CHAPTER 15: THE CARDIOVASCULAR SYSTEM

OBJECTIVES:

1. List the organs that compose the cardiovascular system and discuss the general functions of this system.

2. Describe the location, size, and orientation of the human heart.

3. Define the term cardiology.

4. Describe the structure of the heart in terms of its coverings, layers, chambers, valves, and blood vessels.

5. Name the function of serous fluid around the heart.

6. Give another name for epicardium.

7. Describe the structure and function of the interventricular septum.

8. Explain why the atria are passive chambers, while the ventricles are active.

9. Name the function of heart valves.

10. Distinguish between AV and SL valves in terms of location, structure, and when they close.

11. Define/describe the terms chordae tendineae, papillary muscle, and trabeculae carneae.

12. Name (and locate) the veins that deposit their blood into the atria of the heart (which atria? deox- or oxygenated?).

13. Name (and locate) the arteries that take blood away from the heart (from which ventricle? deox-or oxygenated blood?).


15. Track a drop of blood through the following circulations:

   a. heart/ lungs/ heart;
   b. through myocardium;
   c. to the body (in general).
CHAPTER 15: THE CARDIOVASCULAR SYSTEM

Objectives (continued)

16. Define the terms *ischemia* and *hypoxia*, and explain how they are related to the pathologic conditions of angina pectoris and myocardial infarction.

17. Discuss what causes reperfusion damage.

18. Explain the significance of each component of the cardiac conduction system and trace how the cardiac impulse travels through the myocardium.

19. Name the common term for the sinoatrial (SA) node.

20. Discuss the physiological stages of cardiac muscle contraction and trace how they appear on graph plotting mv vs. time.

21. Explain why the refractory period between cardiac muscle contractions is so long.

22. Trace a typical ECG and label each wave or complex and explain what event of the CCS corresponds to each wave.

23. Name the term referring to all of the events associated with one heartbeat.

24. Define the terms *systole* and *diastole*.

25. Outline the phases of the cardiac cycle in terms of what is happening in the ECG trace, mechanical events (contraction or relaxation), atrial pressure, ventricular pressure, ventricular volume, aortic pressure and timing.

26. Discuss heart sounds in terms of what they represent, how they sound, how they are detected and their significance.

27. Define the terms *cardiac output (CO)*, *heart rate (HR)*, and *stroke volume (SV)*.

28. Discuss the factors the regulate heart rate.

29. Explain what is meant by the human cardiovascular system being a "closed system".

30. Define the term *hemodynamics*. 
CHAPTER 15: THE CARDIOVASCULAR SYSTEM

Objectives (continued)

31. Compare and contrast the 3 types of blood vessels in terms of the following:
   a. direction of blood-flow (in terms of the heart),
   b. wall structure (# of layers and components of those layers),
   c. gas concentrations and
   d. pressure.

32. Define the term anastomoses.

33. Describe how arterioles play a major role in regulating blood flow to capillaries.

34. Discuss the major event that occurs at capillaries.

35. Compare and contrast continuous, fenestrated and sinusoidal capillaries in terms of structure and location.

36. Define the terms blood flow and circulation time and give the value of the normal circulation time in a resting adult.

37. Discuss the factors that affect cardiac output.

38. Define the term blood pressure, name the type of blood vessels where blood pressure is significant, and name the normal (average) value in a resting adult.

39. Define the term blood resistance and discuss the three major factors that determine it.

40. Explain the processes by which materials are exchanged through a capillary.

41. Locate the neural cardiovascular center on a mid-sagittal diagram of the brain, explain where impulses sent to it are first detected, and explain where its outgoing impulses are directed and what happens when they get there.

42. List the hormones involved in regulation of blood pressure and blood flow.

43. Define the terms tachycardia and bradycardia.

44. Distinguish between the pulmonary and systemic circuits (circulatory routes).
CHAPTER 15: THE CARDIOVASCULAR SYSTEM

Objectives (continued)

45. Track a drop of blood through the following:
   a. from the right fingers to the left ear;
   b. from the stomach to the left fingers;
   c. from the right toe to the left kidney;
   d. from the right kidney to the right side of the brain.

46. Name the branches of the ascending aorta, aortic arch, thoracic aorta, and abdominal aorta, and denote what body region they supply with blood.

47. Explain what happens to the aorta at the brim of the pelvis.

48. Although the venous circuit is essentially parallel to the arterial circuit, list the differences between the two.

49. Name the longest vein in the body and the venipuncture site.

50. Discuss hypertension.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

I. INTRODUCTION

The major function of the cardiovascular systems is to circulate substances throughout the body. In other words, its organs function to supply cells & tissues with oxygen & nutrients and also to remove wastes (CO₂ & urea) from cells and tissues.

If cells do not receive O₂ & nutrients and wastes accumulate, cells will die!

Remember this is the cardiovascular system (See Fig 15.1, page 555) the heart, and the accessory organs being the blood vessels and blood.

Cardiology is the study of the heart and the diseases associated with it.

II. LOCATION/SIZE OF HEART: See Fig 15.2 page 555 and Fig 15.4a, page 556.

A. Location = within mediastinum.
B. Size = closed fist; 300g (adult).
C. Base = wide superior border;
D. Apex = inferior point.

III. HEART STRUCTURE

A. Coverings of Heart = Three membranes:

See Fig 15.5, page 557.

1. Serous Pericardium
   a. visceral pericardium = innermost delicate epithelium + CT covering surrounding the heart muscle;
   b. parietal pericardium = inner lining of fibrous pericardium;
   * Recall the pericardial cavity between a & b, filled with serous fluid for lubrication.

2. Fibrous Pericardium = outermost tough, fibrous protective CT layer that prevents overstretching of the heart.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

III. Heart Structure (continued):

B. The Heart Wall is composed of 3 layers:

See Fig 15.5, page 557 and Table 15.1, page 557.

1. **epicardium** = visceral pericardium;

2. **myocardium** = cardiac muscle tissue (recall characteristics);
   bulk of heart;

3. **endocardium** = smooth inner lining of heart chambers and valves.

C. Chambers of the Heart (Fig 15.6, page 559).

1. The upper chambers are called **atria** (plural).
   a. Right and left atrium are separated by the **interatrial septum**;
   b. Atria receive blood from veins (PASSIVE);
   c. are thin walled chambers.

* Note that the atria are covered by ear-like flaps called **auricles** (See Fig 15.4, page 556).
* Note the location of the **fossa ovalis** which is remnant of the fetal foramen ovale (in lab).

2. The lower chambers are called **ventricles**.
   a. Right and left ventricle are separated by the **interventricular septum**;
   b. Ventricles pump blood from the heart into arteries (ACTIVE);
   c. are thick walled chambers.

* Note the **trabeculae carneae** which is the irregular inner surface (ridges and folds) of the ventricles.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

III. Heart Structure (continued)

D. Major Blood Vessels associated with the Heart
   See Fig 15.12, page 564.

1. Arteries carry blood away from the heart.
   a. carry blood that is high in O₂ & low in CO₂, except pulmonary arteries that are low in O₂ & high in CO₂;
   b. Aorta carries blood from the left ventricle to the body;
   c. Pulmonary arteries carry blood from the right ventricle to the lungs (via the pulmonary trunk).
   d. Coronary arteries carry blood to the myocardium.

2. Veins carry blood toward the heart.
   a. carry blood that is high in CO₂ & low in O₂, except the pulmonary veins that are high O₂ & low CO₂.
   b. Superior vena cava brings blood from the head and upper limbs;
   c. Inferior vena cava brings blood from the trunk and lower limbs;
   d. Coronary sinus (posterior surface) brings blood from the myocardium;
      * All of the above (b,c,d) deposit their blood into the right atrium!
   e. Pulmonary veins bring blood from the lungs to the left atrium:
      m 2 from right lung;
      m 2 from left lung.

3. Other features:
   a. Note the presence of the ligamentum arteriosum which is a remnant of the fetal ductus arteriosus. See Figure 15.12a, page 564.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

III. Heart Structure (continued)

E. **Valves of Heart** (See Fig 15.6, page 559, Fig 15.8, page 560 & 15.9, page 561).

General function = **prevent back flow** of blood.

1. **Atrioventricular valves** (AV valves)
   
   a. The **tricuspid** valve lies between the **right** atrium and ventricle;
   
   b. The **bicuspid** valve lies between the **left** atrium and ventricle (Mitral Valve);

2. **Semilunar valves** (SL valves)
   
   a. The **pulmonary SL valve** lies within the pulmonary trunk
   
   b. The **aortic SL valve** lies within the aorta.

* See Heart Valve Summary Table 15.2, page 561.

3. **Other structures associated with valves:**

   Refer to Fig 15.7 page 560 to see the following features.

   a. **Chordae Tendineae** = tendon-like, fibrous cords that connect the cusps of AV valves to the papillary muscle (inner surface) of ventricles; prevent cusps from swinging back into atria.
   
   b. **Papillary Muscle** = the muscular columns that are located on the inner surface of the ventricles
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

IV. BLOOD FLOW (Circulation of Blood)

A. Pathway through Heart and Lungs (Pulmonary Circuit)

See Fig 15.10, page 562 and Fig 15.11, page 563.

1. right atrium (deoxygenated blood)
   (tricuspid valve)
2. right ventricle
3. pulmonary trunk
   (pulmonary semi-lunar valve)
4. pulmonary arteries
5. capillaries (alveoli) in lungs
6. pulmonary veins
7. left atrium
   (bicuspid or Mitral valve)
8. left ventricle
   (aortic semi-lunar valve)
9. ascending aorta

* Note how the ascending aorta arches over the pulmonary trunk and heads downward forming the thoracic aorta and abdominal aorta.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

IV. Bloodflow (continued)

B. **Coronary Circulation** (i.e. **Pathway through Myocardium** or how the heart muscle itself is supplied with blood).

See Fig 15.15, page 566.

1. ascending aorta

2. coronary arteries (1st and 2nd branch of aorta)
   a. *left coronary artery*
   b. right coronary artery

* Definition:

**Anastomoses** = connections between 2 or more branches of arteries that supply the same region with blood.

provide alternate routes for blood to reach a particular region;
many in heart.

3. capillaries in myocardium

4. cardiac veins
   a. great cardiac vein;
   b. middle cardiac vein.

5. coronary sinus

6. right atrium
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

IV. Bloodflow (continued)

C. Summary of Pulmonary, Coronary and General Systemic Circulations

<table>
<thead>
<tr>
<th>Coronary Sinus</th>
<th>Right Atrium (Tricuspid)</th>
<th>Vena cavae (SVC and IVC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right Ventricle</td>
<td>Veins</td>
</tr>
<tr>
<td></td>
<td>Pulmonary Trunk (Semi-lunar valve)</td>
<td></td>
</tr>
<tr>
<td>Cardiac veins</td>
<td>Right &amp; Left Pulmonary Arteries</td>
<td>Venules</td>
</tr>
<tr>
<td>Capillaries</td>
<td>Capillaries in lungs</td>
<td>Capillaries in Body Tissues</td>
</tr>
<tr>
<td>Myocardium</td>
<td>Right &amp; Left Pulmonary Veins</td>
<td></td>
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<tr>
<td></td>
<td>Left Atrium (Bicuspid)</td>
<td>Arterioles</td>
</tr>
<tr>
<td></td>
<td>Left Ventricle</td>
<td></td>
</tr>
<tr>
<td>Right &amp; Left Coronary Arteries</td>
<td>Aorta (semi-lunar valve)</td>
<td>Arteries</td>
</tr>
</tbody>
</table>
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

V. Angina Pectoris and Myocardial Infarction (MI)

See page 563.

Blood clots, fatty atherosclerotic plaques, and smooth muscle spasms within the coronary vessels lead to most heart problems.

A. Definitions:

1. **Ischemia** = reduction of bloodflow;

2. **Hypoxia** = reduced oxygen supply due to ischemia;

3. **Angina pectoris** ("strangled chest") = severe pain that accompanies myocardial ischemia.
   a. crushing chest pain radiating down left arm;
   b. labored breathing, weakness, dizziness, perspiration;
   c. occurs during exertion, fades with rest;
   d. relieved by nitroglycerin.

4. **Myocardial Infarction (MI)** = "heart attack".
   a. death of portion of myocardium;
   b. caused by a thrombus (stationary blood clot) or embolus (moving blood clot) in a coronary artery;
   c. may cause sudden death if conduction system is disrupted (see below) and ventricular fibrillation occurs;
   d. treatments include clot-dissolving agents (i.e. TPA and streptokinase), along with heparin or angioplasty.

5. **Reperfusion Damage** occurs when a oxygen deprived (hypoxic) tissue’s blood supply is reestablished.
   a. due to formation of oxygen free radicals;
   b. damage to enzymes, neurotransmitters, nucleic acids and phospholipids;
   c. implicated in a number of diseases including heart disease, Alzheimer’s, Parkinson’s, cataracts, and rheumatoid arthritis and contributes to aging;
   d. **Anti-oxidants** defend the body against this damage and include the enzyme catalase, Vitamin E, C and beta-carotene.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

VI. Cardiac Conduction System (CCS)

There are specialized areas of cardiac muscle tissue (1%) in the heart that are autorhythmic (self-exciting). These cells compose the CCS and are responsible for initiating and distributing cardiac (electrical) impulses throughout the heart muscle (i.e. cause the heart to beat). These specialized areas together coordinate the events of the cardiac cycle, which makes the heart an effective pump.

A. Components of CCS: See Fig 15.19 and Fig 15.20, page 570.

1. Sinoatrial Node (S-A Node):
   a. located in right uppermost atrial wall;
   b. PACEMAKER = self-exciting tissue (rhythmically and repeatedly [60-100 per minute] initiates cardiac impulses);
   c. Impulse travels throughout atrial fibers via gap junctions in intercalated discs to the...

   a. located in interatrial septum;
   b. serves as a delay signal that allows for ventricular filling;
   c. Cardiac impulse then enters the...

3. Atrioventricular (AV) Bundle (Bundle of His):
   a. only electrical connection between the atria and ventricles;
   b. located in the superior interventricular septum;
   c. Impulse enters both ...

4. Right and left bundle branches
   a. lead downward through interventricular septum toward apex, and impulse finally reaches...

5. Purkinje Fibers (Conduction Myofibers)
   a. large diameter conduction myofibers;
   b. located within the papillary muscles of the ventricles;
   c. conduct the impulse into the mass of ventricular muscle tissue.
   d. cause ventricles to contract which forces blood out.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

VI. B. Summary Table of CCS (Keyed on page 328 of this outline)

<table>
<thead>
<tr>
<th>CCS COMPONENT</th>
<th>LOCATION</th>
<th>SIGNIFICANCE</th>
<th>SENDS CARDIAC IMPULSE TO ...</th>
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VII. Physiology of Cardiac Muscle Contraction

A. Review the differential ion concentrations that maintain a cell’s Resting Membrane Potential (RMP):
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

VII. Physiology of Cardiac Muscle Contraction (continued)

B. Scheme:

1. **Rapid depolarization due to opening of Na+ channels:**
   a. Contractile fibers of the heart have a resting potential of -90mV;
   b. When the potential is brought to -70mV by excitation of neighboring fibers, certain sodium (Na+) channels open very rapidly;
   c. Na+ ions rush into the cytosol of fibers and produce a rapid depolarization.

2. **Plateau due to opening of Ca++ channels**
   a. Ca++ channels open;
   b. Ca++ ions enter cytosol of fibers from ECF;
   c. Ca++ ions pour out of SR into cytosol;
   d. Depolarization is maintained for 0.25 seconds (250msec).
   e. Ca++ binds troponin ... contraction.
   
   Note that epinephrine increases contraction force by increasing Ca++ influx, and drugs called calcium channels blockers (i.e. verapamil) reduce Ca++ inflow and therefore diminish the strength of a heartbeat.

3. **Repolarization due to opening of K+ channels**
   a. K+ channels open;
   b. K+ ions diffuse out of fibers;
   c. Na+ and Ca++ channels close;
   d. -90mV resting potential is restored.

* **Refractory Period** = the time following a contraction when a second contraction cannot be triggered.
   a. longer than contraction itself;
   b. necessary for ventricles to relax and fill with blood before again contracting to eject the blood.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

VIII. ELECTROCARDIOGRAM (ECG) See CA 15.22, page 572.

A. Definition ECG = a recording of the electrical changes that occur in the myocardium during the cardiac cycle (see below);
B. Instrument used to record an ECG = electrocardiograph;
C. used to determine if:
   1. the conduction pathway is normal;
   2. the heart is enlarged;
   3. certain regions are damaged.

D. Three waves per heartbeat:
   1. **P wave** is a small upward wave.
      a. represents atrial depolarization (spreads from SA node throughout both atria);
      b. 0.1 sec after P wave begins, atria contract.
   2. **QRS Complex**
      a. begins as a downward deflection; continues as large, upright, triangular wave; ends as a downward wave;
      b. represents onset of ventricular depolarization (spreads throughout ventricles);
      c. shortly after QRS begins, ventricles start to contract.
   3. **T wave**
      a. dome-shaped, upward deflection;
      b. represents ventricular repolarization;
      c. occurs just before ventricles start to relax;
      d. shape indicates slow process.
   * P-Q Interval and S-T segment

E. Abnormal ECG’s: See Fig 15.23, page 572

1. enlarged P = enlargement of an atrium possibly due to mitral stenosis;
2. enlarged Q wave = MI;
3. enlarged R wave = ventricular hypertrophy.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

IX. CARDIAC CYCLE

A. Introduction

1. includes all of the events associated with one heartbeat;

2. The atria and ventricles alternately contract and relax (i.e. when the two atria contract, the two ventricles relax and vice versa).

3. Blood flows from areas of high pressure to areas of low pressure. As a chamber of the heart contracts, pressure increases, while as a chamber relaxes, pressure decreases.

4. Definitions: See Fig 15.16, page 567.
   a. **systole** = phase of contraction;
   b. **diastole** = phase of relaxation.

5. A complete cardiac cycle includes systole and diastole of both atria, and systole and diastole of both ventricles.

B. General Summary of Cardiac Cycle (Keyed on page 328 of this outline)

<table>
<thead>
<tr>
<th>Phase</th>
<th>VENTRICULAR CONTRACTION (SYSTOLE)</th>
<th>ATRIAL RELAXATION (DIASTOLE)</th>
<th>VENTRICULAR RELAXATION (DIASTOLE)</th>
<th>ATRIAL CONTRACTION (SYSTOLE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood-flow</td>
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</tr>
<tr>
<td>Valves</td>
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<tr>
<td>pres-sure</td>
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</tbody>
</table>
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IX. Cardiac Cycle (continued)

C. Specific Phases of the Cardiac Cycle:

Fig 15.17, page 567 shows the relation between the heart’s ECG and mechanical events (contraction and relaxation), and the consequent changes in atrial pressure, ventricular pressure, ventricular volume, and aortic pressure during the cardiac cycle.

1. **Relaxation (Quiescent) Period** (Early diastole)

   a. follows T-wave;
   b. Ventricular pressure drops;
   c. SL valves close;
   d. isovolumetric relaxation for brief time;
   e. When ventricular pressure drops below atrial pressure, AV valves open;
   f. 0.4 seconds.

2. **Ventricular Filling** (Mid to Late Diastole)

   a. Rapid ventricular filling occurs just after AV valves open (remember atria had filled during ventricular contraction);
   b. SA Node fires (P wave), atria contract, and remainder of ventricular filling occurs;
   c. Atria relax, ventricles depolarize (QRS complex).
   d. 0.1 seconds.

3. **Ventricular Systole**

   a. Impulse passes through AV Node and then through ventricles;
   b. Ventricles contract;
   c. Ventricular pressure increases rapidly;
   d. AV valve close:

      m Isovolumetric Contraction Phase (constant volume) = start of contraction to opening of SL valves = 0.05 sec;
      m Ventricular Ejection Phase = opening of SL valves to closing of SL valves;
   e. 0.3 seconds.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

X. HEART SOUNDS (lub-dup): See Fig 15.18, page 569.

A. Intro
These sounds can be heard through a physician’s stethoscope. They represent the closing of heart valves, and therefore help in diagnosing any problems occurring in the valves.

B. Sounds
1. **lub** = closing of AV valves; loud and long.
2. **dup**: closing of SL valves; short and sharp.

C. Significance
If the closing of the valve cusps is incomplete, some blood may leak back = **murmur**.

XI. CARDIAC OUTPUT (CO)

A. Definition CO = the volume of blood pumped by each ventricle in one minute;
B. CO = heart rate (HR) x stroke volume (SV)
C. SV = volume of blood pumped out by a ventricle with each beat;
D. Normal CO = 5 liters.

XII. Regulation of Heart Rate:

A. Autonomic Nervous System: See Fig 15.24, page 573.
   1. parasympathetic (normal) decreases;
   2. sympathetic (Stressful) increases.

B. Chemicals
   1. hormones (i.e. epinephrine increases);
   2. ions
      a. calcium increases;
      b. potassium and sodium decreases.

C. Age (decreases)

D. Sex
   1. females increased;
   2. males decreased.

E. Temperature
F. Emotion
G. Disease
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

I. INTRODUCTION

The blood vessels form a closed system of tubes that carry blood away from the heart, transport it to all the body tissues and then returns it to the heart. Hemodynamics is the study of the forces involved in accomplishing that feat.

II. TYPES OF BLOOD VESSELS: See Fig 15.25, page 576.

A. Arteries carry blood away from the heart.

1. strong and thick-walled vessels;

2. walls have three distinct layers:
   a. tunica interna (intima) surrounds lumen and is composed of:
      m a layer of endothelium (simple squamous epithelium),
      m a basement membrane,
      m an internal elastic lamina.
   b. tunica media is the thickest layer composed of:
      m smooth muscle cells;
      m elastic fibers.
   c. tunica externa (adventitia) is the outermost layer composed of elastic and collagen fibers.

3. carry blood that is under great pressure.

4. carry blood that is high in oxygen and low in carbon dioxide, except the pulmonary arteries;

5. branch and give rise to thinner vessels called arterioles.

6. may unite with branches of other arteries supplying the same region forming anastomoses (i.e. providing alternate routes).
II. Types of Blood Vessels (continued)

B. **Arterioles**

   See Fig 15.26, page 576 and Fig 15.28, page 577.

   1. very small arteries;
   2. deliver blood to capillaries in tissues;
   3. play a major role in regulating blood flow to capillaries, and therefore blood pressure:
      a. vasoconstriction (contraction) = decreased blood flow = increased blood pressure.
      b. vasodilation = increased blood flow = decreased blood pressure.
         * This will be discussed in greater detail later.

C. **Capillaries** are the smallest, thinnest blood vessels.

   See Fig 15.29 and 15.30, page 578.

   1. connect arterioles to venules;
   2. permit the exchange of gases, nutrients and wastes between blood and tissues;
   3. composed of only a single layer of endothelium and a basement membrane.
   4. three types:
      a. **continuous capillary** = the plasma membranes form a continuous, uninterrupted ring around the lumen; found in skeletal, smooth muscle, CT’s and lungs.
      
      b. **fenestrated capillary** = the endothelial plasma membranes contain pores (holes); found in the kidneys and villi of small intestine.
      
      c. **sinusoids** = contain spaces between the endothelial cells with basement membranes being incomplete or absent; found in liver and spleen.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

II. Types of Blood Vessels (continued)

C. Capillary Exchange: See Fig 15.31, page 580.

Gases, nutrients, and wastes are exchanged between blood in capillaries of tissues in three ways:

1. **diffusion**
   a. most common;
   b. substances include oxygen, CO₂, glucose, & hormones,
   c. lipid-soluble substances pass directly through endothelial cell membrane;
   d. water-soluble substances must pass through fenestrations or gaps between endothelial cells.

2. **vesicular transport** (endo/exocytosis);

3. **bulk flow** (filtration and absorption).
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

II. Types of Blood Vessels (continued)

D. Veins carry blood toward the heart;

1. Venules extend from capillaries and merge together to form veins;

2. thin-walled vessels with 3 tunics:
   Fig 15.25b, page 576 and 15.32b, page 580:
   a. tunica intima = endothelium and basement membrane;
   b. tunica media = thin layer of smooth muscle; much thinner than artery;
   c. tunica externa = thick CT layer.
   ** See Fig 15.25a & b, page 576 and Fig 15.32a & b, page 580 to compare the structure of a vein with an artery.

3. carry blood under low pressure;

4. contain valves;
   See Fig 15.33, page 581.

5. carry blood that is high in carbon dioxide and low in oxygen, except the pulmonary veins.

E. Blood Distribution throughout Body:
  See Fig 15.34, page 581.

1. 60% in systemic veins and venules;
2. 15% in systemic arteries and arterioles;
3. 12% in pulmonary vessels;
4. 8% in heart;
5. 5% in systemic capillaries.

* See Table 15.3, page 581 for a summary of blood vessel structure and function.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

II. Types of Blood Vessels (continued)

F. Major Blood Vessel Summary Table (Keyed on page 329 of this outline)

<table>
<thead>
<tr>
<th>Type of Blood Vessel</th>
<th>Function (i.e. direction of blood flow in terms of heart)</th>
<th>Wall structure (layers and layer components)</th>
<th>Concentration of gases (oxygen and carbon dioxide)</th>
<th>Pressure of blood carried</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
A. BLOOD PRESSURE:

1. Definition: Blood pressure = the pressure exerted by blood on the wall of blood vessel.

2. In clinical use, we most commonly refer to mean (systemic) arterial blood pressure (MABP), because the blood pressure in the veins is essentially insignificant.

3. The mean arterial blood pressure (MABP) rises to its maximum during systole (contraction) and falls to its lowest during diastole (relaxation).

4. In a normal adult at rest, the MABP = 120 mm Hg/ 80 mm Hg.

B. Factors that Influence Arterial Blood Pressure

See Fig 15.36, page 584.

1. Heart Action (cardiac output):
   a. CO is the volume of blood pumped by each ventricle each minute;
      
      m the volume of blood that is circulating through the systemic (or pulmonary) circuit per minute;
      
      m 5.25 liters/minute is normal adult.

   b. CO is affected by:
      m stroke volume (SV);
      m heart rate (HR);
      (Remember that CO = SV X HR);

2. Blood Volume (increase in blood volume increases BP)
   See Fig 15.38, page 589.

3. Peripheral Resistance (resistance; R = opposition to blood flow usually due to friction; CO = MABP/R)
   a. Resistance is the opposition to blood flow primarily due to friction. This friction depends on three things:
      
      m Blood viscosity
      m Total blood vessel length
      m Blood Vessel Radius
III. Hemodynamics (continued)

C. Regulation of Blood Pressure and Blood Flow:

1. Neural Regulation: See Fig 15.24, page 573.
   a. The cardiovascular (CV) center is located in the medulla of the brain stem;
   b. CV Center Input:
      Nerve impulses are sent to the CV center from three areas:
      1. Higher brain centers;
      2. Baroreceptors (or pressoreceptors) that detect changes in BP in aorta and carotid arteries;
      3. Chemoreceptors that detect changes in key blood chemical concentrations (H^+, CO_2, and O_2).
   c. CV Center Output:
      Nerve impulses are sent from the CV center to either:
      1. the SA Node of heart;
      2. the smooth muscle of peripheral blood vessels (i.e. arterioles).
   d. Negative-Feedback Regulation:
      See Figures 15.39 and 15.40, page 589.

1. If BP is too high:
   m this increase is detected by baroreceptors in the carotid a. or aorta;
   m they send an impulse to CV center;
   m the CV center interprets that message and sends a signal to the SA Node and arterioles:
   a. The SA Node decreases heart rate;
   b. The arterioles dilate,
      * both resulting in a decrease in BP back to normal levels.

2. If BP is too low...
   m SA Node increases hr;
   m constriction of arterioles...
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

III. Hemodynamics (continued)

C. Regulation of BP/Blood Flow (continued)

2. **Hormonal Control**

Several hormones affect BP by acting on the heart, altering blood vessel diameter, or adjusting blood volume.

a. *Hormones that increase BP:*

   m **Epinephrine and norepinephrine**
     * increases CO (rate & force of contraction) and causes vasoconstriction of arterioles.

   m **Antidiuretic hormone (ADH)**
     * causes vasoconstriction of arterioles during diuresis and during hemorrhage.

   m **Angiotensin II**
     * causes vasoconstriction of arterioles and causes the secretion of aldosterone (below)

   m **Aldosterone**
     * increases Na\(^+\) and water reabsorption in the kidneys.

b. *Hormones that decrease BP:*

   m **Atrial natriuretic peptide (ANP)**
     * causes vasodilation of arterioles and promotes the loss of salt and water in urine.

   m **Histamine**
     * causes vasodilation of arterioles (plays a key role in inflammation)
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

III. Hemodynamics (continued)

D. Checking Circulation: See Fig 15.35, page 584.

1. Definition: **Pulse** = the pressure wave that travels through arteries following left ventricular systole.
   a. strongest in arteries closest to heart;
   b. commonly measured in radial artery at wrist;
   c. normal pulse = 70-80bpm;
      m tachycardia > 100 bpm;
      m bradycardia < 60 bpm.

   See Clinical application 15.2, page 575.

E. Measuring BP

1. Instrument used is called a **sphygmomanometer**;
2. brachial artery is typically used;
3. procedure will be addressed in laboratory.

   See CA 15.5, page 586-587.
CHAPTER 15: THE Cardiovascular System: Blood Vessels &
Hemodynamics

IV. PATHS OF CIRCULATION: See Fig 15.42, page 594.

A. Pulmonary Circuit = the vessels that carry blood from the right ventricle to the
lungs, and the vessels that return the blood to the left atrium:

See Fig 15.43, page 595.

1. pulmonary trunk
2. right and left pulmonary arteries
3. capillaries in lungs
4. right and left pulmonary veins

B. Systemic Circuit = the vessels that carry blood from the heart to body cells and back
to the heart.

1. Arterial System:

See Fig 15.54, page 605 for general overview.

a. The aorta is divided into the following regions:

m ascending aorta;

m aortic arch;

m thoracic aorta;

m abdominal aorta;

* The abdominal aorta terminates at the brim of the
pelvis and branches into each leg = common iliac
arteries.

b. There are many arteries that branch from these regions of the
aorta and supply blood to many areas of the body. The arteries you
will need to know are listed below, and the body part they supply with
blood, follows in parentheses:
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

IV. B. 1. b. Arterial Circuit (continued)

**Branches of the ascending aorta:** See Fig 15.45, pg 596.
1. right coronary a. (myocardium);
2. left coronary a. (myocardium).

**Branches of the aortic arch:** See Fig 15.45, page 596.
1. brachiocephalic a. (right side of head and right arm):
   a. right subclavian a. (right arm):
      m axillary a. (armpit)
      1. brachial a. (upper arm)
         a. radial a. (lateral forearm);
         b. ulnar a. (medial forearm)
             m palmar arches (palm)
                 1. digital a. (fingers)

   Fig 15.47, pg 598. m vertebral a. (cervical vertebrae/skull)
   1. basilar a. (brain)
      a. Circle of Willis (brain)

   b. right common carotid a. (right side of head)
      m external carotid a. (scalp)
      m internal carotid a. (brain)

2. left common carotid artery (left side of head):
   a. external carotid a.
   b. internal carotid a.

3. left subclavian artery (left arm):
   Branches follow same pattern as right subclavian artery above.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

IV. B. 1. b. Arterial Circuit (continued)

Branches of thoracic aorta:

1. intercostals (intercostal/chest muscles);
2. superior phrenics (superior diaphragm);
3. bronchial arteries (bronchi of lungs);
4. esophageal arteries (esophagus).

Branches of abdominal aorta: See Fig 15.46a&b, pg 597.

1. inferior phrenics (inferior diaphragm);
2. celiac trunk (artery)
   a. common hepatic a. (liver);
   b. left gastric a. (left stomach);
   c. splenic artery (spleen);
3. superior mesenteric (small intestine, cecum, ascending/transverse colon, pancreas);
4. suprarenals (adrenals)
5. renal arteries (kidneys);
6. gonadal arteries (ovarian/testicular);
7. inferior mesenteric (descending/sigmoid colon, rectum)

Branches of Common Iliac Arteries (right and left): See Fig 15.53, page 603.

1. external iliac a. (lower extremities)
   a. femoral a. (thigh)
      m popliteal a. (knee region)
      1. posterior tibial a. (lower leg)
      2. anterior tibial a.
         a. dorsalis pedis a.
      m plantar a.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

IV. B. 2. Venous System: See Overview Figure 15.61, page 611.

Veins, that return blood to the heart after gas, nutrient, and waste exchange, usually follow pathways that are parallel to the arteries that supplied that particular region with blood. The veins you'll need to learn are identical to the arterial list with the following exceptions:

a. jugular veins (head); See Fig 15.55, page 606.
   m external jugular vein (face and scalp);
   m internal jugular vein (brain).

b. median cubital vein (venipuncture site): Fig 15.56, pg 606.

c. Note that there are 2 brachiocephalic veins; they are formed by the union of the subclavian and jugular vein from each side. See Fig 15.57, page 607.

d. Superior Vena Cava (formed by the union of the brachiocephalic veins = head and upper limbs).

e. coronary sinus (cardiac veins);
   m cardiac veins (caps of myocardium).

f. hepatic vein (drains hepatic portal system): See Fig 15.58, page 608.
   m hepatic portal vein (drains gastric, mesenteric and splenic veins);
   1. gastric vein (stomach);
   2. mesenteric veins (intestines);
   3. splenic vein (spleen);
   * The veins above do not drain directly into the inferior vena cava. Instead, the blood drained from these abdominal organs travels to the liver via the portal vein. Recall the hepatic portal system discussed during digestion.

h. great saphenous vein = the longest vein in the body. Extends from the medial ankle to the external iliac vein. See Fig 15.60, page 610.

j. Inferior Vena Cava (drains veins from abdominal & lower limbs).
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

IV. Paths of Circulation (continued)

C. Tracing Bloodflow

1. From right fingers to left ear:
   
   right finger capillaries to
   right digital veins to
   right venous palmar arches to
   right radial or ulnar vein to
   right brachial vein to
   right axillary vein to
   right subclavian vein to
   right brachiocephalic vein to
   superior vena cava to
   right atrium...
   left ventricle to
   aorta (ascending and arch) to
   left common carotid artery to
   left external carotid artery to
   left ear capillaries.

   Could the above tracing have been different at any points?

2. From the stomach to the left fingers.

3. From the right toe to the left kidney.

4. From the right kidney to the ride side of brain.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: BLOOD VESSELS & HEMODYNAMICS

V. Disorders/Homeostatic Imbalances of the Cardiovascular System:

A. Rheumatic Fever (intro on page 554)
B. Pericarditis (page 556)
C. Mitral Valve Prolapse (page 558)
D. Abnormal Calcium or Potassium Levels (page 573)
E. Arrhythmias (CA 15.2, pages 574-575)
F. Blood Vessel Disorders (CA 15.3, pages 583-583)
G. Hypertension: (CA 15.6, pages 590-591)
H. Cardiac Tamponade (page 592)
I. Hypoplastic Left Heart Syndrome (page 594)
J. Pulmonary Edema (page 594)
K. Aneurysm: See CA 15.8, page 612-613 concerning Marfan’s Syndrome.
L. Coronary Artery Disease (CAD): See CA 15.9, page 614.

VI. Other Interesting Applications Concerning the CV System

A. Heart Transplantation (page 575 and CA 15.1, page 569)
B. Exercise and the CV System (CA 15.7, page 593)

VII. Innerconnections of the Cardiovascular System

See page 615.
CHAPTER 15: THE CARDIOVASCULAR SYSTEM: THE HEART

Summary Table of CCS (outline page 307)

<table>
<thead>
<tr>
<th>CCS COMPONENT</th>
<th>LOCATION</th>
<th>SIGNIFICANCE</th>
<th>SENDS CARDIAC IMPULSE TO ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinoatrial Node</td>
<td>right uppermost atral wall</td>
<td>“Pacemaker”; initiates cardiac impulse 60-100 times per minute</td>
<td>Atrioventricular Node</td>
</tr>
<tr>
<td>Atrioventricular Node</td>
<td>interatrial septum</td>
<td>delay signal to allow for ventricular filling</td>
<td>Atrioventricular Bundle</td>
</tr>
<tr>
<td>Atrioventricular Bundle</td>
<td>superior interventricular septum</td>
<td>only electrical junction between atria &amp; ventricles</td>
<td>right and left bundle branches</td>
</tr>
<tr>
<td>right and left bundle branches</td>
<td>lateral interventricular septum</td>
<td>passes signals down to apex</td>
<td>Purkinje fibers</td>
</tr>
<tr>
<td>Purkinje fibers</td>
<td>in papillary muscles of ventricles</td>
<td>conduct impulse to the mass of ventricular myocardium and forces blood out</td>
<td>N/A</td>
</tr>
</tbody>
</table>

General Summary of Cardiac Cycle (outline page 310)

<table>
<thead>
<tr>
<th>Phase</th>
<th>VENTRICULAR CONTRACTION (SYSTOLE)</th>
<th>ATRIAL RELAXATION (diastole)</th>
<th>VENTRICULAR RELAXATION (DIASTOLE)</th>
<th>ATRIAL CONTRACTION (systole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood-flow</td>
<td>blood is forced from ventricles into arteries</td>
<td>atria fill with blood</td>
<td>ventricles fill with blood</td>
<td>blood is forced from atria into ventricles</td>
</tr>
<tr>
<td>Valves</td>
<td>SL open AV closed</td>
<td>SL open AV closed</td>
<td>AV open SL closed</td>
<td>AV open SL closed</td>
</tr>
<tr>
<td>pres-sure</td>
<td>V high</td>
<td>A low</td>
<td>V low</td>
<td>A high</td>
</tr>
</tbody>
</table>
### Major Blood Vessel Summary Table

<table>
<thead>
<tr>
<th>Type of Blood Vessel</th>
<th>Artery</th>
<th>Vein</th>
<th>Capillary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function (i.e. direction of blood flow in terms of heart)</td>
<td>carries blood away from heart</td>
<td>carries blood toward heart</td>
<td>connects arterioles and venules; exchange site for gases, nutrients &amp; wastes between blood and tissues</td>
</tr>
<tr>
<td>Wall structure (layers and layer components)</td>
<td>three tunics: innermost = tunica intima (endothelium plus basement membrane); middle = tunica media (thick smooth muscle plus elastic fibers); outermost = tunica adventitia (collagen and elastic fibers)</td>
<td>same three tunics as arteries but tunica media is much thinner; equipped with valves</td>
<td>only tunica intima (single layer of endothelium plus its basement membrane)</td>
</tr>
<tr>
<td>Concentration of gases (oxygen and carbon dioxide)</td>
<td>high in oxygen; low in carbon dioxide</td>
<td>high in carbon dioxide; low in oxygen</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure of blood carried</td>
<td>high</td>
<td>low so they are equipped with valves</td>
<td>N/A</td>
</tr>
</tbody>
</table>