

TOPIC 14: CARDIOVASCULAR SYSTEM: ANATOMY & ELECTRICAL ACTIVITY OF THE HEART

(All cd references refer to Interactive Physiology cd, Cardiovascular menu)

I. Introduction to circulatory system

- A. Overall function
 1. Need to get nutrients and oxygen to all cells in body
 2. Need to remove wastes from all cells in body
 3. Blood is transport medium which does this
 4. So need to get blood to pass by all cells in body
- B. Circulatory System consists of 3 components
 1. **Heart:** acts as a pump for blood (Topics 14 & 15)
 2. **Blood vessels:** passageways for blood (Topic 16)
 3. **Blood:** transport medium (Topic 17)
- C. Circulatory System has two separate loops (Fig 13.2)
 1. **Pulmonary:** blood movement between heart and lungs
 2. **Systemic:** blood movement between heart and all other parts of body

II. Structure of heart (cd: Anatomy Review: 3, 4, 5, 7)

- A. Location in body
 1. Size of clenched fist, located in chest cavity, midway between sternum and backbone
 2. Broad base at top of heart, tapers to an apex at bottom
 3. Top lies to right of sternum, apex is to left of sternum
- B. Heart as a dual pump (Figs 13.2)
 1. Divided into 2 halves separated by muscle wall
 - a) each half functions as a *separate* pump
 - b) **Right side receives blood from systemic** circulation and **pumps it to pulmonary** circulation so that the blood can be oxygenated
 - c) **Left side receives blood from pulmonary** circulation and **pumps it to systemic** circulation so that rest of body gets freshly oxygenated blood
 2. Each half divided into two chambers
 - a) upper chamber is called **atrium** (atria is plural) and receives blood returning to heart and transfers it to the
 - b) lower chamber, called **ventricle**, pumps the blood out of the heart
 3. Blood vessels that return blood to heart are called **veins**
 - a) **venae cavae** brings blood from systemic circulation to heart
 - b) **pulmonary veins** brings blood from lungs to heart
 4. Blood vessels that carry blood away from heart are called **arteries**
 - a) **aorta** carries blood from heart to systemic circulation
 - b) **pulmonary artery** carries blood from heart to lungs
 5. Blood flow in circulatory systems (fig. 13.3)
 - a) pulmonary: *all* blood flows through lungs
 - b) systemic: blood divided up among different body systems (i.e., one drop of blood visits only one body tissue/trip, not all tissues/trip)

- c) both sides of heart simultaneously pump equal amounts of blood
 - (1) pulmonary circulation is low pressure, low resistance
 - (2) systemic circulation is high pressure high resistance
 - (3) hence the left side of heart performs more work & the heart muscle on the left is much thicker
 - C. One-way blood flow in heart
 - 1. Blood flow in heart is in one fixed direction
 - a) requires valves to prevent backflow
 - 2. Four one way valves (Fig 13.7 & 13.8)
 - a) Open and close passively because of pressure differences
 - (1) forward pressure gradient open valves
 - (2) backward pressure gradient closes valves
 - b) Two atrioventricular (AV) valves
 - (1) one on each side of heart between atrium and ventricle
 - c) One aortic valve
 - (1) junction of left ventricle and aorta
 - d) One pulmonary valve
 - (1) junction of right ventricle and pulmonary artery
 - e) No valves between atria and veins
 - (1) backflow not a problem because atrial pressure not higher than venous pressure, and entry sites of vein into atria are compressed during atrial contraction
 - D. Cardiac muscle: Myocardium
 - 1. Structure
 - a) cardiac muscle fibers interlaced & arranged spirally around circumference of the heart
 - b) During ventricular contraction, diameter of chambers reduced, and apex is pulled upwards; wrings blood out of chambers
 - 2. Interconnections of cardiac muscle cells (Fig 13.9)
 - a) adjacent cells joined end to end
 - b) joining point, called intercalated discs, composed of
 - (1) gap junctions (allows AP to pass from cell to cell) (but no gap junctions between atrial and ventricular cells; hence APs can not be passed directly between atria & ventricles)
 - (2) desmosomes (good at holding cells together under mechanical stress)
- III. Electrical and contractile activity of heart cells (cd: Cardiac Action Potential 5 through 17)
- A. Two types of myocardial cells
 - 1. 99% are **contractile cells** which do mechanical work of pumping
 - 2. 1 % are **autorhythmic cells** which are specialized for initiating and conducting action potentials
 - B. Autorhythmic cell action potentials (Fig 13.12)
 - 1. Initial phase of slow depolarization caused by a decrease in passive outward leak of K^+ by K^+ channels closing in membrane and an increase in Na^+ leaking into the cell; inside of cell slowly becomes more positive & drifts toward threshold

2. Eventually a voltage is reached that allows voltage gated Ca^{++} T-type channels to open, and Ca^{++} begins to enter the cell, causing it to reach threshold
 3. At threshold voltage gated Ca^{++} L-type channels open, and Ca^{++} rushes in, depolarizing the membrane rapidly; this causes an action potential
 4. Membrane repolarizes by exit of K^+ from cell as K^+ channels are opened.
- C. Contractile cell action potentials (Fig 13.13)
1. AP in contractile cells are quite different than in cardiac autorhythmic cells
 2. When an AP reaches a contractile cardiac cell via a gap junction, Na^+ channels open wide and Na^+ rushes into cell. This results in depolarization of membrane. Na^+ channels then close around +30 mv.
 3. Depolarization of membrane causes opening of slow Ca^{++} channels, and Ca^{++} moves slowly into cell. In addition, depolarization causes K^+ channels to inactivate.
 4. These two mechanisms work together to create the plateau phase of the AP.
 5. Repolarization eventually occurs as Ca^{++} channels close, and K^+ channels open and K^+ moves out of cell.
- D. Molecular basis of contractile cell contraction (Fig 13.14)
1. AP moves across cell membrane, and Ca^{++} enters cell from ECF (as in smooth muscle)
 2. AP also moves down into T tubules and causes release of Ca^{++} from SR (as in skeletal muscle)
 - a) All this Ca^{++} entering contributes to plateau phase, as well as to prolonged contraction of cardiac muscle (about 3 times longer than skeletal muscle contraction)
 3. Ca^{++} binds to troponin, and tropomyosin moves away from binding sites on actin, allowing cross bridge cycling as in skeletal muscle.
 4. Ca^{++} eventually removed by active transport, and muscle relaxes.
 5. Long refractory period of cardiac AP and muscle contraction prevents tetanus of cardiac muscle: tetanus of cardiac muscle would cause death!
- IV. Electrical Activity of Entire Heart (cd: Intrinsic Conduction System 3 through 6)
- A. Autorhythmic regions of heart (Fig 13.10)
1. sinoatrial node (**SA node**) in right atrial wall near opening of superior vena cava. AP/min: 70-80. *This is the pacemaker of the heart under normal conditions & sets AP pace of whole heart.*
 2. atrioventricular node (**AV node**) at base of right atrium near the septum, just above atria-ventricles junction. AP/min: 40-60. In normal conditions helps spread AP to ventricles from right atrium.
 3. **bundle of His** is a tract of specialized cells that originates in AV node and travels around the tip of the ventricles. AP per min: 20 to 40. Under normal conditions helps spread AP to rest of ventricles.
 4. **purkinje fibers**: small terminal fibers extending from bundle of His. Under normal conditions helps spread AP to rest of ventricles.
- B. Spread of Action Potential in Heart (Fig 13.11)
1. SA node in right atrium initiates an AP

2. AP spreads through both atria via gap junctions between atrial cells. The interatrial pathway extends from SA node to left atrium; the AP moves rapidly through to the left atrium, so that left and right atria contract simultaneously.
 3. AP spread to AV node from SA node via the internodal pathway. Because atria are connected to ventricles by non-conducting tissue, AP has to go through AV node to get to ventricles.
 4. AP travels slowly through the AV node, which allows time for complete ventricular filling. The AV nodal delay is about 0.1 second, which is enough time for atria to contract & empty their contents into ventricles.
 5. AP goes from AV node through the bundle of His and through Purkinje fibers throughout ventricular myocardium. This rapid conduction of AP to all parts of ventricles allows for a coordinated ventricular contraction to eject blood from ventricles
- C. Electrocardiograms (ECG or EKG)
1. What an ECG represents
 - a) recording heart electrical activity that reaches body surface; it is NOT a direct recording of actual heart electrical activity
 - b) recording of overall spread of electrical activity throughout heart, NOT a single AP in the heart.
 - c) recording represents comparisons in voltage detected by electrodes on 2 different parts of body surface, NOT the actual potential
 2. ECG trace (Fig 13.16)
 - a) P wave: atrial depolarization
 - b) PR segment: AV nodal delay
 - c) QRS complex: ventricular depolarization (note that atrial repolarization occurs at the same time)
 - d) ST segment: ventricles are contracting and emptying
 - e) T wave: ventricular repolarization
 - f) TP interval: ventricles are relaxing (and passively filling)