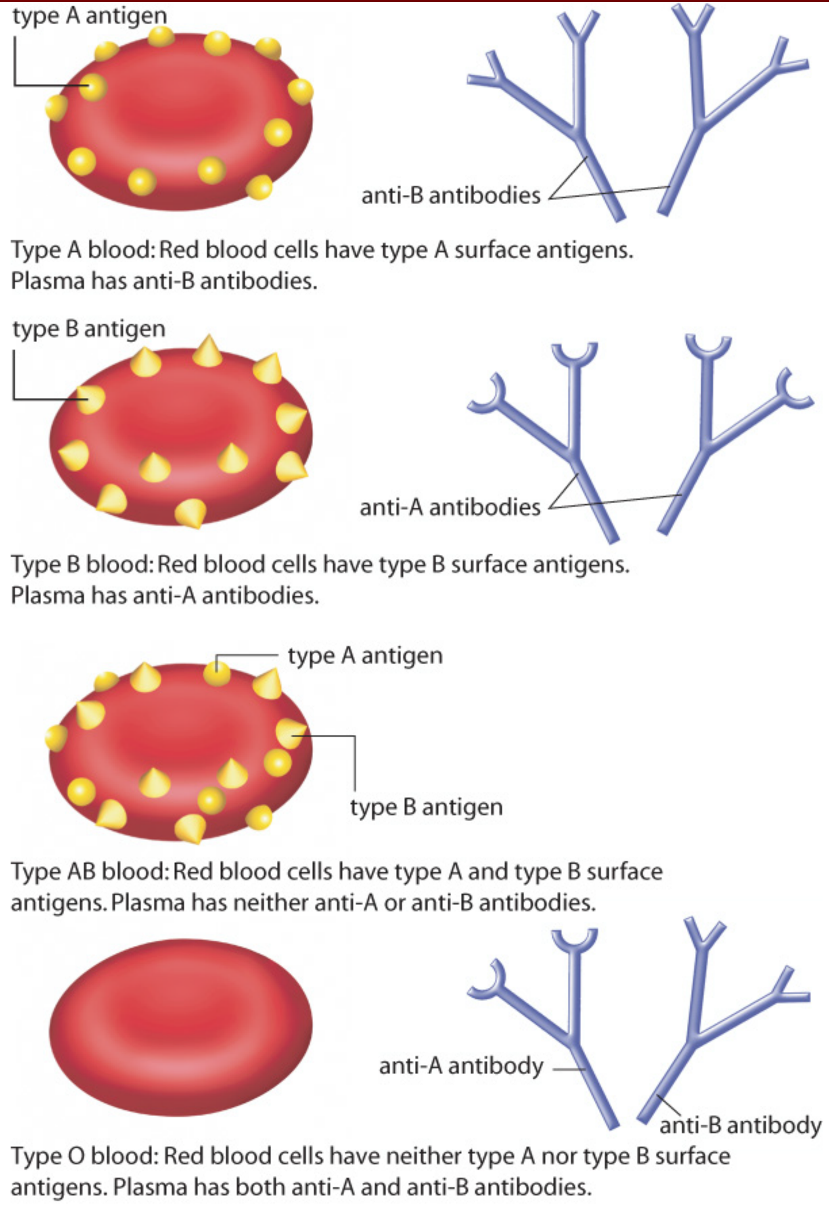


Figure 8.30 In the ABO system, blood type depends on the presence or absence of antigens A and B on the surface of red blood cells. In these diagrams, A and B antigens are represented by different shapes on the red blood cells. The possible anti-A and anti-B antibodies in the plasma are represented for each blood type.

Rhesus Factor

- A second antigen, Rhesus factor, is also found on red blood cells
- People can be Rh+ or Rh- (either the antigen is present or it is not)
- This can often affect the health of a fetus

Rhesus Factor and Pregnancy

- If the baby receives Rh+ factor from the father, but the mother is Rh-, the baby's blood will come into contact with the mother's immune system at birth
- As a result, the mother starts to produce antibodies against the Rh+ blood
- Any subsequent fetuses that are Rh+ will experience clumping of blood in their veins due to the mother's antibodies
- Treatment for this condition usually involves a transfusion of Rh- blood into the baby at birth (it allows times for the mother's antibodies to break down)

Immune System Disorders

1. Autoimmune Disorder

2. Allergies