N3: ANATOMY AND PHYSIOLOGY
1st Semester, Academic Year 2023-2024

LECTURE: CARDIOVASCULAR SYSTEM: BLOOD VESSELS AND HEMODYNAMICS
STUDY GUIDE

Introduction
Hemodynamics is how your blood flows through your blood vessels. Many factors affect how well your blood can move throughout your body. Your heart and blood vessels can make adjustments to deliver enough oxygen for your body's needs. Conditions that affect your circulatory system make it less efficient in delivering blood to your organs.

I. Learning Outcomes:
At the end of the session, you should be able to:

1. Contrast the structure and function of arteries, arterioles, capillaries, venules, and veins.
2. Describe the processes which cause movement of fluids between capillaries and interstitial spaces.
3. Explain the factors that regulate the volume of blood flow.
4. Describe the factors that determine mean arterial pressure and systemic vascular resistance.
5. Describe how blood pressure is regulated.
6. Describe the major routes that blood takes through various regions in the body.
7. Compare the systemic , pulmonary and fetal circulations.

II. Activities

ACTIVITY	DESCRIPTION
1. Synchronous lecture	Powerpoint slides and video presentation
2. Supplementary Activities	Submission in discussion forum in VLE

III. References:
Tortora, & Derrickson. (2012). Chapter 21 The Cardiovascular System: Blood Vessels and Hemodynamics. In *Principles of anatomy and physiology* (13th ed.) or its equivalent in other editions.

IV. General Instructions

- Read Chapters 21 of the reference book. Use the study guide provided.
- After reading, you can watch the slide presentation provided for this module. The link is posted separately.
- There are other links to videos which are optional viewing.
- There are activities provided in this guide to further facilitate learning. There will be a forum assigned to each of the activities. This is where you will make your submissions.

V. Topic and Study Guide

BLOOD VESSELS AND HEMODYNAMICS

A. Structure and functions of blood vessels

1. Basic structure of blood vessels
   a. Tunica interna (intima)
   b. Tunica media
   c. Tunica externa
2. Types of blood vessels
   a. Arteries
      1) Elastic arteries
      2) Muscular arteries
   * Anastomoses
   b. Arterioles
   - Metarteriole
   - Precapillary sphincter
   c. Capillaries
   - capillary bed
   - Thoroughfare channel
   - Three types of capillaries:
      1) Continuous capillaries
      2) Fenestrated capillaries
      3) Sinusoids
   d. Venules
   - Postcapillary venules
   - Muscular venules
   e. Veins
   - Vascular (venous) sinus
   - Anastomotic veins
   - Superficial veins
   - Deep veins

Additional resources:
* Refer to Figure 21.1 (page 810, 13th edition Tortora): Distinguishing features of blood vessels

*You can view this video to further illustrate (optional):

https://www.youtube.com/watch?v=uCNHpK1Xtd8
The Circulatory system part 2: The Blood Vessels by Professor Dave Explains

3. Blood distribution
   - The largest portion of your blood volume at rest—about 64%—is in systemic veins and venules
   - Because systemic veins and venules contain a large percentage of the blood volume, they function as **blood reservoirs** from which blood can be diverted quickly if the need arises
   - Venoconstriction- to divert blood to where it is needed the most
   - Among the principal blood reservoirs are the veins of the abdominal organs (especially the liver and spleen) and the veins of the skin

B. Capillary exchange

Capillary exchange is the movement of substances between blood and interstitial fluid. The 7% of the blood in systemic capillaries at any given time is continually exchanging materials with interstitial fluid. Substances enter and leave capillaries by three basic mechanisms: diffusion, transcytosis, and bulk flow.

1. Diffusion
   - O_2, CO_2, glucose, amino acids, hormones
   - From area of greater concentration to area of lesser concentration
   - Through intercellular clefts, through fenestrations or through diffusion through endothelial cells
   - Lipid-soluble materials such as steroid hormones may diffuse through lipid bilayer of endothelial plasma membranes
   - In sinusoids, large molecules like proteins and blood cells can pass. Examples- hepatocytes and red bone marrow
   - Blood-brain barrier- most brain capillaries are sealed with tight junctions.
2. Transcytosis
   - Through endocytosis and exocytosis
   - For large, non-lipid soluble substances-example insulin, certain antibodies
3. Bulk Flow: filtration and reabsorption
   - a passive process in which *large* numbers of ions, molecules, or particles in a fluid move together in the same direction
   - occurs from an area of higher pressure to an area of lower pressure, and it continues as long as a pressure difference exists
   - more important for regulation of the relative volumes of blood and interstitial fluid
   - **Filtration**: pressure-driven movement of fluid and solutes from blood capillaries into interstitial fluid
   - **Reabsorption:** Pressure-driven movement from interstitial fluid into blood capillaries
   - Two pressures promote filtration:
     - Blood hydrostatic pressure (BHP)- pressure generated by pumping action of the heart
     - Interstitial fluid osmotic pressure (IFOP)
   - Promotes reabsorption: Blood colloid osmotic pressure (BCOP)
   - Net filtration pressure (NFP)-balance of these pressures
   - Starling's law of the capillaries- fluid movements between blood and tissues are determined by differences in hydrostatic and colloid osmotic (oncotic) pressures between plasma inside microvessels and fluid outside them
   - NFP= (BHP+IFOP) – (BCOP+IFHP)
   - NFP: Net filtration pressure
   - BHP: Blood hydrostatic pressure→ favors filtration
   - IFOP: Interstitial fluid osmotic pressure→favors filtration
   - BCOP: Blood colloid osmotic pressure→favors reabsorption
   - IFHP: Interstitial fluid Hydrostatic pressure→favors reabsorption
   - At the arterial end of capillary: net outward pressure of 10 mmHg→ fluid moves out of capillary into interstitial spaces (filtration)
   - At the venous end: negative value means net inward pressure and fluid moves out from tissue spaces to capillaries (reabsorption)

-- 85% of fluid filtered out of capillaries is reabsorbed, the rest stays in interstitial spaces and enter lymphatic system

* Refer to Figure 21.7 Dynamics of capillary exchange (Starling's law of the capillaries) (p. 813, Tortora, 13th ed)

*You can view this video to further illustrate (optional):

https://www.youtube.com/watch?v=6ecmOuCIoNc
Capillary Exchange and Edema, Animation by Alila Medical Media

C. Hemodynamics: factors affecting blood flow

1. Blood flow is the volume of blood that flows through any tissue in a given time period (in mL/min).
    - Total blood flow is cardiac output (CO), the volume of blood that circulates through systemic (or pulmonary) blood vessels each minute.
    - CO = heart rate (HR) x stroke volume (SV)
    - Cardiac output affected by:
        1. Pressure difference that drives blood flow through a tissue- the greater the pressure difference, the greater the blood flow
        2. Resistance to blood flow- the higher the resistance, the smaller the blood flow
2. Blood pressure (BP): the hydrostatic pressure exerted by blood on the walls of a blood vessel.
    - BP is determined by cardiac output, blood volume, and vascular resistance.
    - BP is highest in the aorta and large systemic arteries.
    - **Systolic blood pressure** is the highest pressure attained in arteries during systole
    - **Diastolic blood pressure** is the lowest arterial pressure during diastole
    - **Mean arterial pressure (MAP):** the average blood pressure in arteries
        - about 1/3 of the way between the diastolic and systolic pressures
        - It can be estimated as follows:
          MAP = diastolic BP + 1/3 (systolic BP - diastolic BP)

    - CO = MAP / R   or   MAP= CO x R

    - So MAP increases with CO and SV and HR so long as resistance is unchanged.
    - Blood volume
        - Any decrease in blood volume (as in hemorrhage) decreases amount of blood circulating→ blood pressure drops
        - Any increases in blood volume (as in water retention), BP increases
        - BP can be maintained by homeostatic mechanisms

3. Vascular resistance
    - the opposition to blood flow due to friction between blood and the walls of the blood vessels
    - Factors affecting vascular resistance:
      a. Size of the lumen
        - Resistance is inversely proportional to the fourth power of the diameter (d) of the blood vessel's lumen.
        - The smaller the diameter of the blood vessel, the higher the resistance
        - Example: vasoconstriction and vasodilation
    - Systemic vascular resistance (SVR) or total peripheral resistance (TPR)
        - Refers to all the vascular resistances offered by systemic blood vessels
        - The diameters of arteries and veins are large, so their resistance is very small.
        - The smallest vessels—arterioles, capillaries, and venules—contribute the most resistance.

- A major function of arterioles is to control SVR—and therefore blood pressure and blood flow to particular tissues—by changing their diameters (vasoconstriction or vasodilation)
- The main center for regulation of SVR is the vasomotor center in the brain stem.

b. Blood viscosity

- Viscosity of blood depends on ratio of RBCs to plasma (fluid) volume and on concentrations of plasma proteins.
- The higher the viscosity, the higher the resistance
- Examples: dehydration, polycythemia, anemia, hemorrhage

c. Total blood vessel length

- Resistance is directly proportional to the length of the blood vessel.
- The longer a blood vessel, the greater the resistance.
- Example: obesity

4. Venous Return

- the volume of blood flowing back to the heart through the systemic veins
- occurs due to the pressure generated by contractions of the heart's left ventricle
- If pressure increases in the right atrium or ventricle, venous return will decrease.
- Example: tricuspid valve regurgitation
- Two other mechanisms which pump blood from the lower body to the heart:
  a. skeletal muscle pump
  b. respiratory pump

*You can view this video to further illustrate (optional):

https://www.youtube.com/watch?v=FKJr5uqPv5s
Mechanisms of Venous Return, Animation by Alila Medical Media

5. Velocity of Blood Flow

- The speed or velocity of blood flow (in cm/sec) is inversely related to the cross-sectional area.
- Velocity is slowest where the total cross-sectional area is greatest.
- Thus, the velocity of blood flow decreases as blood flows from the aorta to arteries to arterioles to capillaries, and increases as it leaves capillaries and returns to the heart.
- Aids the exchange of materials between blood and interstitial fluid

* Refer to Figure 21.10 Summary of factors that increase blood pressure. (p. 817, Tortora, 13th ed)

D. Control of Blood Pressure and Blood Flow

1. Cardiovascular center in the brain

- **cardiovascular (CV) center** in the medulla oblongata
- Regulates HR, SV
- Controls neural, hormonal and local negative feedback systems that regulate BP and blood flow
- Nerve impulses from higher brain regions like cerebral cortex, limbic system and hypothalamus affect the CV center and also from sensory receptors.
- Sensory receptors:
  - Proprioceptors
  - Baroreceptors-changes in pressure and stretch in blood vessels

    - Chemoreceptors- changes in concentrations of chemicals in the blood
- Output from CV center→ sympathetic or parasympathetic neurons of the ANS
- Sympathetic NS→ cardiac accelerator nerves→ increase HR and contractility
- Sympathetic NS→ vasomotor nerves (blood vessels in the abdominal viscera and skin)→vasocontriction (vasomotor tone or resting level of systemic vascular resistance) or venoconstriction→ moves blood out of venous blood reservoir to increase BP
- Parasympathetic NS→through CN X or vagus nerve→decrease HR

* Refer to Figure 21.12 Location and function of CV center in the medulla. (p. 818, Tortora, 13th ed)

2. Neural regulation of blood pressure
   - Negative feedback mechanism

   a. Baroreceptor reflex
   b. Chemoreceptor reflex

* Refer to Figure 21.13 ANS innervation of the heart and the baroreceptor reflexes that help regulate blood pressure (p. 819, Tortora, 13th ed)
* Refer to Figure 21.14 Negative feedback regulation of blood pressure via baroreceptor reflexes (p. 820, Tortora, 13th ed)

3. Hormonal regulation – from previous module on endocrine system

E. Circulatory Routes

1. Systemic circulation

Please read Chapter 21 but for the circulatory routes, concentrate on the major arteries and veins and which areas they supply or drain.

* Refer to Figure 21.17 Circulatory routes (p. 827, Tortora, 13th ed)
* Refer to Figure 21.18 and table on (Exhibit 21.A) The Aorta and its branches (p. 828-829, Tortora, 13th ed)
* Refer to Figure 21.23 and table on (Exhibit 21.G) Veins of the systemic circulation (p. 847-848, Tortora, 13th ed)
* Refer to Figure 21.24 and table on (Exhibit 21.H) Veins of the head and neck (p. 849-850, Tortora, 13th ed)

2. Pulmonic circulation- previous module

3. Fetal circulation

Read the section on fetal circulation, taking note of how the fetal circulation is different from post-natal circulation (or after birth circulation) and the changes that take place in the circulation after birth.

* Refer to Figure 21.30 a to c Fetal circulation and changes at birth. (p. 864-865, Tortora, 13th ed)

*You can view this video to further illustrate (optional):

https://www.youtube.com/watch?v=HVBu9HhTkD4
"Fetal Circulation" by Lisa McCabe, for OPENPediatrics