The Blood

Dr. Gary Mumaugh

Blood is the river of life

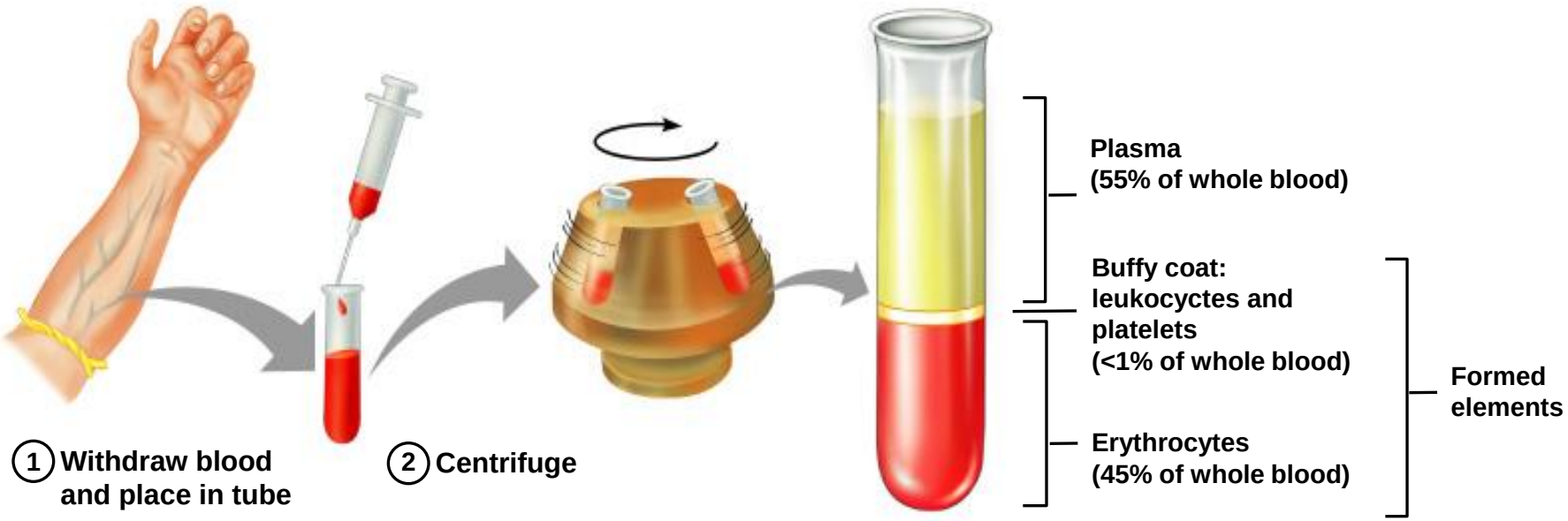
Overview of Blood Circulation

- Blood leaves the heart via arteries that branch repeatedly until they become capillaries
- Oxygen (O_2) and nutrients diffuse across capillary walls and enter tissues
- Carbon dioxide (CO_2) and wastes move from tissues into the blood
- Oxygen-deficient blood leaves the capillaries and flows in veins to the heart
- This blood flows to the lungs where it releases CO_2 and picks up O_2
- The oxygen-rich blood returns to the heart

Composition of Blood

- Blood is the body's only fluid tissue
- It is composed of liquid plasma and formed elements
- Formed elements include:
  - Erythrocytes, or red blood cells (RBCs)
  - Leukocytes, or white blood cells (WBCs)
  - Platelets
- Hematocrit – the percentage of RBCs out of the total blood volume
  - Normal 47% male, 42% female

Components of Whole Blood



Physical Characteristics and Volume

- Blood is a sticky, opaque fluid with a metallic taste
- Color varies from scarlet (oxygen-rich) to dark red (oxygen-poor)
- The pH of blood is 7.35–7.45
- Temperature is 38°C, slightly higher than “normal” body temperature
- Blood accounts for approximately 8% of body weight
- Average volume of blood is 5–6 L for males, and 4–5 L for females

Functions of Blood - Distribution

- Blood transports:
  - Oxygen from the lungs and nutrients from the digestive tract
  - Metabolic wastes from cells to the lungs and kidneys for elimination
  - Hormones from endocrine glands to target organs

Functions of Blood - Regulation

- Blood maintains:
  - Appropriate body temperature by absorbing and distributing heat
  - Normal pH in body tissues using buffer systems
  - Adequate fluid volume in the circulatory system

Functions of Blood - Protection

- Blood prevents blood loss by:
  - Activating plasma proteins and platelets
  - Initiating clot formation when a vessel is broken
- Blood prevents infection by:
  - Synthesizing and utilizing antibodies
  - Activating complement proteins
  - Activating WBCs to defend the body against foreign invaders

Blood Plasma

- 55% of whole blood. Mostly water.
- Contains over 100 solutes, including:
  - Proteins – albumin, globulins, clotting proteins, and others
  - Nonprotein nitrogenous substances – lactic acid, urea, creatinine
  - Organic nutrients – glucose, carbohydrates, amino acids
  - Electrolytes – sodium, potassium, calcium, chloride, bicarbonate
  - Respiratory gases – oxygen and carbon dioxide

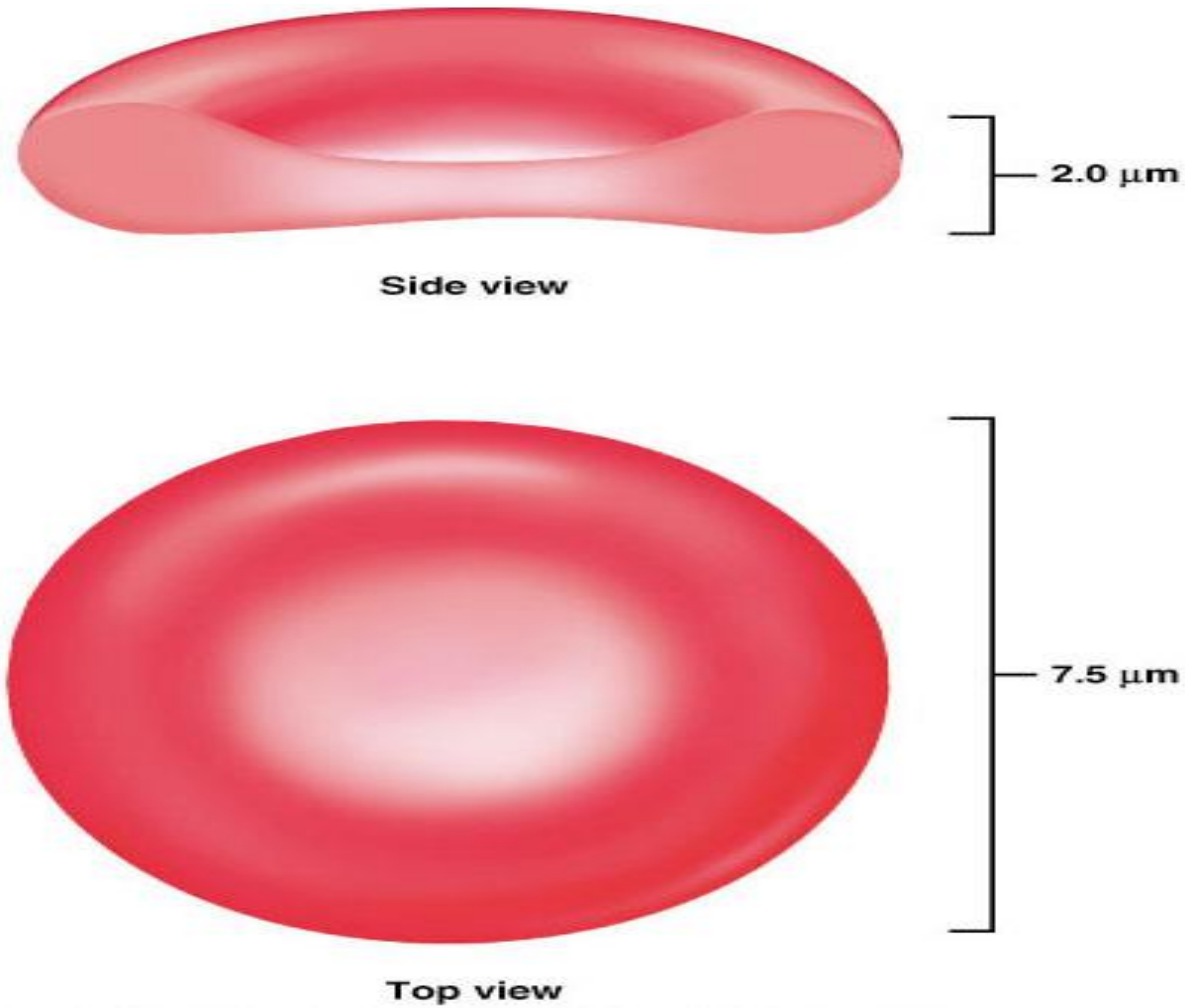
Formed Elements

- Erythrocytes, leukocytes, and platelets make up the formed elements
  - Only WBCs are complete cells
  - RBCs have no nuclei or organelles, and platelets are just cell fragments
- Most formed elements survive in the bloodstream for only a few days
- Most blood cells do not divide but are renewed by cells in bone marrow

Erythrocytes (RBCs)

- Biconcave discs, anucleate, essentially no organelles
- Filled with hemoglobin (Hb), a protein that functions in gas transport
- Contain the plasma membrane protein that:
  - Give erythrocytes their flexibility
  - Allow them to change shape as necessary
- Structural characteristics contribute to its gas transport function
  - Biconcave shape that has a huge surface area relative to volume
  - Discounting water content, erythrocytes are more than 97% hemoglobin

Erythrocytes (RBCs)



RBC Counts

- RBC counts is the number of RBCs in a cubic millimeter or microliter of blood
- It may vary depending on age and health
- Typical ranges include:
  - 4,600,000 – 6,200,000 in males
  - 4,200,000 – 5,400,000 in adult females
  - 4,500,000 – 5,100,000 in children
- RBC counts reflects blood's oxygen carrying capacity

Erythrocyte Function

- Erythrocytes are dedicated to respiratory gas transport
- Each RBC contains approximately 300 million hemoglobin molecules
- In the systemic capillaries, hemoglobin gives up much of it's oxygen
- In the pulmonary capillaries, RBCs pick up oxygen

Production of Erythrocytes

- Hematopoiesis – blood cell formation
- Hematopoiesis occurs in the red bone marrow of the:
  - Axial skeleton and girdles
  - Epiphyses of the humerus and femur

Production of Erythrocytes: Erythropoiesis

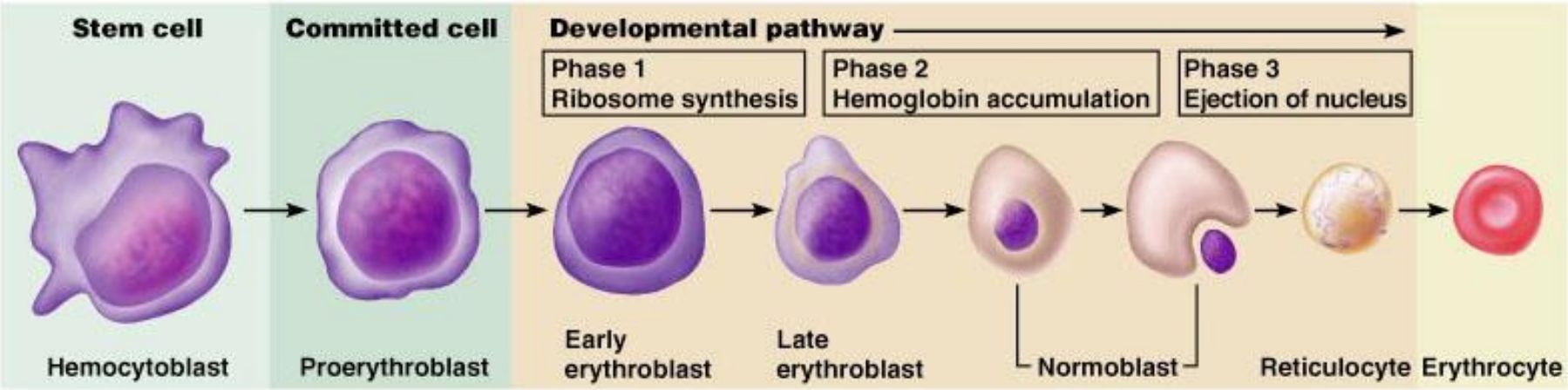


Figure 17.5

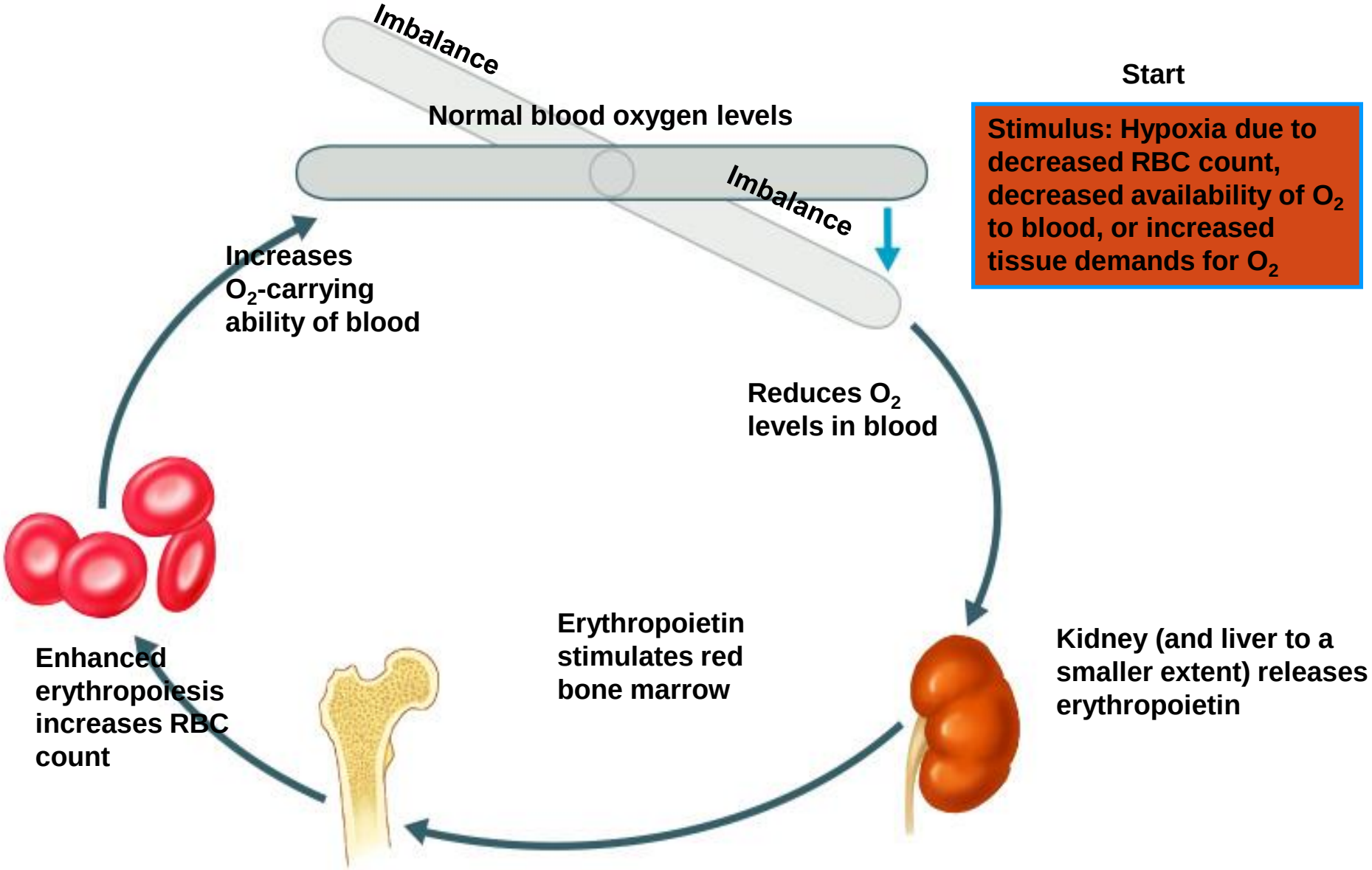
Regulation of Erythropoiesis

- Circulating erythrocytes – the number remains constant and reflects a balance between RBC production and destruction
  - Too few red blood cells leads to tissue hypoxia
  - Too many red blood cells causes undesirable blood viscosity
- Erythropoiesis is hormonally controlled and depends on adequate supplies of iron, amino acids, and B vitamins

Hormonal Control of Erythropoiesis

- Erythropoietin (EPO) release by the kidneys is triggered by:
  - Hypoxia due to decreased RBCs
  - Decreased oxygen availability
  - Increased tissue demand for oxygen

Erythropoietin Mechanism



Dietary Requirements of Erythropoiesis

- Erythropoiesis requires:
  - Proteins, lipids, and carbohydrates
  - Iron, vitamin B_{12}, and folic acid
- The body stores iron in Hb (65%), the liver, spleen, and bone marrow

Lifespan of Erythrocytes

- The life span of an erythrocyte is 100–120 days
- Old erythrocytes become rigid and fragile, and their hemoglobin begins to degenerate
- Dying erythrocytes are engulfed by macrophages
- Heme and globin are separated and the iron is salvaged for reuse

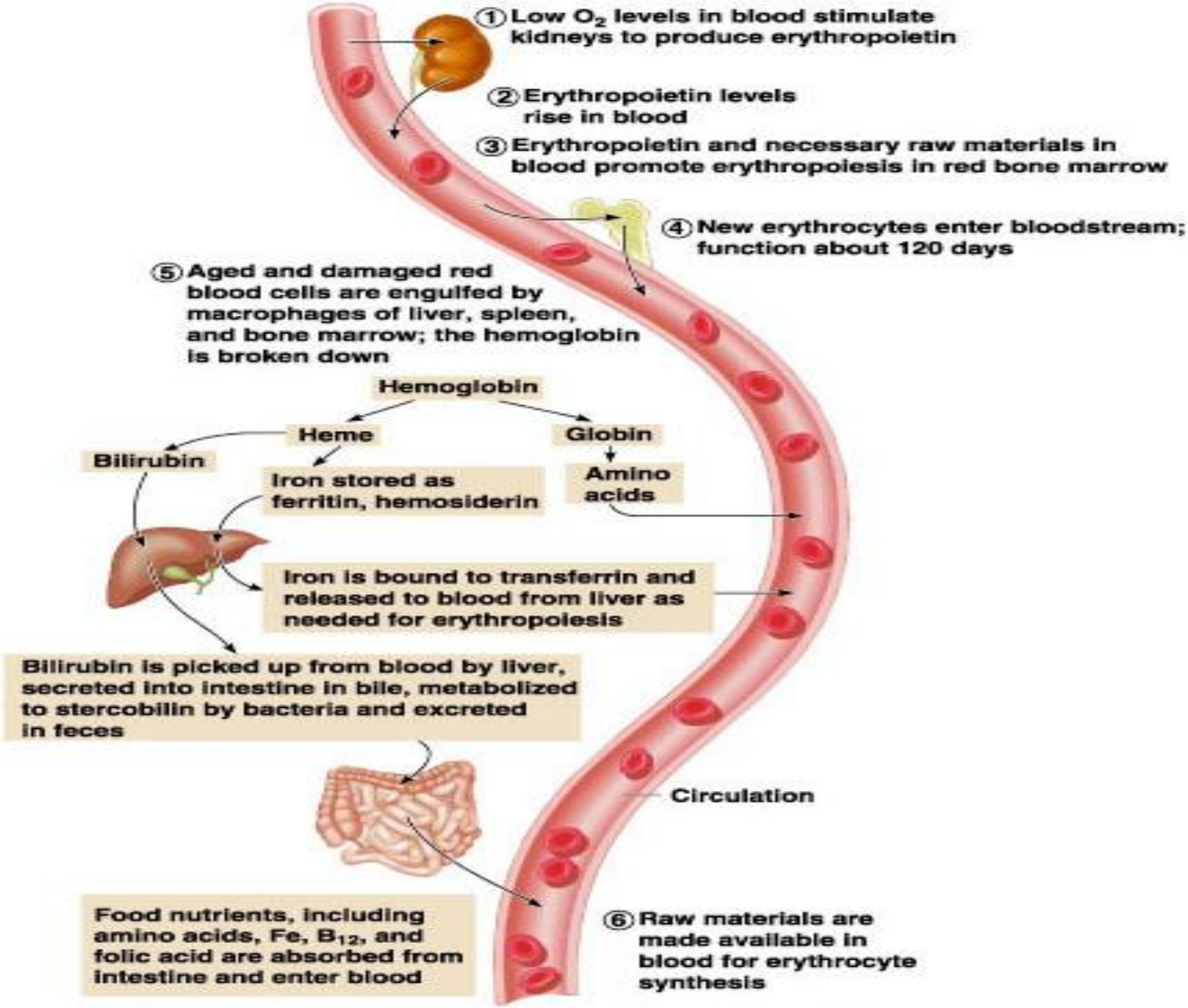

① Low O_2 levels in blood stimulate kidneys to produce erythropoietin
② Erythropoietin levels rise in blood
③ Erythropoietin and necessary raw materials in blood promote erythropoiesis in red bone marrow
④ New erythrocytes enter bloodstream; function about 120 days
⑤ Aged and damaged red blood cells are engulfed by macrophages of liver, spleen, and bone marrow; the hemoglobin is broken down
Hemoglobin
Heme
Globin
Bilirubin
Iron stored as ferritin, hemosiderin
Amino acids
Iron is bound to transferrin and released to blood from liver as needed for erythropoiesis
Bilirubin is picked up from blood by liver, secreted into intestine in bile, metabolized to stercobilin by bacteria and excreted in feces
Circulation
Food nutrients, including amino acids, Fe, B_{12}, and folic acid are absorbed from intestine and enter blood
⑥ Raw materials are made available in blood for erythrocyte synthesis

Figure 17.7

Erythrocyte Disorders

- Anemia – blood has abnormally low oxygen-carrying capacity
  - It is a symptom rather than a disease itself
  - Blood oxygen levels cannot support normal metabolism
  - Signs/symptoms include fatigue, paleness, shortness of breath, and chills

Anemia: Insufficient Erythrocytes

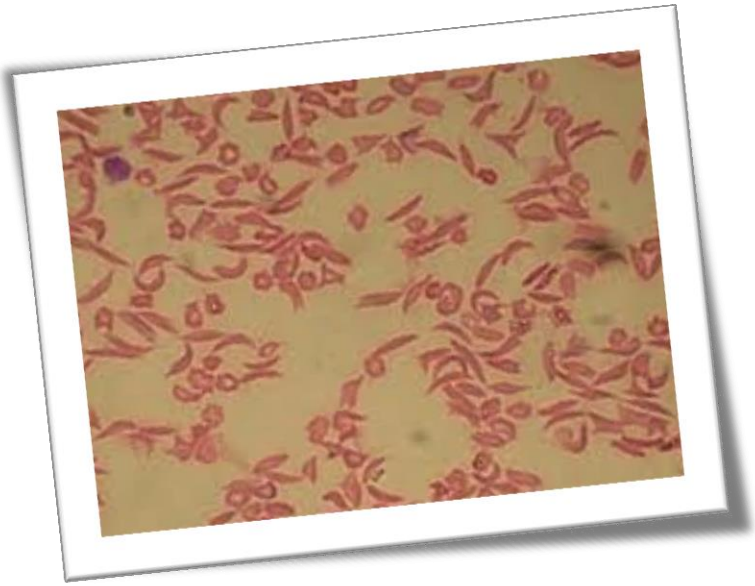
- Hemorrhagic anemia – result of acute or chronic loss of blood
- Hemolytic anemia – prematurely ruptured erythrocytes

Anemia: Decreased Hemoglobin Content

- Iron-deficiency anemia results from:
  - A secondary result of hemorrhagic anemia
  - Inadequate intake of iron-containing foods
  - Impaired iron absorption
- Pernicious anemia results from:
  - Deficiency of vitamin B_{12}
  - Lack of intrinsic factor needed for absorption of B_{12}

Anemia: Abnormal Hemoglobin

- Sickle-cell anemia – results from a defective gene coding for an abnormal hemoglobin called hemoglobin S (HbS)
  - This defect causes RBCs to become sickle-shaped in low oxygen situations



Leukocytes (WBCs)

- Leukocytes, the only blood components that are complete cells:
  - Are less numerous than RBCs
  - Make up 1% of the total blood volume
  - Can leave capillaries via diapedesis
  - Move through tissue spaces
- Leukocytosis – WBC count over 11,000 per cubic millimeter
  - Normal response to bacterial or viral invasion

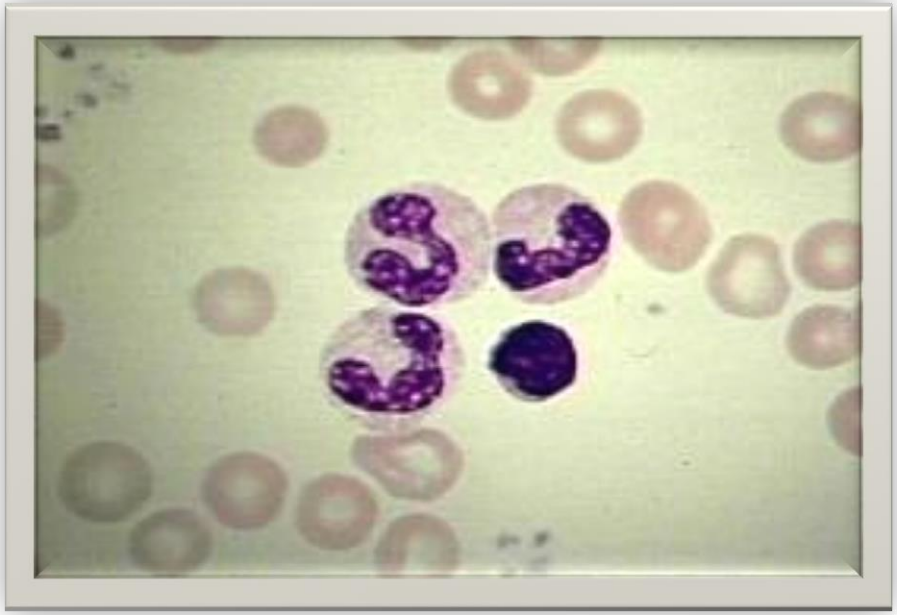
Number of Leuckocytes
“Never Let Monkeys Eat Bananas”

From the most to the least prevelent

Neutrophils, Lymphocytes, Monocytes, Eosinophils, Basophils

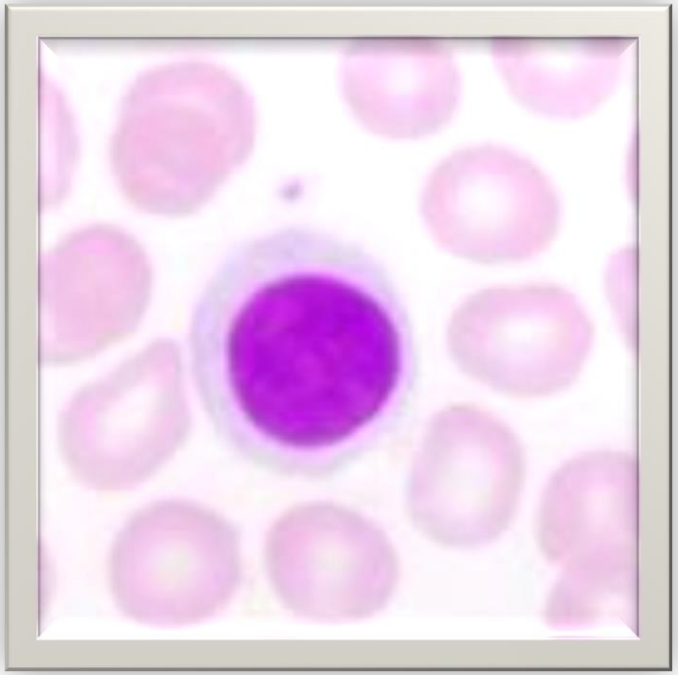
Neutrophils

- Neutrophils are the most numerous WBC
- 50-70% of WBC popluation
- Attracted to sites of inflammation
- Neutrophils are our body's bacteria slayers
- Are phagoctyic



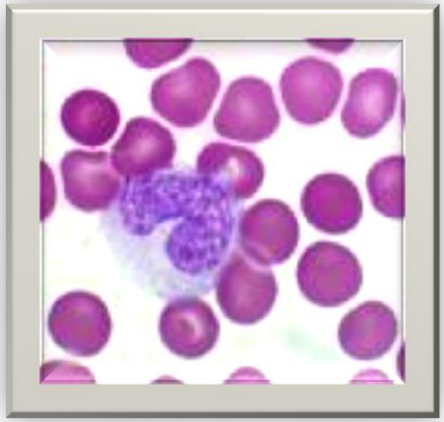
Lymphocytes

- Account for 25% or more of WBCs
  - Only a small number is found in the blood
  - Most are found in lymph tissue
- Critical role in Immunity



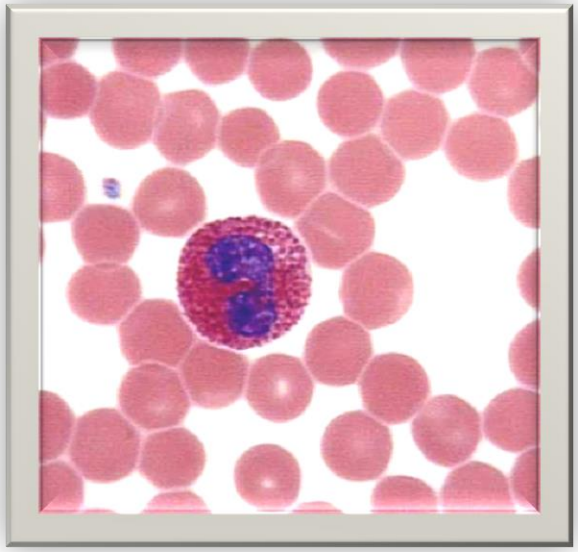
Monocytes

- Monocytes account for 4–8% of leukocytes
  - They are the largest leukocytes
  - They leave the circulation, enter tissue, and differentiate into macrophages
  - They have massive appetites
- Defends against chronic infections, viruses and parasites



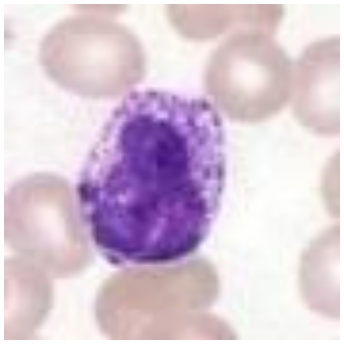
Eosinophils

- Eosinophils account for 1–4% of WBCs
- Lead the body's counterattack against parasitic worms
- Lessen the severity of allergies by phagocytizing immune complexes



Basophils

- Account for 0.5% of WBCs
- Rarest of all WBC
- Releases histamine in inflammations
  - Histamine – inflammatory chemical that acts as a vasodilator and attracts other WBCs (antihistamines counter this effect)



Summary of Formed Elements

TABLE 17.2 Summary of Formed Elements of the Blood

Cell Type	Illustration	Description*	Cells/mm^3 (μl) of Blood	Duration of Development (D) and Life Span (LS)	Function
Erythrocytes (red blood cells, RBCs)		Biconcave, anucleate disc; salmon-colored; diameter 7–8 μm	4–6 million	D: 5–7 days LS: 100–120 days	Transport oxygen and carbon dioxide
Leukocytes (white blood cells, WBCs)		Spherical, nucleated cells	4800–10,800		
Granulocytes					
▪ Neutrophil		Nucleus multilobed; inconspicuous cytoplasmic granules; diameter 10–12 μm	3000–7000	D: 6–9 days LS: 6 hours to a few days	Phagocytize bacteria
▪ Eosinophil		Nucleus bilobed; red cytoplasmic granules; diameter 10–14 μm	100–400	D: 6–9 days LS: 8–12 days	Kill parasitic worms; destroy antigen-antibody complexes; inactivate some inflammatory chemicals of allergy

*Appearance when stained with Wright's stain.

TABLE 17.2 Summary of Formed Elements of the Blood *(continued)*

Cell Type	*Illustration*	*Description**	*Cells/mm^3 (μl) of Blood*	*Duration of Development (D) and Life Span (LS)*	*Function*
▪ Basophil		Nucleus lobed; large blue-purple cytoplasmic granules; diameter 8–10 μm	20–50	D: 3–7 days LS: ? (a few hours to a few days)	Release histamine and other mediators of inflammation; contain heparin, an anticoagulant
Agranulocytes					
▪ Lymphocyte		Nucleus spherical or indented; pale blue cytoplasm; diameter 5–17 μm	1500–3000	D: days to weeks LS: hours to years	Mount immune response by direct cell attack or via antibodies
▪ Monocyte		Nucleus U or kidney shaped; gray-blue cytoplasm; diameter 14–24 μm	100–700	D: 2–3 days LS: months	Phagocytosis; develop into macrophages in tissues
Platelets		Discoid cytoplasmic fragments containing granules; stain deep purple; diameter 2–4 μm	150,000–400,000	D: 4–5 days LS: 5–10 days	Seal small tears in blood vessels; instrumental in blood clotting

*Appearance when stained with Wright's stain.

Production of Leukocytes

- Overproduction of WBC occurs in leukemia and infectious mononucleosis
- On the opposite end of the spectrum is Leukopenia, which is an abnormally low WBC count.
  - Common with cancer medications and glucocorticoids
- Many hematopoietic hormones are used clinically to stimulate bone marrow

Leukocytes Disorders: Leukemias

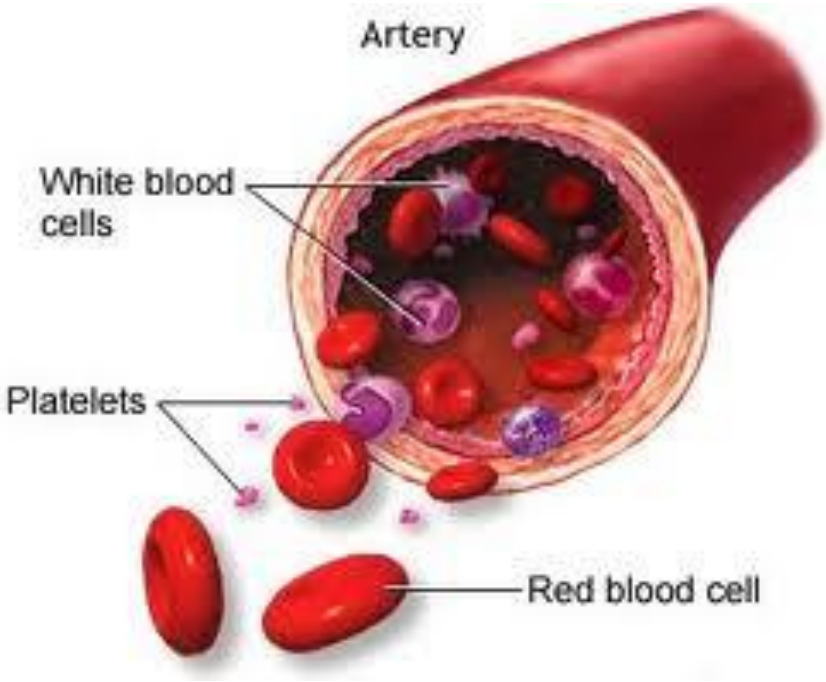
- “White blood”
- Leukemia refers to cancerous conditions involving white blood cells
- In all leukemias, the bone marrow becomes almost totally occupied by cancerous WBC and immature WBC before flowing into the boodstream.
- Because other cells can be crowded out, severe anemia and bleeding problems occur.
- Chronic leukemia is more prevalent in older people.

Leukemia

- Immature white blood cells are found in the bloodstream in all leukemias
- Bone marrow becomes totally occupied with cancerous leukocytes
- The white blood cells produced, though numerous, are not functional
- Death is caused by internal hemorrhage and overwhelming infections
- Treatments include irradiation, antileukemic drugs, and bone marrow transplants

Platelets

- Platelets are also known as thrombocytes
- They lack a nucleus and are roughly half the size of a RBC
- There are approximately 130,000 – 360,000 per cubic millimeter of blood
- They repair damaged blood vessels by sticking to broken surfaces



Hemostasis

- "Stopping or halting bleeding"
- A series of reactions designed for stoppage of bleeding
- During hemostasis, three phases occur in rapid sequence
  - Vascular spasms – immediate vasoconstriction in response to injury
  - Platelet plug formation
  - Coagulation (blood clotting)

Vascular Spasm

- The immediate response to blood vessel injury is constriction of the damaged vessel
- The spasm becomes more efficient as the amount of tissue damage increases
- A strong constricted artery can reduce blood loss for 20-30 minutes

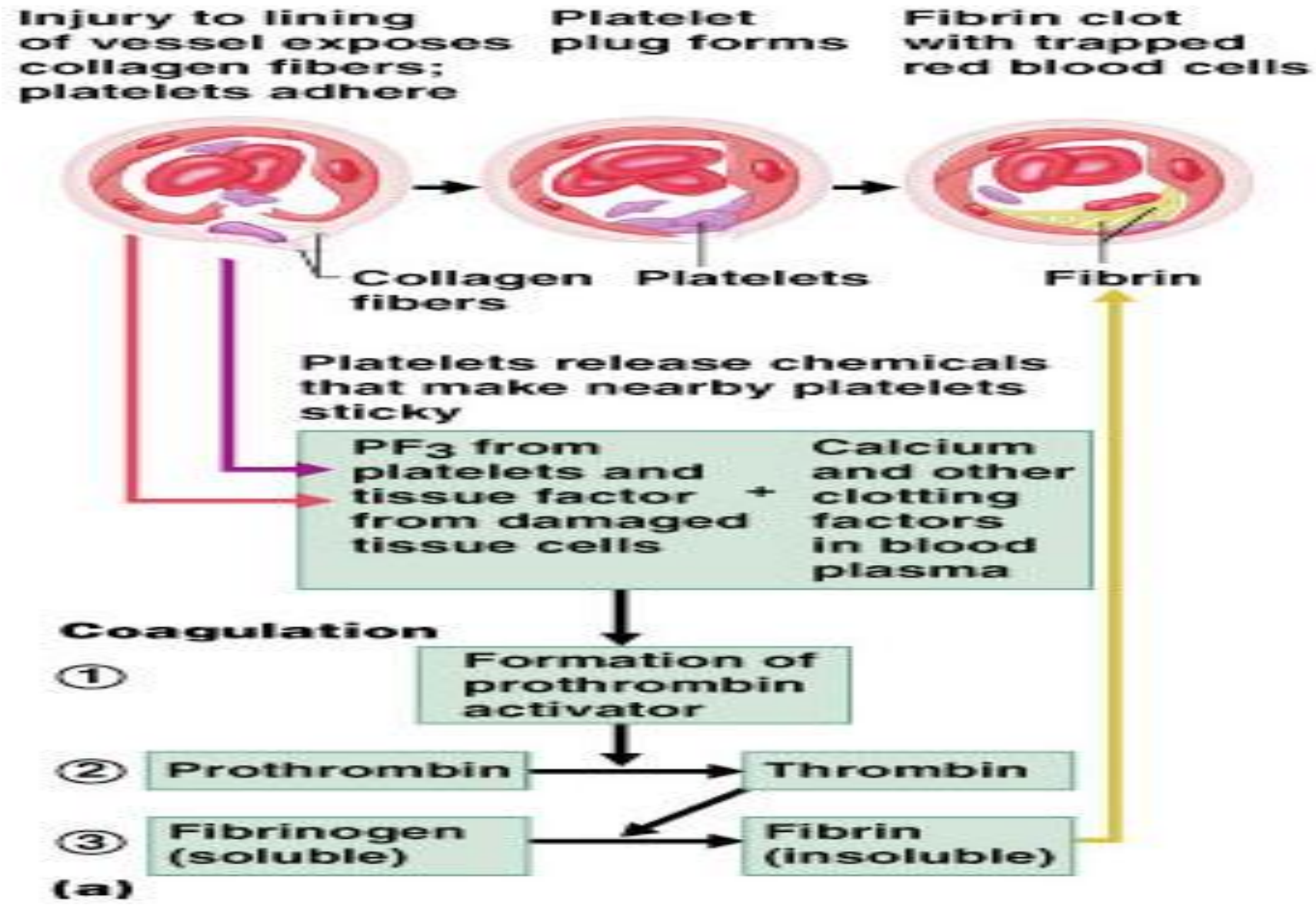
Platelet Plug Formation

- They are fragments of very large cells
- They are essential for the clotting process that occurs when blood vessels are ruptured or the vessel lining is injured
- They stick to the damaged site forming a temporary plug
- Because they do not have a nucleus, they degenerate in about 10 days

Coagulation or Blood Clotting

- A set of reactions in which blood is transformed from a liquid to a gel
- Coagulation follows intrinsic and extrinsic pathways
- The process is very complicated involving 30 different structures

Coagulation



Clot Retraction and Repair

- Clot retraction – stabilization of the clot by squeezing serum from the fibrin strands
  - Within 30-60 minutes the clot is stabilized by a platelet induced process
- Repair
  - Platelet contains contractile proteins and they interact a lot like muscle cells
  - Fibroblasts form a connective tissue patch

Fibrinolysis

- A clot is not a permanent solution to blood vessel injury
- Fibrinolysis removes uneeded clots when healing has occurred
- Without fibrinolysis, the blood vessels would gradually become completely blocked.

Hemostasis Disorders

- Thrombus – a clot that develops and persists in an unbroken blood vessel
  - Thrombi can block circulation, resulting in tissue death
  - Coronary thrombosis – thrombus in blood vessel of the heart
- Embolus – a thrombus freely floating in the blood stream
  - Pulmonary emboli can impair the ability of the body to obtain oxygen
  - Cerebral emboli can cause strokes

Prevention of Undesirable Clots

- Substances used to prevent undesirable clots include:
  - Aspirin – an antiprostaglandin that inhibits thromboxane A_2
  - Heparin – an anticoagulant used clinically for pre- and postoperative cardiac care
  - Warfarin – used for those prone to atrial fibrillation

Blood Transfusions

- Whole blood transfusions are used:
  - When blood loss is substantial
  - In treating thrombocytopenia
- The body can only compensate for so much blood loss
  - Loss of 15-30% can cause weakness and pallor
  - Loss of more then 30% can be fatal

Human Blood Groups

- RBC membranes have glycoprotein antigens on their external surfaces
- These antigens are:
  - Unique to the individual
  - Recognized as foreign if transfused into another individual
- Presence or absence of these antigens is used to classify blood groups

Blood Groups

- Humans have 30 varieties of naturally occurring RBC antigens
- The antigens of the ABO and Rh blood groups cause vigorous transfusion reactions when they are improperly transfused

ABO Blood Groups

- The ABO blood groups consists of:
  - Two antigens (A and B) on the surface of the RBCs
  - Two antibodies in the plasma (anti-A and anti-B)
- An individual with ABO blood may have various types of antigens and spontaneously preformed antibodies
- Agglutinogens and their corresponding antibodies cannot be mixed without serious hemolytic reactions

TABLE 17.4 ABO Blood Groups

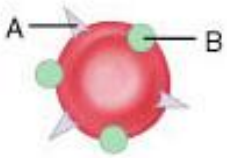
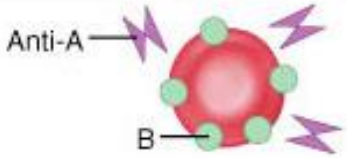
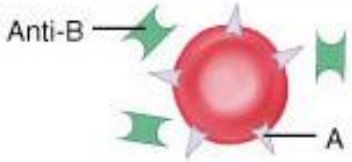
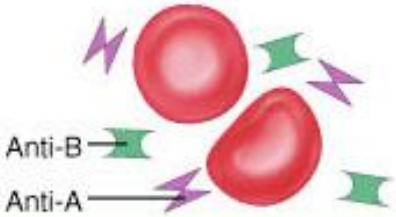
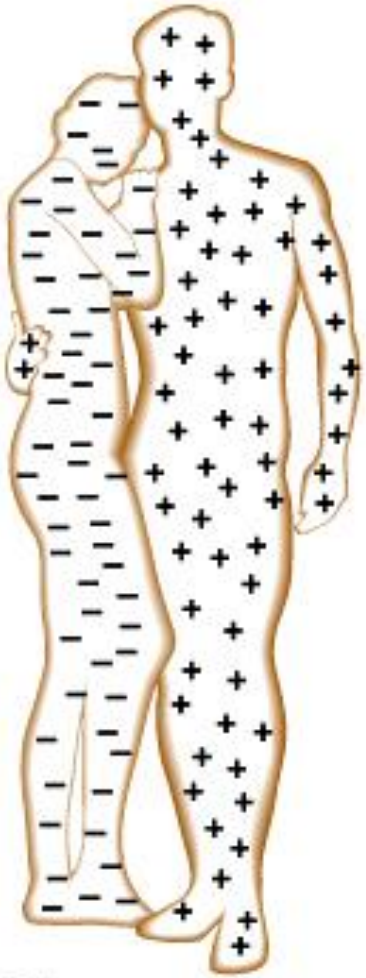
Blood Group	Frequency (% U.S. Population)				RBC Antigens (Agglutinogens)	Illustration	Plasma Antibodies (Agglutinins)	Blood That Can Be Received
	White	Black	Asian	Native American				
AB	4	4	5	<1	A B		None	A, B, AB, O Universal recipient
B	11	20	27	4	B		Anti-A (a)	B, O
A	40	27	28	16	A		Anti-B (b)	A, O
O	45	49	40	79	None		Anti-A (a) Anti-B (b)	O Universal donor

Table 17.4

Hemolytic Disease of the Newborn

- Hemolytic disease of the newborn – Rh^+ antibodies of a sensitized Rh^- mother cross the placenta and attack and destroy the RBCs of an Rh^+ baby
- Rh^- mother becomes sensitized when Rh^+ blood (from a previous pregnancy of an Rh^+ baby or a Rh^+ transfusion) causes her body to synthesis Rh^+ antibodies
- The drug RhoGAM can prevent the Rh^- mother from becoming sensitized
- Treatment of hemolytic disease of the newborn involves pre-birth transfusions and exchange transfusions after birth

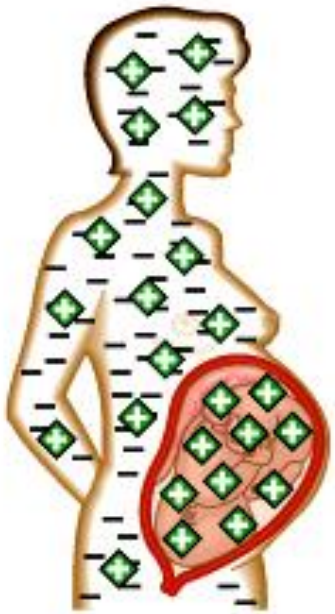


Rh-negative woman and Rh-positive man conceive a child

Rh-negative woman with Rh-positive fetus

Cells from Rh-positive fetus enter woman's bloodstream

Woman becomes sensitized—antibodies (◇) form to fight Rh-positive blood cells



In the next Rh-positive pregnancy, maternal antibodies attack fetal red blood cells

Transfusion Reactions

- Transfusion reactions occur when mismatched blood is infused
- Donor's cells are attacked by the recipient's plasma agglutinins causing:
  - Diminished oxygen-carrying capacity
  - Clumped cells that impede blood flow
  - Ruptured RBCs that release free hemoglobin into the bloodstream
- Circulating hemoglobin precipitates in the kidneys and causes renal failure

Blood Typing

When serum containing anti-A or anti-B agglutinins is added to blood, agglutination will occur between the agglutinin and the corresponding agglutinogens

Positive reactions indicate agglutination

Blood type being tested	**RBC agglutinogens**	**Serum Reaction**	
		Anti-A	Anti-B
AB	A and B	+	+
B	B	–	+
A	A	+	–
O	None	–	–

BLOOD TYPE & RH	HOW MANY HAVE IT?	BLOOD TYPE & RH
O Rh Positive	1 Person in 3	37.4%
O Rh Negative	1 Person in 15	6.6%
A Rh Positive	1 Person in 3	35.7%
A Rh Negative	1 Person in 16	6.3%
B Rh Positive	1 Person in 12	8.5%
B Rh Negative	1 Person in 67	1.5%
AB Rh Positive	1 Person in 29	3.4%
AB Rh Negative	1 Person in 167	.6%

Blood Transfusions

Blood Type	%	Receive Blood?	Give Blood?
O+	37%	O+, O-	O+, A+, B+, AB+
O-	6%	O-	Any Type
A+	34%	O+, O-, A+, A-	A+, AB+
A-	6%	O-, A-	A+, A-, AB+, AB-
B+	10%	O+, O-, B+, B-	B+, AB+
B-	2%	O-, B-	B+, B-, AB+, AB-
AB+	4%	Any Type	AB+
AB-	1%	O-, A-, B-, AB-	AB-, AB+

The Big Picture

- Blood plasma transports substances, including heat, around the body, linking all body tissues together
  - Substances can be transported between almost any two points in the body
- Blood tissue contains formed elements—blood cells and platelets
  - RBCs assist in the transport of oxygen and carbon dioxide
  - WBCs assist in the defense mechanisms of the whole body
  - Platelets prevent loss of the fluid that constitutes the internal environment

- No organ or system of the body can maintain proper levels of nutrients, gases, or water without direct or indirect help from blood
  - Other systems assist the blood
- Blood is useless unless it continues to transport, defend, and maintain balance