Module 8 – The Cardiac Cycle

Principal Functions of the Cardiovascular System

1. Transports oxygen and nutrients to all cells of the body
2. Transports carbon dioxide and waste products from the cells
3. Helps regulate body temperature and pH
4. Transports and distributes hormones and other substances thoughout the body

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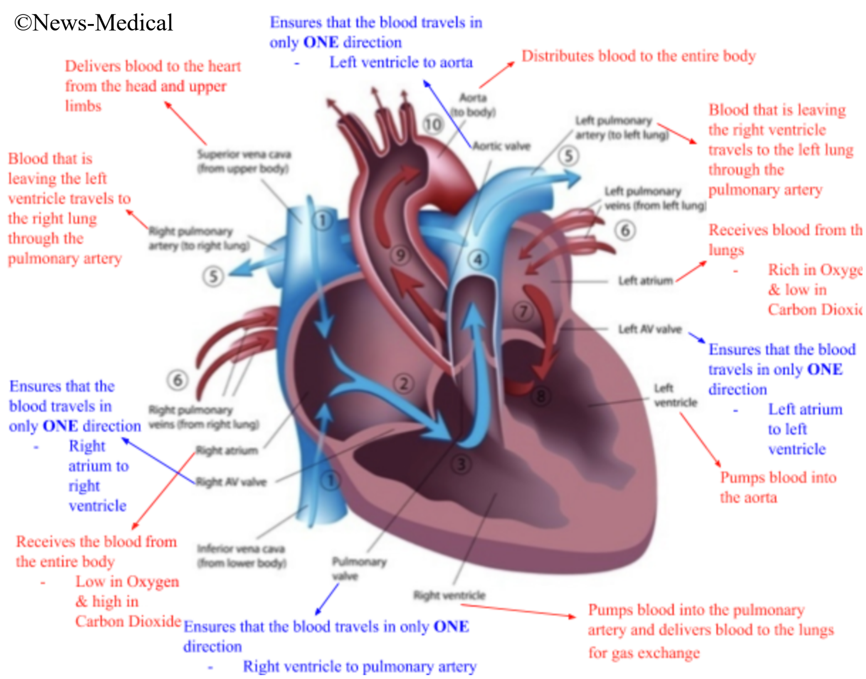


Pathway of Blood in the Heart

Superior Vena Cava → Right Atrium → Tricuspid Valve → Right Ventricle → Pulmonary Valve → Pulmonary Artery → Lungs → Pulmonary Vein → Left Atrium → Bicuspid Valve → Left Ventricle → Aortic Valve→ Aorta → Body

SA Node Action Potential:

1. Pacemaker potential ***depolarizes*** the membrane to threshold (-40mV)
2. Voltage-gated Ca++ channels open and Ca++ enters the cell leading to depolarization
3. Ca++ channels close as voltage-gated K+ channels begin to open, moving K+ out of the cell leading to repolarization (+20mV)
4. After repolarization, the pacemaker potential begins depolarizing the membrane again

Pathway of the Action Potential

SA Node → Atrial Muscle → AV Node → Each branch of Bundle of His → Apex of the Heart → Purkinje Fibers → Ventricular Muscle

Myocardial Cells:

1. **Contractile Cells**
   - Forms most of the walls in the ***atria*** and ***ventricles***
   - Contain the same contractile proteins (actin and myosin) arranged in bundles of myofibrils surrounded by a sarcoplasmic reticulum
   - Cells are joined together by **intercalated discs**
2. **Nodal/Conducting Cells**
   - Contracts weakly as it contains very few contractile elements
   - Able to ***spontaneously*** generate action potentials without nervous input like regular neurons and conduct action potentials to atrial and ventricular muscles ***rapidly***

Origin of Self-Excitability:

- **Sinoatrial Node (SA Node)** located in upper posterior wall of the right atrium

Characteristics of the SA Node Leading to Self-Excitability:

- **Na+** permeability in the SA node is slightly ***higher*** than other cells
- **Ca++** permeability in the SA node is also higher
- **Movement of K+ out** of the cell causes hyperpolarization/repolarization
- ***Decrease*** in K+ permeability occurs as action potential reaches threshold

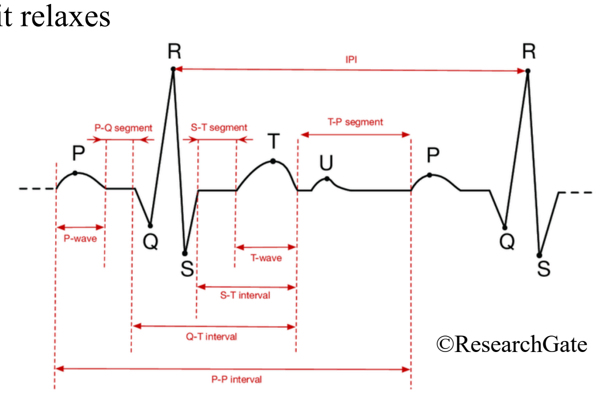
Electrocardiogram (ECG)

A recording of the electrical potentials generated by the heart through placing electrodes on the external skin around the heart

P wave – electrical activity associated with the depolarization of the atrial muscles, resulting in contractions

QRS complex – depolarization of the ventricular muscle *prior* to its contraction

T wave – repolarization of the ventricular muscle as it relaxes



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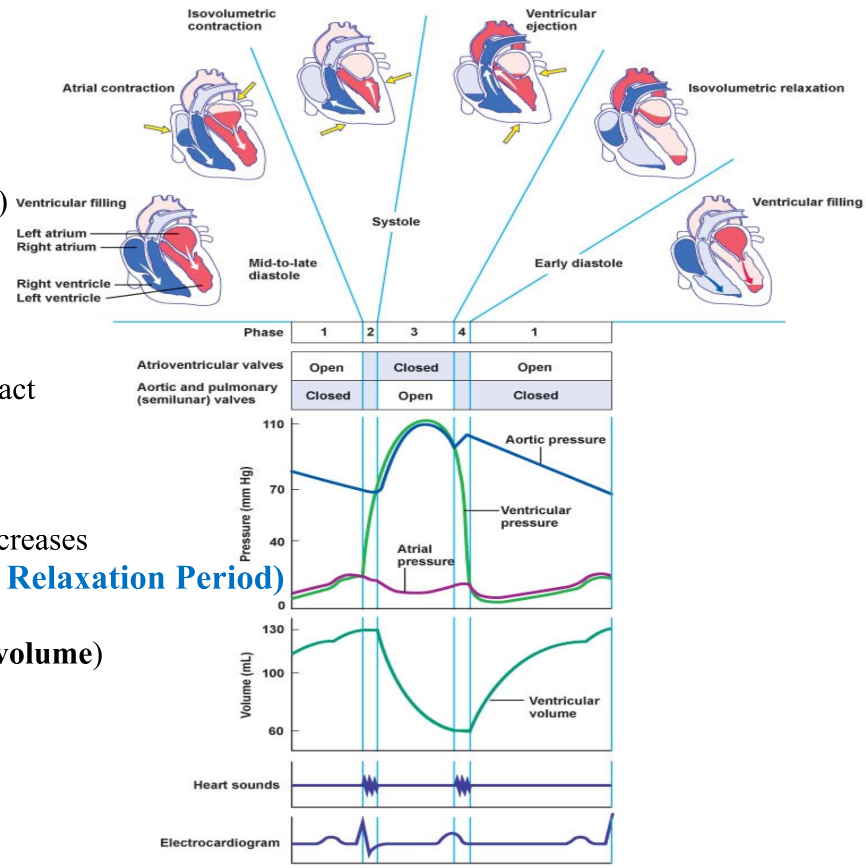
Cardiac Cycle



1. Atrial Systole
- Atria contract and complete ventricular filling
- Ventricular volume ↑ slightly (**end diastolic vol**)
- Depolarization of atria (**P wave**)

2. Isovolumetric Ventricular Contraction
- Mitral (AV) valve closes
- No change in ventricular volume
- Ventricles depolarize (**QRS complex**) and contract

3. Ventricular Systole (Ejection Period)
- Ventricles still contracting
- Aortic valve opens
- Blood flows into aorta → ventricular volume decreases

4. Early Ventricular Diastole (Isovolumetric Relaxation Period)
- Aortic valve closes
- Some blood remains in ventricles (**end systolic volume**)
- Ventricular volume doesn't change

5. Late Ventricular Diastole
- Mitral valve opens → blood flows into ventricle
- Ventricular volume increases (**P wave *begins***)
- Cycle repeats

	Atrial Systole	Isovolumetric Ventricular Contraction	Ventricular Systole	Early Ventricular Diastole	Late Ventricular Diastole
Chambers	Atria contract Ventricles relaxed	Atria relaxed Ventricles begin contracting	Atria relaxed Ventricles contract	Atria relaxed Ventricles relax	Atria relaxed Ventricles relaxed
Blood Flow	From atria to ventricles	None	From ventricles to aorta	None	From atria to ventricles
Pressure change	Atrial > Ventricular	Ventricular > Atrial	Ventricular > Aortic	Aortic > Ventricular > Atrial	Atrial > Ventricular
Valves	AV valve open Aortic valve closed	AV valve closes Aortic valve closed	AV valve closed Aortic valve opens	AV valve closed Aortic valve closes	AV valve opens Aortic valve closed

CO = HR X SV

SV = EDV – ESV

End diastolic volume (EDV*)* – blood in ventricle at the end of diastole (~120mL)
End systolic volume (ESV) – blood in ventricle at the end of systole (~50mL)

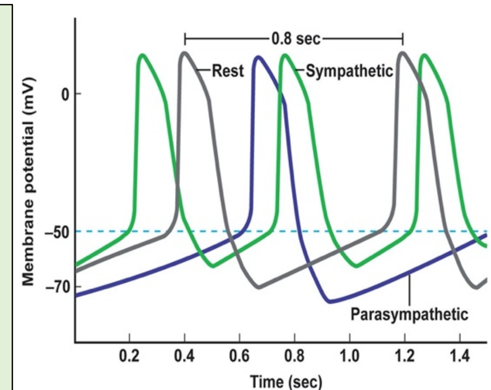
Altering Heart Rate

Parasympathetic: ↓ HR to *70bpm*

1. Release ACh onto SA and AV nodes
   - ↑ ***K^+ permeability***, ↓ Na^+ and Ca^{2+} permeability.
   - K^+ moves *out* of the cell causing ***hyperpolarization*** → ↓ AP
2. Slows down APs at the AV node because atria need to finish contracting before ventricles can begin contractions
3. Decreases slope of pacemaker potential = ↓ AP

Sympathetic: ↑ HR

1. Release epinephrine (or norepinephrine) onto SA
   - ↑ ***Na^+ and Ca^{2+} permeability***
   - Cells ***depolarize*** → ↑ AP
2. Threshold is reached much faster
3. Increased slope of pacemaker potential



Altering Stroke Volume

Sympathetic: ↑ HR 1. Release norepinephrine onto muscle cells: ○ ↑ ***Ca^{2+} entry into muscle cells*** ○ ↑ contraction force and SV	**Increase EDV = increase SV** 1. **Constrict veins to ↑ venous return** ○ Sympathetic NS innervates smooth muscle in veins 2. **Exercising** ○ Repeatedly squeeze veins that run in between large groups of muscle ○ Known as "**muscle pump**"
Parasympathetic: ↓ HR to *70bpm* 1. Release ACh onto cardiac muscle: ○ ↓ ***Ca^{2+} enters the muscle cells*** ○ ↓ contraction force and SV	

EDV and Preload

- **Preload** – load on heart just before it contracts (keep definition formatting
- Blood in ventricles stretches heart muscle
- ***Higher EDV*** = ↑ Preload
    - ***Ca^{2+} channels open***
    - ↑ contraction force and SV
    - More blood ejected = ↓ ESV = ↑ SV

Frank-Starling Law

- Increase EDV → increase SV and ***vice versa*** (because of EDV and preload mechanism)
- More blood in ventricle → more forceful contraction → more blood out → higher SV

Review Questions

1. How can we alter the heart's performance? *Recall the formula $CO = HR \times SV$
    a. Change the heart rate.
    b. Change the amount of blood pumped out (stroke volume).
    c. All of the above.
    d. None of the above.

2. Why is the sinoatrial (SA) node of the heart called the pacemaker?
    a. It is located in the left atrium.
    b. Its pacemaker potential has the fastest spontaneous depolarization rate compared to other areas of the heart.
    c. Force of contraction in the atria is more powerful than that in the ventricles.
    d. The SA node is innervated by both the parasympathetic and sympathetic nervous system.

3. In regards to the conducting system in the heart, which of the following statements are correct? Select the correct answer(s).
    1. The conduction of the action potential through the AV node is faster in order to ensure that the atria have fully contracted prior to ventricular contraction.
    2. The atrial action potential is slower than the SA nodal action potential.
    3. The Bundle of His conducts the action potential between the SA node and the AV node.
    4. The Purkinje Fibers conduct the action potential at the fastest rate compared to other regions of the heart.

    a. 1 & 3 only
    b. 1, 2, & 3 only
    c. 2 & 4 only
    d. 4 only

4. The P wave of the ECG represents:
    a. Ventricular depolarization
    b. SA node excitation
    c. Atrial depolarization
    d. Atrial Systole

5. After the second heart sound, which heart valves are open?
    a. Both atrioventricular and semilunar valves are open
    b. Semilunar valves only
    c. Atrioventricular valves only
    d. All valves are closed

6. What is true regarding the atrial systole phase of the cardiac cycle?
    a. Atria contract and ventricles relax; both AV and semilunar valves are open
    b. Atria and ventricles are both relaxes; both AV and semilunar valves are open
    c. Atria contract and ventricles relax; AV valves open and semilunar valves are closed
    d. Atria contract and ventricles relax; AV valves closed and semilunar valves are open

Answer Key:
1. C 2. B 3. D 4. C 5. D 6.C