

Chapter 19: The Cardiovascular System: The Blood

Chapter Objectives

FUNCTIONS OF BLOOD

1. Define the transportation, regulation, and protection functions of the blood.

PHYSICAL CHARACTERISTICS OF BLOOD

2. Provide values for the physical parameters of the blood.

COMPONENTS OF BLOOD

3. Illustrate the proportions of the major components of the blood plasma and cells.

BLOOD PLASMA

4. List the components of plasma and explain their importance.

FORMED ELEMENTS OF BLOOD

5. List the varieties and relative number of formed elements in blood.
6. Identify the three types of granular leukocytes.
7. Identify the two types of agranular leukocytes.
8. Describe platelets and their function.
9. Identify the basic properties of red blood cells as well as the normal quantity.
10. Note the structure and content of red blood cells and the usual concentrations of hemoglobin.

HEMOGLOBIN

11. Describe the components of hemoglobin.
12. Describe the steps in the degradation of hemoglobin.

FORMATION OF BLOOD CELLS

13. Follow the formation of all blood cells from the pluripotent stem cells to the final formed elements.
14. Describe the stages of RBC development, the conditions and hormones that regulate their production through negative feedback, and nutrients required for their construction.
15. Identify the hemopoietic growth factors that regulate the differentiation and proliferation of particular progenitor cells.

HEMOSTASIS

16. Define vascular spasm.
17. List the sequence of events in platelet plug formation.
18. Identify the principal stages involved in blood clotting and explain the general actions of the various factors that promote and inhibit blood clotting.

19. Specify the conditions that initiate the extrinsic coagulation pathway and the factors and events that are unique to this route.
20. Specify the conditions that initiate the intrinsic coagulation pathway and the factors and events that are unique to this route.
21. Discuss the actions of the factors in the common final pathway.
22. Discuss the materials and actions required to produce clot retraction and their purpose in preparation for tissue repair.
23. Establish how vitamin K is involved with factors of the coagulation pathway.
24. Show how fibrinolysis works through plasmin enzymes to prevent the inappropriate formation and expansion of blood clots.

BLOOD GROUPS AND BLOOD TYPES

25. Describe which antigens and antibodies are present in each ABO and Rh blood grouping and under what condition they are present.
26. Describe how Rh antigens of a first fetus and the mother's immune response to them can lead to hemolytic disease of the next newborn.

Chapter Lecture Notes

Functions of Blood

Transportation

O₂, CO₂, metabolic wastes, nutrients, heat & hormones

Regulation

helps regulate pH through buffers

helps regulate body temperature

helps regulate water content of cells by interactions with dissolved ions and proteins

Protection from disease & loss of blood

Physical Characteristics of Blood

Thicker (more viscous) than water and flows more slowly than water (4.5-5.5g/ml vs 1g/ml)

Temperature of 100.4 °F (38°C)

pH 7.35-7.45

8 % of total body weight

0.85-0.9% saline

Blood volume

5 to 6 liters in average male

4 to 5 liters in average female

Components of Blood

Blood consists of two components (Fig 19.1 & Table 19.1)

Plasma-straw colored liquid that contains dissolved substances including clotting factors

Serum = plasma minus the clotting factors.

Formed elements

Red blood cells (RBCs)

White blood cells (WBCs)

Platelets

Blood consists of 55% plasma and 45% formed elements

Blood Plasma

91.5% water and 8.5% solutes

8.5% solutes = 7% proteins + 1.5% other solutes

Plasma proteins

clotting factors (fibrinogen)

globulins (including antibodies)

albumins and specialized carrier proteins (lipoproteins)

Other solutes

Glucose

Fatty acids

Enzymes

Hormones

Gases - O₂, CO₂

Ions - Na⁺, K⁺, HCO₃⁻, Cl⁻, Ca⁺²

Wastes - urea, uric acid, ammonium salts, creatine, creatinine, and bilirubin.

Formed Elements of Blood

White blood cells (leukocytes) (Fig 19.7 & Table 19.2)

Granular leukocytes (contain granules in the cytoplasm)

neutrophils - 60-70% of total WBCs

eosinophils - 2-4%

basophils - 0.5-1%

Agranular leukocytes

lymphocytes = T cells, B cells, and natural killer cells - 20-25%

monocytes - 3-8% (Most found as macrophages in tissues)

Total white blood cell count - 5,000-10,000/ μ l

Leukocytosis is a high white blood cell count

microbes, strenuous exercise, anesthesia or surgery

Leukopenia is low white blood cell count

radiation, shock or chemotherapy

Only 2% of total WBC population is in circulating blood at any given time

rest is in lymphatic fluid, skin, lungs, lymph nodes & spleen

Platelets (special cell fragments, thrombocytes)

Disc-shaped, 2 - 4 micron cell fragment with no nucleus

Normal platelet count is 150,000-400,000/drop of blood

Platelets help stop blood loss from damaged vessels by forming a platelet plug. Their

granules also contain chemicals that promote blood clotting.

Red blood cells (erythrocytes, RBCs) (Fig 19.2, 19.4 & Table 19.3)

Biconcave disk 8 microns in diameter

increased surface area/volume ratio

flexible shape for narrow passages

plasma membrane and cytoplasm, no nucleus or other organelles

Contain oxygen-carrying protein hemoglobin (Hb) that gives blood its red color

1/3 of cell's weight is hemoglobin

Total RBC count

Males – 5.4 million/ μ L

Females – 4.8 million/ μ L

Anemia - not enough RBCs or not enough hemoglobin

Polycythemia - too many RBCs (over 65%)

dehydration, tissue hypoxia, blood doping in athletes

The blood test, *hemoglobin A1c*, can be used to monitor blood glucose levels in diabetics

Production of abnormal hemoglobin can result in serious blood disorders such as

thalassemia and sickle cell anemia. (Fig 19.15)

RBCs live only 120 days (Fig 19.5)

wear out from bending to fit through capillaries

no repair possible due to lack of organelles

Worn out cells removed by fixed macrophages in spleen & liver

Breakdown products are recycled

Hemoglobin

Hemoglobin consists of two components (Fig 19.4)

Globin - a protein that is made up of two alpha and two beta chains

Heme – an iron containing, ringlike nonprotein pigment that binds to each of the four globin chains

Many gases, including O₂, CO₂, CO, NO, and SNO, bind to the heme portion of the molecule

Heme synthesis

Uroporphyrinogen cosynthetase is missing in congenital porphyria

Lead binds Ferrochelatase and inactivates the enzyme

Hemoglobin breakdown and recycling (liver & spleen) (Fig 19.5)

globin portion broken down into amino acids & recycled

heme portion split into iron (Fe^{+3}) and biliverdin (green pigment)

Iron(Fe^{+3}) is

stored in liver, muscle or spleen attached to ferritin or hemosiderin protein

transported from liver & spleen through blood stream to muscle or red bone marrow

attached to transferrin protein

reused in red bone marrow for hemoglobin synthesis

Biliverdin (green pigment) converted to Bilirubin (yellow pigment)

indirect bilirubin - bilirubin (insoluble) bound to albumin in circulating blood

Transported to liver for waste removal

direct bilirubin - bilirubin with glucose attached (soluble)

Secreted by liver into the small intestine as part of bile

Bilirubin is converted to urobilinogen then stercobilin (brown pigment in feces) by

bacteria of large intestine

If bilirubin or urobilinogen is reabsorbed from intestines into blood, they are converted to

a yellow pigment, urobilin, in the kidneys and excreted in urine

Formation of Blood Cells

Process of blood cells formation is hematopoiesis or hemopoiesis

In the embryo occurs in yolk sac, liver, spleen, thymus, lymph nodes & red bone marrow

In adult occurs only in red bone marrow of flat bones like sternum, ribs, skull & pelvis and

ends of long bones

Blood cells are formed from pluripotent hematopoietic stem cells - hemocytoblasts

Originating from the hemocytoblasts are the myeloid stem cells and lymphoid stem cells.

(Fig 19.3)

Myeloid stem cells differentiate into progenitor cells (CFUs) which will develop into all the formed elements of blood except for lymphocytes.

Lymphoid stem cells give rise to lymphocytes.

Erythrocyte formation – erythropoiesis (Fig 19.3)

Tissue hypoxia (cells not getting enough O₂) is the primary stimulus for erythropoiesis

(Fig 19.6)

Erythropoietin (EPO) - produced by the kidneys increases RBC precursors

Hemocytoblast → myeloid stem cell → colony forming unit – erythrocyte (CFU-E) → proerythroblast (blast cell) → reticulocyte → ERYTHROCYTE

Proerythroblast starts to produce hemoglobin

Reticulocytes are formed when the nucleus is ejected.

Reticulocytes are orange in color with traces of visible rough ER

Reticulocytes escape from bone marrow into the blood and in 1-2 days, they eject the remaining organelles to become a mature RBC

Platelet formation (Fig 19.3)

Hemocytoblast → myeloid stem cell → megakaryocyte-colony-forming cells (CFU-Meg) → megakaryoblasts (blast cell) → megakaryocytes → PLATELET (THROMBOCYTE)

Short life span (5 to 9 days in bloodstream)

Thrombopoietin (TPO) - hormone from liver stimulates platelet formation

WBC formation (Fig 19.3)

Colony-stimulating factor (CSF) & interleukins stimulate WBC production - Cytokines are hormones produced by bone marrow cells to stimulate proliferation in other marrow cells

Hemocytoblast → myeloid stem cell → colony forming unit - granulocyte macrophage

(CFU-GM) → eosinophilic myeloblast (blast cell) → EOSINOPHIL

Hemocytoblast → myeloid stem cell → colony forming unit - granulocyte macrophage

(CFU-GM) → basophilic myeloblast (blast cell) → BASOPHIL

Hemocytoblast → myeloid stem cell → colony forming unit - granulocyte macrophage

(CFU-GM) → myeloblast (blast cell) → NEUTROPHIL

Hemocytoblast → myeloid stem cell → colony forming unit - granulocyte macrophage

(CFU-GM) → monoblast (blast cell) → MONOCYTE → macrophage

Hemocytoblast → lymphoid stem cell → T lymphoblast (blast cell) → T

LYMPHOCYTE (complete development in the thymus)

Hemocytoblast → lymphoid stem cell → B lymphoblast (blast cell) → B

LYMPHOCYTE (complete development in the lymph nodes) → plasma cells

Hemocytoblast → lymphoid stem cell → NK lymphoblast → NATURAL KILLER

CELL

Hemostasis

Stoppage of bleeding in a quick & localized fashion when blood vessels are damaged

Prevents hemorrhage (loss of a large amount of blood)

Methods utilized

vascular spasm

platelet plug formation

blood clotting (coagulation = formation of fibrin threads)

Vascular spasm

Damage to blood vessel stimulates pain receptors

Reflex contraction of smooth muscle of small blood vessels

Can reduce blood loss for several hours until other mechanisms can take over

Only for small blood vessel or arteriole

Platelet plug formation (Fig 19.9)

Platelet adhesion

Platelets stick to exposed collagen in connective tissue underlying damaged epithelial (simple squamous) cells in vessel wall (endothelium)

Platelet release reaction

Platelets activated by adhesion

Extend projections to make contact with each other

Activation leads to activation of other platelets (positive feedback mechanism)

Platelets release vasoconstrictors decreasing blood flow through the injured vessel

Platelet aggregation

Activated platelets stick together and activate new platelets to form a mass called a platelet plug

Plug reinforced by fibrin threads formed during clotting process

Blood clotting (Fig 19.10 & 19.11 & Table 19.4)

Blood clotting involves a cascade of reactions that may be divided into three stages:

formation of prothrombinase (prothrombin activator) – intrinsic or extrinsic pathways

conversion of prothrombin into thrombin – final common pathway

conversion of soluble fibrinogen into insoluble fibrin – final common pathway

The clotting cascade can be initiated by either the extrinsic pathway or the intrinsic pathway

Extrinsic pathway

Damaged tissues leak tissue factor (thromboplastin) into bloodstream

In the presence of Ca^{+2} , clotting factor X combines with V to form prothrombinase

Faster pathway - Prothrombinase forms in seconds

Intrinsic pathway

Activation occurs

endothelium is damaged & platelets come in contact with collagen of blood vessel wall

platelets damaged & release phospholipids

Slower pathway - Requires several minutes for reaction to occur

Substances involved: Ca^{+2} and clotting factors XII, X and V

Final Common Pathway

Prothrombinase and Ca^{+2}

catalyze the conversion of prothrombin to thrombin

Thrombin

in the presence of Ca^{+2} converts soluble fibrinogen to insoluble fibrin threads

activates fibrin stabilizing factor XIII

accelerates formation of prothrombinase

activates platelets to release phospholipids

Clot retraction and blood vessel repair

Platelets pull on fibrin threads causing clot retraction

trapped platelets release factor XIII stabilizing the fibrin threads

Edges of damaged vessel are pulled together

Fibroblasts & endothelial cells repair the blood vessel

Normal clotting requires adequate vitamin K

fat soluble vitamin produced by bacteria in large intestine and absorbed if lipids are present

absorption slowed if bile release is insufficient

required for synthesis of 4 clotting factors by liver cells (hepatocytes) - factors II (prothrombin), VII, IX and X

Fibrinolysis dissolves small, inappropriate clots and clots at a site of a completed repair

Inactive plasminogen is incorporated into the clot

activation occurs because of factor XII and thrombin

plasminogen becomes plasmin (fibrinolysin) which digests fibrin threads

Thrombolytic agents (streptokinase or tissue plasminogen activator (t-PA)) are injected to dissolve clots

directly or indirectly activate plasminogen

Anticoagulants suppress or prevent blood clotting

Heparin – antagonist to thrombin

administered during hemodialysis and surgery

warfarin (Coumadin)

antagonist to vitamin K so blocks synthesis of clotting factors

slower than heparin

stored blood in blood banks treated with citrate phosphate dextrose (CPD) that removes Ca^{+2}

Blood Groups and Blood Types

RBC surfaces are marked by genetically determined glycoproteins & glycolipids (agglutinogens or antigens)

at least 24 different blood groups - ABO, Rh, Lewis, Kell, Kidd and Duffy systems

In the ABO system, antigens A and B determine blood types (Fig 19.12 & 19.14 & Table 19.6)

display only antigen A - blood type A

display only antigen B - blood type B

display both antigens A & B - blood type AB

display neither antigen - blood type O

Plasma naturally contains antibodies (agglutinins) at birth that react with antigens that are foreign to the individual

anti-A antibody reacts with antigen A

Only found in type B and O individuals

anti-B antibody reacts with antigen B

Only found in type A and O individuals

Type AB individuals have no antibodies

People with type AB blood called “universal recipients” since have no antibodies in plasma

only true if cross match the blood for other antigens

People with type O blood cell called “universal donors” since have no antigens on their cells

theoretically can be given to anyone

Rh group

Antigen was discovered in blood of *Rhesus* monkey

People with Rh antigens on RBC surface are Rh⁺. Normal plasma contains no anti-Rh

antibodies (Table 19.5)

Antibodies develop only in Rh⁻ blood type & only with exposure to the antigen

transfusion of positive blood

during a pregnancy with a positive blood type fetus (Fig 19.13)

Transfusion reaction upon 2nd exposure to the antigen results in hemolysis of the RBCs in

the donated blood

Rh negative mom and Rh⁺ fetus will have mixing of blood at birth

Mom's body creates Rh antibodies unless she receives a RhoGam shot soon after first

delivery, miscarriage or abortion

RhoGam binds to loose fetal blood and removes it from body before she reacts

In 2nd child, hemolytic disease of the newborn may develop causing hemolysis of the fetal

RBCs