The cardiovascular system is subdivided into two functional parts

1. Blood vascular system

1. Lymph vascular system
Blood vascular system

- Distributes nutrients, gases, hormones to all parts of the Body
- Collects wastes produced during cellular metabolism
- Consists of blood vessels (arteries, arterioles, capillaries, venules, veins) and a muscular pump (heart)
Lymph vascular system

- Collects tissue fluid from tissues and returns it to the blood vascular system.

- Consists of blind-ended capillaries (lymphatic capillaries) connected to venous vessel (lymphatic vessels) and various lymphoid organs (e.g., lymph nodes).
Structure of vessel walls

- Except for the smallest vessels, blood and lymphatic vessel walls can also be viewed as three-layered structures.
  
  - a. Inner layer = *tunica intima*
  - b. Middle layer = *tunica media*
  - c. Outer layer = *tunica adventitia*
Tunica intima

- Thin

- (1) Endothelium

- (2) A subendothelial layer (L.C.T. + muscular cell)

- **Internal elastic lamina**
- (in arteries- have fenestrae)
Endothelium

- Angiotensin I $\rightarrow$ AngiotensinII (effect on B.P)
- Lipolysis of Lipoprotein
- Produce Vasoactive factors (endothelin, NO)
- Produce VEGF (Vascular Endothelium Growth Factor)

- Prevent the adhesion of the blood cells to the wall of the vessel and prevent the thrombosis and further complications of thrombosis.
Tunica media

- thick
- (1) Circular smooth muscle (5 - 40 layers)
- (2) Small amount of CT with collagen fibers, elastic and reticular fibers, Gp, PG
- (3) Thickness decreases as diameter of vessel decreases

- External elastic lamina (May be indistinct in smaller muscular arteries)
Tunica adventitia

- thick
- collagen I, Elastic fiber
Atherosclerosis

- Problem in ECM (Collagen I, III, GAG, Elastin)
- an artery wall thickens as a result of:
  - the accumulation of calcium and fatty materials such as cholesterol and triglyceride.
vasa vasorum

- a network of small blood vessels
- provide blood supply and nourishment for tunica adventitia and outer parts of tunica media of large vessels
large vein
medium-sized vein
venules
capillaries
elastic arteries
muscular arteries
arterioles
A Comparison of a Typical Artery and a Typical Vein
Largest, conducting arteries – lead directly from heart, subject to high pressures

Superior & inferior vena cava and their tributaries

Pulmonary trunk & aorta and their major branches
aneurysm

- Greek: "dilation"
- is a localized, blood-filled balloon-like bulge in the wall of a blood vessel
- can occur in any blood vessel
- Aneurysms can also occur within the heart itself.

A ruptured aneurysm can lead to bleeding and subsequent hypovolemic shock, leading to death.

- Aneurysms are a result of a weakened blood vessel wall, and can be a result of a hereditary condition or an acquired disease.
Glomus body (glomus apparatus)

- Is a component of the dermis layer of the skin
- Involved in body temperature regulation.
- Consists of an arterio-venous shunt (anastomosis)
- Surrounded by a capsule of connective tissue.
- Most numerous in the fingers and toes

- (-) IEL, ↑TML, ↓Lumen

**Role:**
- Regulation of blood temperature
Regulation of blood flow with their T.M↑
subendothelial
I.E.L is prominence
↑ T.M.L

- External and internal jugular,
  brachial & femoral veins
  $\emptyset \ 2 - 9 \ mm$

- External and internal carotids, brachial & femoral arteries
  $\emptyset \ ~ 4 \ mm$
Dr. Maria Zahiri

↓ subendothelial
pericyte
↓ T.M.L

↓ subendothelial
(-) I.E.L
↓ T.M.L

Ø ~ 10-50 µm

Ø ~ 30 µm
Capillaries

• smallest of a body's blood vessels (microcirculation)

• endothelial linings are only one cell layer thick (5-10 μm) connect arterioles and venules

• enable the exchange of water, oxygen, carbon dioxide, and many other nutrients and waste chemical substances between blood and the tissues
Types

- There are three main types of capillaries:
  - Continuous
  - Fenestrated
  - Sinusoidal
Continuous (Somatic)

- Endothelial cells provide an uninterrupted lining, and they only allow small molecules, like water and ions to diffuse through tight junctions.

- Tight junctions can be further divided into two subtypes:
  - with numerous transport vesicles (skeletal muscles, connective tissue, gonads, Exocrine glands)
  - with few vesicles (central nervous system)

- These capillaries are a constituent of the blood-brain-barrier.
**Fenestrated (Visceral)**

- "fenestra," Latin for "window"
- have pores in the endothelial cells (60-80 nm in diameter)
- Have a diaphragm
- In the renal glomerulus there are cells with no diaphragms called podocyte foot processes or "pedicels,"
- endocrine glands, intestines, pancreas, and glomeruli of kidney
• Both of these types of blood vessels have continuous basal lamina
Sinusoidal capillaries

- are a special type of fenestrated capillaries
- have larger openings in the endothelium

- allow red and white blood cells (7.5μm - 25μm diameter) and various serum proteins to pass using a process that is aided by a discontinuous basal lamina

- These capillaries lack pinocytotic vesicles

- Sinusoid blood vessels are primarily located in the bone marrow, lymph nodes, and adrenal gland.
Metarteriole

- A short vessel that links arterioles and venules
- Instead of a continuous tunica media, they have individual smooth muscle cells placed a short distance apart, each forming a precapillary sphincter that encircles the entrance to that capillary bed.
- Constriction of these sphincters reduces or shuts off blood flow through their respective capillary beds.
- This allows the blood to be diverted to elsewhere in the body
Microanatomy of Lymphatic Vessels

• **A. Lymph capillaries**
  • 1. Structure - blind-ended tubules; consist only of endothelium (which lacks cell junctions); similar to post capillary venules of blood vascular system
  • 2. Function - to collect excess tissue fluid

• **B. Small to medium lymphatic vessels**
  • 1. Structure
  • (similar to venous blood vessels of the next smaller size)

  • a. **Smaller lymphatic vessels** consist of endothelium surrounded by collagen and elastic fibers and a few smooth muscle cells
Medium-sized lymphatic vessels

• b.
• (1) **Tunica intima** - thin; endothelium surrounded by few collagen and elastic fibers; may be folded to form valves

• (2) **Tunica media** - thin; helically arranged smooth muscle, elastic fibers

• (3) **Tunica adventitia** - thicker; collagen and elastic fibers, few smooth muscle cells

• 2. Function - to collect lymph from lymph capillaries
Large lymphatic vessels

- C. include the thoracic duct and right lymphatic duct.
- 1. Structure
  - a. **Tunica intima** - thin
    - (1) Endothelium
    - (2) Subendothelial layer of collagen and elastic fibers, some longitudinal smooth muscle
  - b. **Tunica media** - thickest; longitudinal and circular smooth muscle bundles, loose FECT (similar to a medium blood vein)
  - c. **Tunica adventita** - not well developed; coarse collagen fibers, few longitudinal smooth muscle

- 2. Function - to collect lymph from medium sized lymphatic vessels and return it to large veins

- D. Lymphatic vessels of any size may appear empty, may contain faint pink material (proteins), or may contain lymphocytes.
• 1. The heart wall can be viewed as a three-layered structure.

• a. Inner layer = endocardium
• b. Middle Layer = myocardium
• c. Outer layer = epicardium (also called the pericardium)
1. **endocardium** - in a sense, simply a continuation of tunica intima

a. consists of 3 parts

   * endothelium resting on a basal lamina and associated thin layer of collagenous fibers

   * Beneath the endothelium is the sub-endothelial layer of connective tissue containing elastic fibers and a few smooth muscle cells (some texts call this loose C.T. and others dense C.T.)

   * Beneath that lies the subendocardial layer of loose connective tissue that contains small blood vessels and nerves. In the ventricle, the Purkinje fibers are associated with the subendocardial zone.
2. Myocardium - consists of 2 components

a. fascicles of cardiac muscle cells that connect to the fibrous connective tissue skeleton of the heart

b. Noncontractile, modified muscle cells that form the impulse (action potential) generating and conducting system of the heart

c. cardiac muscle
3. Epicardium - epithelium and connective tissue covering of heart. Also called the visceral pericardium.

   a. squamous to cuboidal epithelial external lining - a continuation of the mesothelium that lines the pericardial cavity.

   b. below this is a layer of connective tissue with high concentration of elastic fibers - elastic layer
Blood

- Artery
- White blood cells
- Platelets
- Red blood cells
Function Blood

- Deliver O2
- Remove metabolic wastes
- Maintain temperature, pH, and fluid volume
- Protection from blood loss- platelets
- Prevent infection- antibodies and WBC
- Transport hormones
Blood

- Plasma: 55%
- Buffy coat: <1%
- Formed elements: 45%
Blood Plasma Components - 55%

90% Water
8% Solutes:
  • Proteins
    Albumin (60 %)
    Alpha and Beta Globulins
    Gamma Globulins
    fibrinogens
  • Gas
  • Electrolytes
Buffy Coat - <1%

- Leukocytes
- Platelets
Formed Elements of the Blood-45%

- Erythrocytes (red blood cells)
- Leukocytes (white blood cells)
- Platelets (thrombocytes)
Erythrocytes
**Erythrocyte** → 7.5 μm in dia

- Anucleate - so can't reproduce
- Hematopoiesis - production of RBC
- Function - transport respiratory gases
- Hemoglobin - 2 α chains and 2 β chains
- Lack mitochondria. Why?

- Men - 5 million cells/mm³
- Women - 4.5 million cells/mm³
- Life span 100-120 days and then destroyed in spleen (RBC graveyard)
Hematopoiesis

- Hematopoiesis (hemopoiesis): blood cell formation
  - Occurs in red bone marrow of axial skeleton, girdles and proximal epiphyses of humerus and femur
Hematopoiesis

- Hemocytoblasts (hematopoietic stem cells)
  - Give rise to all formed elements
  - Hormones and growth factors push the cell toward a specific pathway of blood cell development
- New blood cells enter blood sinusoids
Erythropoiesis

- Erythropoiesis: red blood cell production
  - A hemocytoblast is transformed into a proerythroblast
  - Proerythroblasts develop into early erythroblasts
Figure 17.5

Stem cell

Committed cell

Developmental pathway

Phase 1 Ribosome synthesis

Phase 2 Hemoglobin accumulation

Phase 3 Ejection of nucleus

Hemocytoblast

Proerythroblast

Early erythroblast

Late erythroblast

Normoblast

Reticulocyte-Erythrocyte

Ejection of committed cell

Developmental pathway:

Ribosome synthesis

Hemoglobin accumulation

Ejection of nucleus

Cell types:

Hemocytoblast

Proerythroblast

Early erythroblast

Late erythroblast

Normoblast

Reticulocyte-Erythrocyte
Regulation of Erythropoiesis

- Too few RBCs leads to tissue hypoxia
- Too many RBCs increases blood viscosity
- Balance between RBC production and destruction depends on
  - Hormonal controls
  - Adequate supplies of iron, amino acids, and B vitamins
Hormonal Control of Erythropoiesis

- Erythropoietin (EPO)
  - Direct stimulus for erythropoiesis
  - Released by the kidneys in response to hypoxia
Hormonal Control of Erythropoiesis

• Causes of hypoxia
  ▫ Hemorrhage or increased RBC destruction reduces RBC numbers
  ▫ Insufficient hemoglobin (e.g., iron deficiency)
  ▫ Reduced availability of $O_2$ (e.g., high altitudes)
Hormonal Control of Erythropoiesis

• Effects of EPO
  ▫ More rapid maturation of committed bone marrow cells
  ▫ Increased circulating reticulocyte count in 1–2 days

• Testosterone also enhances EPO production, resulting in higher RBC counts in males
Blood Cell Production

Stem cells are located in red bone marrow.

Stem cells multiply and become specialized.

Mature blood cells:
- Erythrocyte (red blood cell)
  - Nucleus lost
  - Erythroblast
- Neutrophil
  - Granular leukocytes
- Eosinophil
- Basophil
- Monocyte
  - Agranular leukocytes
- Lymphocyte
- Megakaryoblast
  - Megakaryocyte
  - Platelets
RBC Diseases

**Anemia** - when blood has low $\text{O}_2$ carrying capacity; insufficient RBC or iron deficiency. Factors that can cause anemia - exercise, B12 deficiency
RBC Diseases

Sickle-cell anemia

• HbS results from a change in just one of the 287 amino acids in the β chain in the globin molecule.

• Found in 1 out of 400 African Americans.
Polycythemia - excess of erythrocytes, ↑ viscosity of blood; 8-11 million cells/mm³
Usually caused by cancer; however, naturally occurs at high elevations
2. White Blood Cells (Leukocytes)

- Mobile units of body’s defense system:
- “Seek and Destroy” Functions:
  1. Destroy invading microorganisms
  2. Destroy abnormal cells (ie: cancer)
- Clean up cellular debris (phagocytosis)
  3. Assist in injury repair
5 - Types of WBC’s

Agranulocytes

Granulocytes

Each WBC has a specific function
Blood Cell Origin and Production

Figure 11-8
Types of WBC’s

Polymorphonuclear Granulocytes

1. Neutrophils
2. Eosinophils
3. Basophils
1. NEUTROPHILS

* 50-70% of all leukocytes (most abundant of WBC’s)

* Important in inflammatory responses

* Phagocytes that engulf bacteria and Debris
2. **EOSINOPHILS**

* 1-4% of the WBC's

* Attack parasitic worms

* Important in allergic reactions
3. BASOPHILS

* 0.5% of the WBC's

* Release histamine and heparin

* Important in Allergic Reactions
Types of WBC’s

Mononuclear Agranulocytes

4. Monocytes
5. Lymphocytes
(B and T cells)
4. MONOCYTES

* 2-6% of the WBC's

* Exit blood (diapedesis) to become macrophages

* Phagocytic = defend against viruses and bacteria
5. LYMPHOCYTES

* 25-33 % of the WBC's

* B-lymphocytes: Produce Antibodies

* T-lymphocytes: Directly destroy virus-invaded cells and cancer cells
Blood vessel
White blood cell
Red blood cell
Plasma
Platelets
3. Platelets (Thrombocytes)

* Cell fragments bound to megakaryocytes
* “Bud Off” and are released into the blood
Types of Leukocytes

4,000-11,000 cells/mm$^3$

Never let monkeys eat bananas

**Granulocytes**
- Neutrophils - 40-70%
- Eosinophils - 1-4%
- Basophils - <1%

**Agranulocytes**
- Monocytes - 4-8%
- Lymphocytes - 20-45%
WBC Diseases

- **Leukopenia**
  - Abnormally low WBC count—drug induced

- **Leukemias**
  - Cancerous conditions involving WBCs
  - Named according to the abnormal WBC clone involved
Platelets

- Small fragments of megakaryocytes
- Formation is regulated by thrombopoietin
- Blue-staining outer region, purple granules
- Granules contain serotonin, Ca$^{2+}$, enzymes, ADP, and platelet-derived growth factor (PDGF)
Stem cell Developmental pathway

Hemocytoblast

Promegakaryocyte

Megakaryoblast

Megakaryocyte

Platelets

Figure 17.12
Hemostasis- stoppage of bleeding

Platelets: 250,000-500,000 cells/mm³
Hemostasis:

1. Vessel injury

2. Vascular spasm

3. Platelet plug formation

4. Coagulation
Hemostasis
(+ feedback)

Clotting Factors

- Prothrombin
- Thrombin
- Fibrinogen
- Fibrin

Thromboplastin

Prothrombin → Thrombin
Fibrinogen → Fibrin

Fibrin traps RBC & platelets
Platelets release thromboplastin
Blood Clot

- RBC
- Platelet
- Fibrin thread
Disorders of Hemostasis

- Thromboembolytic disorders: undesirable clot formation
- Bleeding disorders: abnormalities that prevent normal clot formation
Thromboembolistic Conditions

- **Thrombus**: clot that develops and persists in an unbroken blood vessel
  - May block circulation, leading to tissue death
- **Embolus**: a thrombus freely floating in the blood stream
  - Pulmonary emboli impair the ability of the body to obtain oxygen
  - Cerebral emboli can cause strokes
Thromboembolitic Conditions

- Prevented by
  - **Aspirin**
    - Antiprostaglandin that inhibits thromboxane A2
  - **Heparin**
    - Anticoagulant used clinically for pre- and postoperative cardiac care
  - **Warfarin**
    - Used for those prone to atrial fibrillation