

## The Cardiovascular System: The Heart

### I. Introduction

- A. The major function of the cardiovascular system is to circulate substances throughout the body. In other words, its organs function to supply cells and tissues with oxygen and nutrients and also to remove wastes, CO<sub>2</sub> and urea, from cells and tissues.
- B. If cells do not receive O<sub>2</sub> and nutrients *and* wastes accumulate, cells will die!
- C. Remember this is the cardiovascular **system**, which is composed of the heart and blood vessels. Blood, a connective tissue, is circulated through these organs.
- D. **Cardiology** is the study of the heart and the diseases associated with it.

### II. Location and Size of the Heart

- A. Location = within mediastinum
- B. Size = closed fist, ~300g in an adult
- C. Base = wide superior border
- D. Apex = inferior point

### III. Heart Structure

#### A. The Coverings of the Heart = Three Membranes

- 1. **Serous Pericardium** (1<sup>st</sup> and 2<sup>nd</sup> membranes)
  - a) **Visceral Pericardium** = innermost layer, delicate simple squamous epithelium and CT surrounding the heart muscle itself
  - b) **Parietal Pericardium** = outer serous membrane lining inner surface of fibrous pericardium
  - c) Between visceral and parietal pericardia is the **pericardial cavity**, filled with **serous fluid** for lubrication
- 2. **Fibrous Pericardium** = outermost (3<sup>rd</sup> membrane) layer of tough, fibrous connective tissue that prevents overstretching of the heart

#### B. The **Heart Wall** = is composed of three layers

- 1. **Epicardium** = which is in fact the visceral pericardium
- 2. **Myocardium** = thick layer of cardiac muscle, bulk of heart
- 3. **Endocardium** = smooth inner lining of slick endothelium of heart chambers and valves

#### C. Chambers of the Heart

- 1. The **Atria** = the upper chambers of the heart
  - a) The right and left atrium are separated by the **interatrial septum**
  - b) Atria receive blood from veins passively

- c) Are thin walled chambers
    - Note that the atria are covered by ear-like flaps called **auricles**
    - Note the location of the **fossa ovalis** which is the remnant of the fetal foramen ovale
2. The **Ventricles** = the lower chambers of the heart
- a) The right and left ventricle are separated by the **interventricular septum**
  - b) Ventricles pump blood from the heart into arteries
  - c) Are thick walled chambers
    - Note the **Trabeculae Carneae**, which is the irregular inner surface of the ventricles

#### D. Major Blood Vessels Associated with the Heart

##### 1. Arteries

- a) Carry blood away from the heart
- b) Carry blood that is high in O<sub>2</sub> and low in CO<sub>2</sub>, except the pulmonary arteries that are low in O<sub>2</sub> and high in CO<sub>2</sub>
- c) **Aorta** carries blood from the left ventricle to the body
- d) **Pulmonary Arteries** carry blood from the right ventricle to the lungs (via the pulmonary trunk)
- e) **Coronary Arteries** carry blood to the myocardium

##### 2. Veins

- a) Carry blood toward the heart
- b) Carry blood that is low in O<sub>2</sub> and high in CO<sub>2</sub>, except the pulmonary veins that are high in O<sub>2</sub> and low in CO<sub>2</sub>
- c) **Superior Vena Cava** brings blood from the head, upper torso and upper limbs into the right atrium
- d) **Inferior Vena Cava** brings blood from the lower torso and lower limbs into the right atrium
- e) **Pulmonary Veins** bring blood from the lungs to the left atrium
  - 2 from right lung
  - 2 from left lung
- f) **Coronary Sinus** brings blood from the myocardium directly into the right atrium

##### 3. **Ligamentum arteriosum** = which is the remnant of the fetal ductus arteriosus

#### E. Valves of the Heart

- Prevents back flow of blood in the system
- There are four valves to the heart

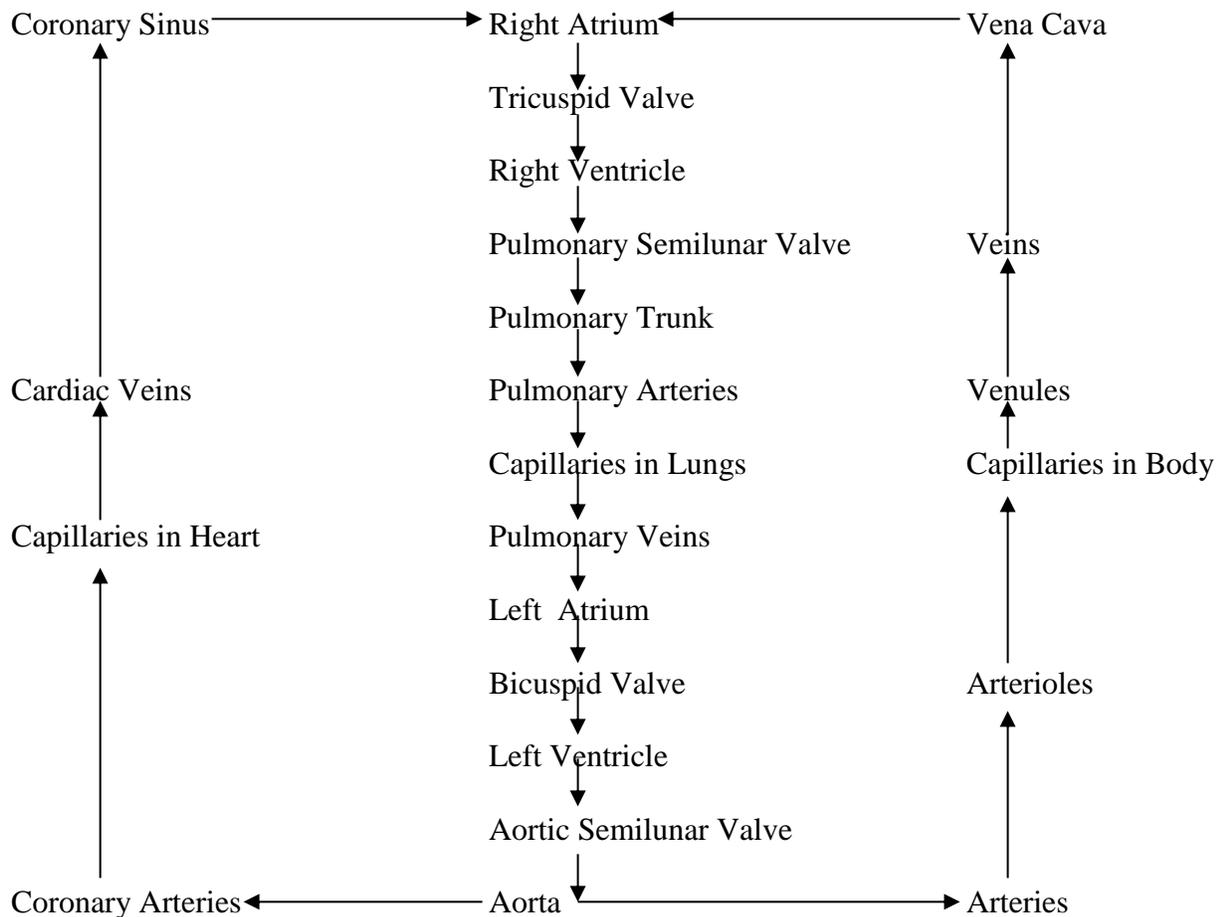
1. The **Atrioventricular Valves** (AV valves)
  - a) There are two, one right and one left
  - b) Separate the atria from the ventricles
  - c) The **tricuspid** valve lies between the right atrium and ventricle
  - d) The **bicuspid** valve lies between the left atrium and ventricle
  - e) The bicuspid is also known as the **Mitral Valve**
  - f) Structures associated with the AV valves:
    - **Chordae Tendineae** = tendon-like, fibrous cords that connect the cusps of the AV valves to the papillary muscles of ventricles, prevents cusps from swinging back into atria
    - **Papillary Muscle** = the muscular columns that are located on the inner surface of the ventricles
  
2. The **Semilunar Valves** (SL valves)
  - a) There are two, one right and one left
  - b) Separate ventricles from major arteries
  - c) The **pulmonary semilunar valve** lies within the pulmonary trunk
  - d) The **aortic semilunar valve** lies with the aorta

#### IV. Blood Flow: The Circulation of Blood

- A. Pathway through the Heart and Lungs: The Pulmonary Circuit
  1. Right atrium (deoxygenated blood)
    - a) Tricuspid valve
  2. Right ventricle
    - a) Pulmonary semilunar valve
  3. Pulmonary trunk
  4. Pulmonary arteries
  5. Alveolar capillaries in lungs
  6. Pulmonary veins
  7. Left atrium
    - a) Bicuspid valve
  8. Left ventricle
    - a) Aortic semilunar valve
  9. Ascending aorta
  
- B. Coronary Circulation: Pathway Through the Myocardium (or how the heart muscle itself is supplied with blood)
  1. Ascending aorta (oxygenated blood)
  2. Coronary arteries (1<sup>st</sup> and 2<sup>nd</sup> branch of aorta)
    - a) Left coronary artery
    - b) Right coronary artery
    - c) **Anastomoses** = connections between two 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 (exchange of gases)
  4. Cardiac veins (deoxygenated blood)
    - a) Great cardiac vein
    - b) Middle cardiac vein
  5. Coronary sinus
  6. Right atrium

### C. Summary of Pulmonary, Coronary and Systemic Circulations



### V. Angina Pectoris and Myocardial Infarction (MI)

- A. Blood clots, fatty atherosclerotic plaques, and smooth muscle spasms within coronary vessels lead to most heart problems
- B. Definitions:
  1. **Ischemia** = reduction of blood flow to a region
  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 and ventricular fibrillation occurs
  - d) Treatments include clot-dissolving agents (TPA and streptokinase) along with blood thinners (heparin) or angioplasty
  
5. **Reperfusion Damage**
  - a) Occurs when a oxygen deprived tissue’s blood supply is reestablished
  - b) Due to the formation of oxygen free radicals
  - c) Damage to enzymes, neurotransmitters, nucleic acids and phospholipids
  - d) Implicated in a number of diseases: including heart disease, Alzheimer’s, Parkinson’s, cataracts, and rheumatoid arthritis
  - e) Anti-oxidants defend the body against this damage and include the enzyme catalase, vitamin E and C, and beta-carotene

## VI. Cardiac Conduction System (CCS)

- A. There are specialized areas of cardiac muscle tissue (1%) in the heart that are conductive and **auto-rhythmic** (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.
  
- B. Components of the CCS:
  1. The **Sinoatrial Node** (S-A Node)
    - a) Located in the right uppermost part of the interatrial septum
    - b) **PACEMAKER** = self-exciting tissue, rhythmic and repeats
    - c) 60-100 per minute, initiates cardiac impulses
    - d) Impulse travels throughout atrial muscle fibers via gap junctions to the A-V Node

2. The **Atrioventricular Node (A-V Node)**
  - a) Located in lower portion of interatrial septum
  - b) Serves as a delay signal that allows for ventricular filling
  - c) The cardiac impulse then travels to the Bundle of His
  
3. The **Atrioventricular (AV) Bundle (Bundle of His)**
  - a) Only electrical connection between the atria and ventricles
  - b) Located in the superior portion of the interventricular septum
  - c) This then splits the impulse into the right and left branches
  
4. The **Right and Left Bundle Branches**
  - a) Lead downward through the interventricular septum toward apex
  - b) The right branch leading to the right myocardium and the left branch leading to the left myocardium
  - c) The impulse finally reaches the Purkinje Fibers
  
5. The **Purkinje Fibers** (Conductive myofibers)
  - a) Large diameter conduction muscle cells
  - 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

## VII. Physiology of Muscle Contraction

- A. Review the differential ion concentrations that maintain a cell's resting membrane potential (RMP)
- B. Series of events:
  1. Rapid depolarization due to opening  $\text{Na}^+$  channels
    - a) Contractile fibers of the heart have a resting potential of  $-90\text{mV}$
    - b) When the potential is brought to  $-70\text{mV}$  by excitation of neighboring fibers, certain sodium channels open very rapidly
    - c)  $\text{Na}^+$  ions (positive charge) rush into cytosol of muscle fibers and produce a rapid depolarization
  
  2. Plateau due to opening of  $\text{Ca}^{++}$  channels
    - a) Calcium ion channels open
    - b)  $\text{Ca}^{++}$  ions enter cytosol of fibers from blood and SR
    - c) Depolarization is maintained for 0.25 seconds
    - d)  $\text{Ca}^{++}$  binds to Troponin, which eventually leads to contraction
  
  3. Repolarization due to opening of  $\text{K}^+$  channels
    - a) Potassium ion channels open
    - b)  $\text{K}^+$  ions diffuse out of muscle fibers, positive charge leaves cells
    - c) Sodium and Calcium channels close
    - d)  $-90\text{mV}$  resting potential is restored

4. Refractory Period = the time following a contraction when a second contraction cannot be triggered
  - a) Longer than a contraction itself
  - b) Necessary for ventricles to relax and fill with blood before again contracting to eject the blood

## VIII. Electrocardiogram (ECG)

- A. ECG = a recording of the electrical activity that occurs in the myocardium during the cardiac cycle
- 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. Rules to remember:
  1. Depolarization precedes contraction
  2. Repolarization precedes relaxation
- E. There are **3** waves per heartbeat
  1. The **P-wave** is a small upward wave
    - a) Represents atrial depolarization
    - b) Spreads from S-A Node throughout both atria
    - c) 0.1 seconds after P-wave begins, atria contract
  2. The **QRS Complex**
    - a) Begins as a downward deflection, continues as a large, sharp, upright triangular wave, ends as a downward wave
    - b) Represents onset of ventricular depolarization
    - c) Spreads throughout ventricles
    - d) Shortly after QRS begins, ventricles start to contract
  3. The **T-wave**
    - a) Domed shaped, low upward deflection
    - b) Represents ventricular repolarization
    - c) Occurs just before ventricles start to relax
    - d) Shape indicates a slow process
  4. Note P-Q Interval and the S-T Segment
- F. Abnormal ECG's
  1. Enlarged P-wave = enlargement of atrium possibly due to mitral stenosis
  2. Enlarged Q-wave = MI
  3. Enlarged R-wave = ventricular hypertrophy

## IX. Cardiac Cycle

### A. Introduction

1. Includes all of the events 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 a chamber relaxes, pressure decreases.
4. Definitions:
  - 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. Specific Phases of the Cardiac Cycle

1. Relaxation (Quiescent) Period (early ventricular diastole)
  - a) Follows T-wave
  - b) Ventricular pressure drops
  - c) Semilunar valves close
  - d) Iso-volumetric relaxation (both atria and ventricles) for a brief time
  - e) When ventricular pressure drops below atrial pressure, AV valves open
  - f) 0.4 seconds
2. Ventricular Filling (mid to late ventricular diastole)
  - a) Rapid ventricular filling occurs just after AV valves open
  - b) Atria had filled during the previous ventricular contraction
  - c) S-A Node fires (P-wave), atria contract and the remainder of ventricular filling occurs
  - d) Atria relax, ventricles depolarize (QRS Complex)
  - e) 0.1 seconds
3. Ventricular Systole
  - a) Impulses passes through A-V Node and then through ventricles
  - b) Ventricles contract
  - c) Ventricular pressure increases rapidly
  - d) AV valves close
  - e) Iso-volumetric Contraction Phase (constant volume) = start of contraction until opening of SL valves = 0.05 seconds
  - f) Ventricular Ejection Phase = opening of SL valves to closing of SL valves
  - g) 0.3 seconds

## X. Heart Sounds

- A. Introduction: 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 (ventricular systole), loud and long
  - 2. **dup** = closing of SL valves (ventricular diastole), short and sharp
- C. If the closing of the valve cusps is incomplete, some blood may leak back = murmur

## XI. Cardiac Output (know terms and abbreviations)

- A. Cardiac Output (**CO**) = the volume of blood pumped by each ventricle in one minute
- B. Heart Rate (**HR**) = the number of beats per minute
- C. Stroke Volume (**SV**) = volume of blood pumped out by a ventricle with each beat
- D.  $CO = \text{Heart Rate (HR)} \times \text{Stroke Volume (SV)}$
- E. Normal CO = 5 liters

## XII. Regulation of the Cardiac Cycle / Heart Rate

- A. Autonomic Nervous System (medulla oblongata of brainstem)
  - 1. Parasympathetic decreases (normal)
  - 2. Sympathetic increases (stressful)
- B. Chemicals
  - 1. Hormones (epinephrine increases)
  - 2. Ions (calcium increases, potassium and sodium decreases)
- C. Age = decreases
- D. Sex (gender)
  - 1. Females = increased
  - 2. Males = decreased
- E. Temperature
- F. Emotions
- G. Disease