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Cardiovascular Electrophysiology

Primary Care Paramedicine

Module: 12

Section: 04

Electrophysiology

- Goals
  - Myocardial action potential
  - Electrical components of the heart
  - Components of an Electrocardiogram
  - 3-lead rhythm interpretation

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Cardiovascular Electrophysiology

MYOCARDIAL ACTION POTENTIAL

Myocardial Action Potential

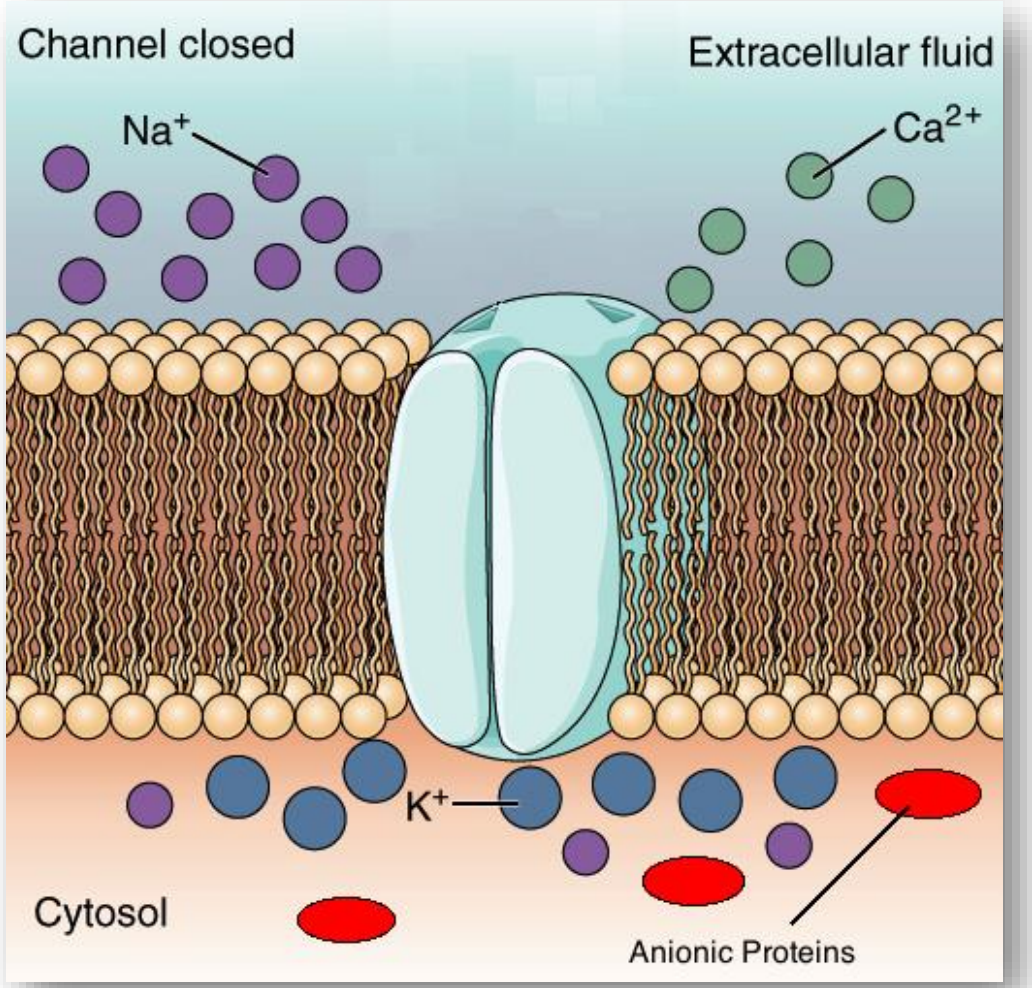
- Cardiac muscle tissue is comprised of unique muscle cells called cardiomyocytes
- Stimulation for contraction occurs in a similar fashion to that of skeletal or smooth muscle cells, however cardiac myocytes have some unique properties.
  - Prolonged action potential
  - Opening of Ca^{2+} channels

Myocardial Action Potential

- As is the case with other action potentials in the body, the presence of electrolytes in their respective intracellular and extracellular fluids is key
  - Intracellular: K^+, negatively charged proteins
  - Extracellular: Ca^{2+}, Na^+, Cl^-
- When electrolytes are in their normal locations, gradients are established
  - Concentration gradient
  - Electrochemical gradient

Myocardial Action Potential

- Difference in concentration of electrolytes between ECF and Cytosol create concentration gradient
- Difference in overall charge across the membrane gives rise to an electrochemical gradient



Resting Membrane Potential

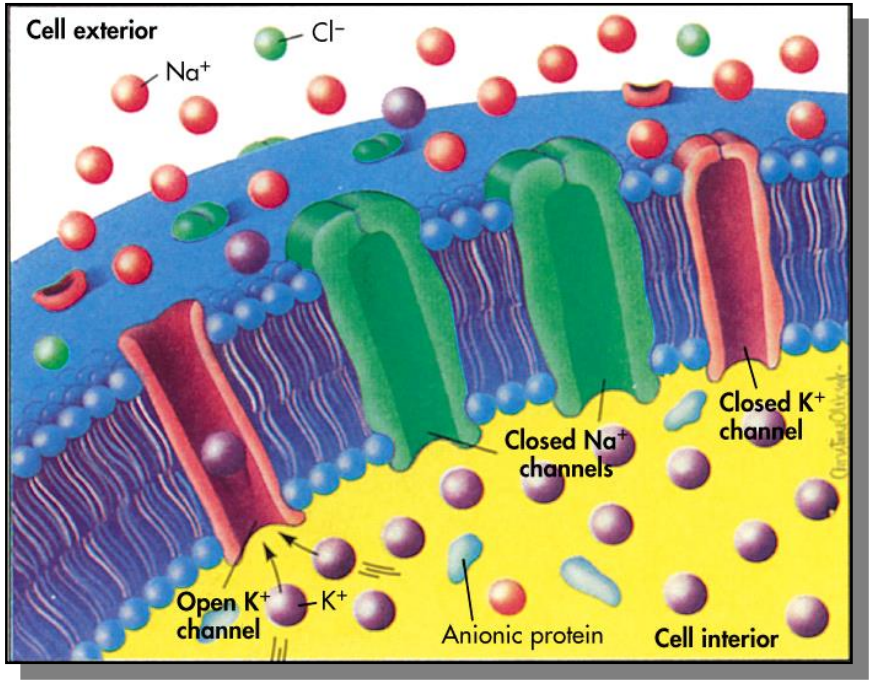
- When not stimulated, the cardiomyocyte is said to be at Resting Membrane Potential
- At this time the inside of the cell (cytosol) is more negatively charged than the outside (ECF)
  - The difference in charge from one side of the membrane to the other is -90 mV (RMP)
  - Cytosol negative due to anionic proteins and passive ‘leaking’ out of K^+ into ECF

Resting Membrane Potential

- With more positive charge in the ECF and more negative charge in the cytosol the membrane is now polar
- When the charges on either side of the membrane are equal the membrane is non polar.
- The process that changes the membrane from polar to non polar is called depolarization
- A process that converts the membrane back to polar is called repolarization

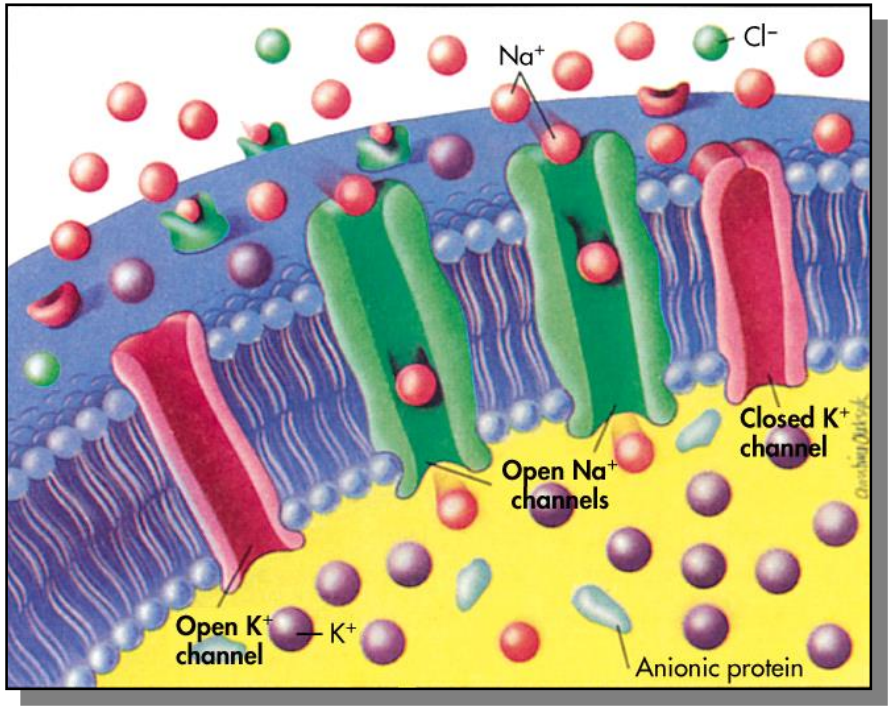
Ion Channels

- Cell membrane is selectively permeable
  - Relatively permeable to K^+
  - Less permeable to Ca^{2+}
  - Minimally permeable to Na^+
- Transmembrane transport proteins allow for movement of non-permeable ions through the membrane
  - Open/close based on voltage created from electrochemical gradient



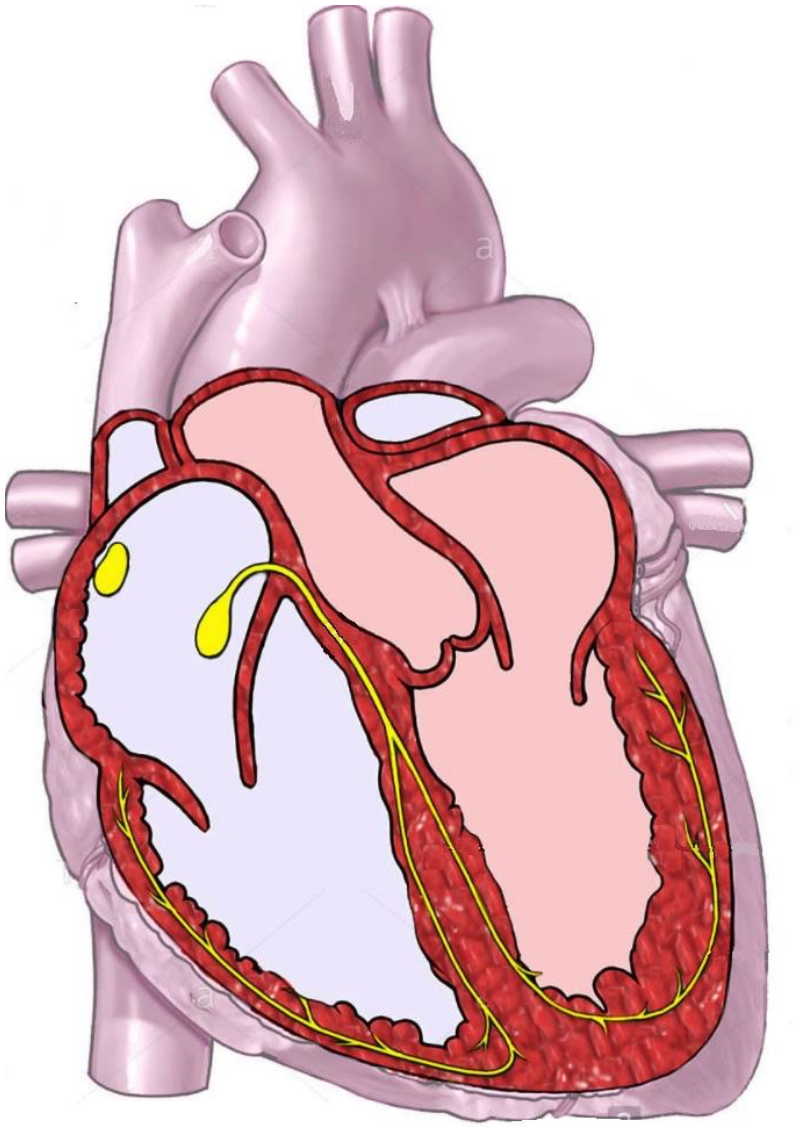
Ion Channels

- Some channels, when open, allow for rapid movement of electrolytes (“fast channels”)
- Other channels only allow reduced flow of electrolytes (“slow channels”)



Impulse Initiation

- There are 2 types of cardiomyocytes:
  - Pacemaker cells
  - Non-pacemaker cells

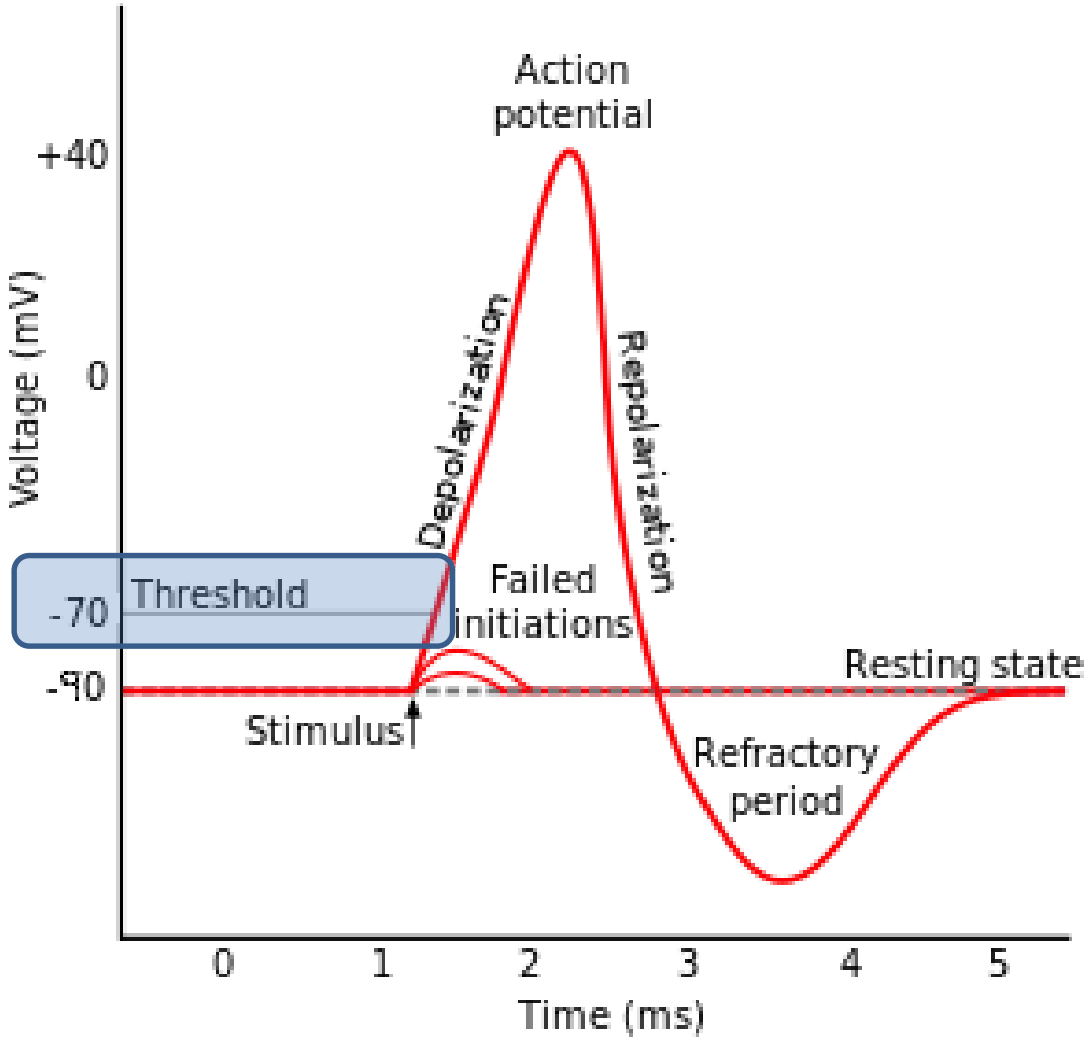


Impulse Initiation

- Pacemaker cells
  - Impulse initiation is accomplished by the individual cell (i.e. no external stimulus)
    - This gives rise to the unique property of cardiac muscle tissue known as Automaticity
- Non-pacemaker cells
  - Receive stimulation from other cardiomyocytes (pacemaker cells) or nerve cells to initiate an impulse
- In either case, once an impulse has been initiated an Action Potential has begun

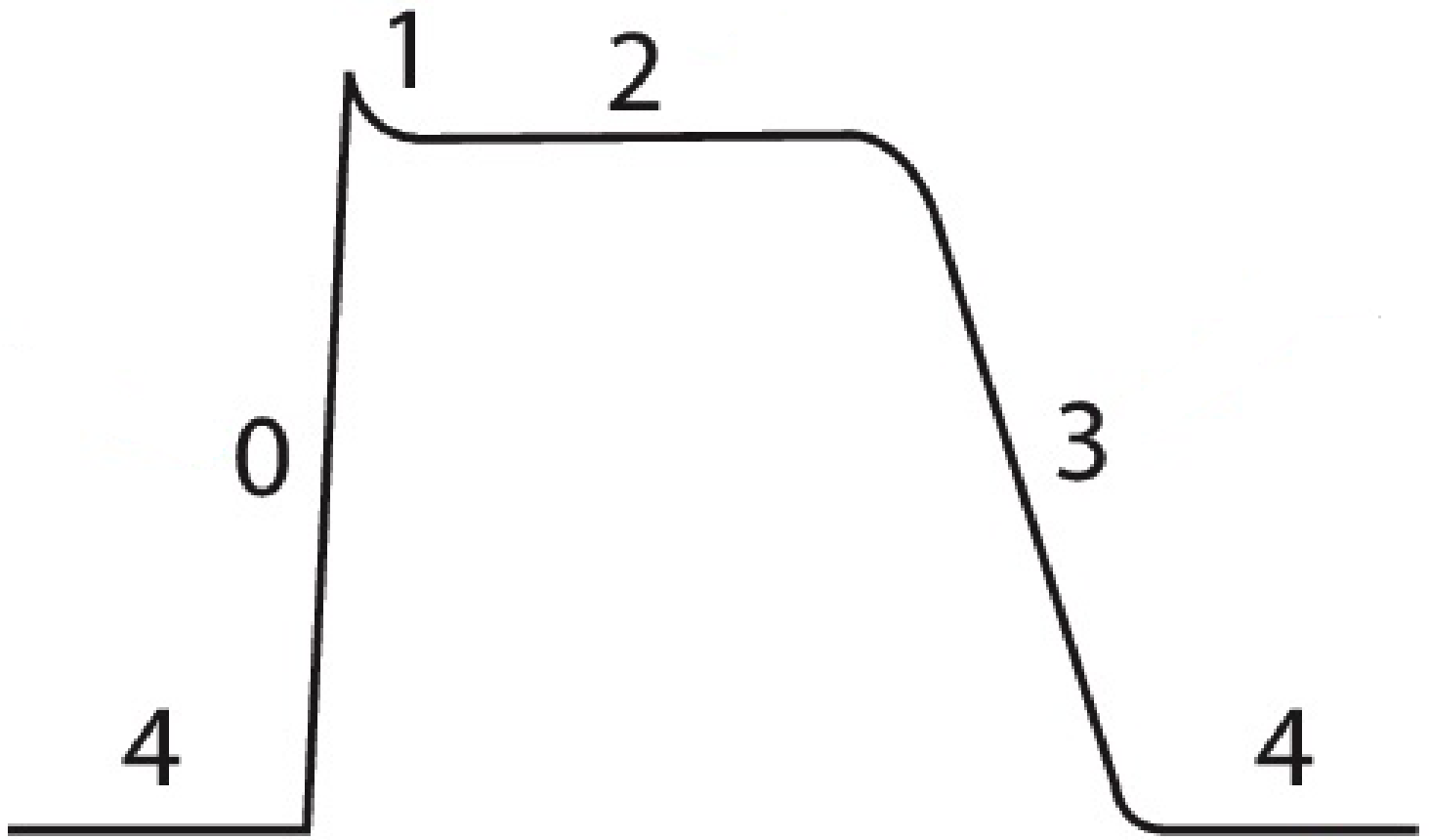
Threshold Potential

- As is the case with skeletal muscle, not all impulses result in cardiomyocyte contraction
  - The impulse must be great enough to overcome the Threshold Potential
    - For cardiomyocytes this value is -70 mV



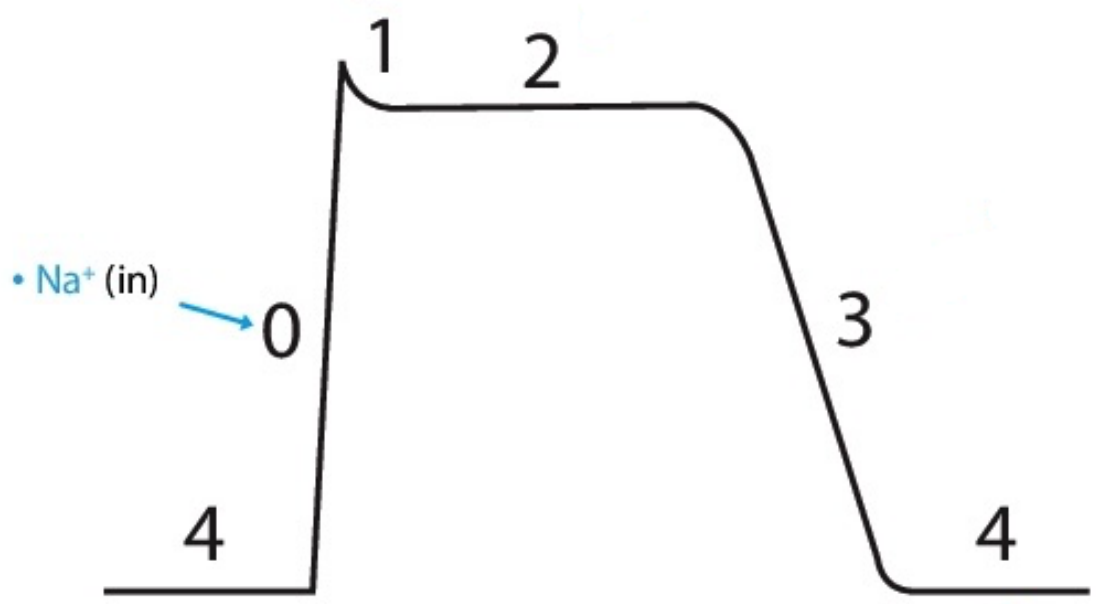
Cardiac Action Potential

- Cardiac action potential is divided into five phases
  - Phase 0
  - Phase 1
  - Phase 2
  - Phase 3
  - Phase 4



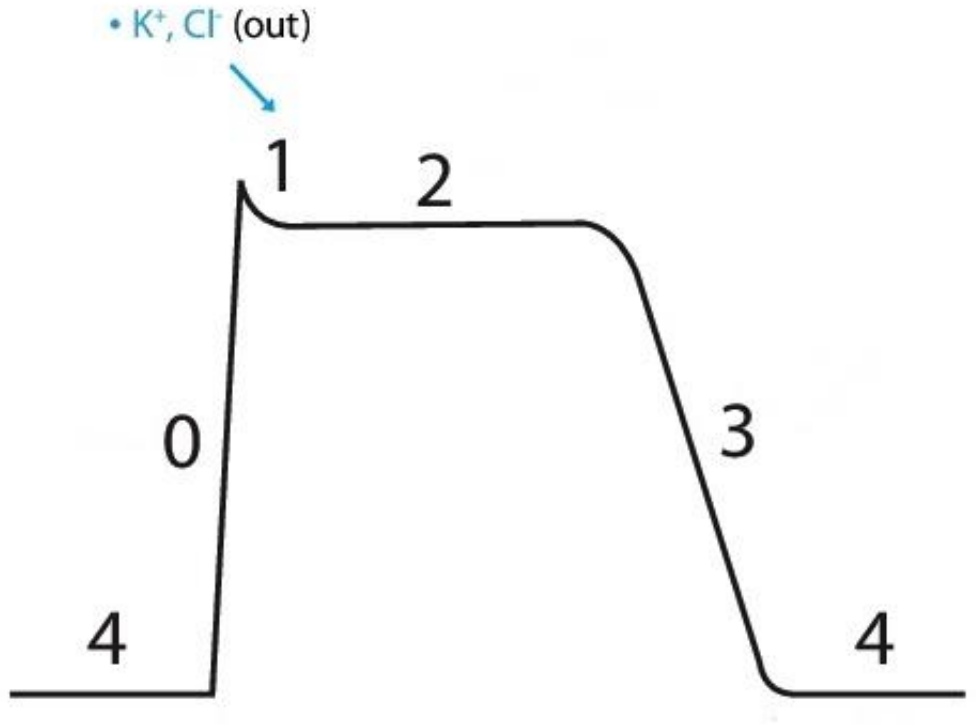
Phase 0
Rapid Depolarization Phase

- As the membrane reaches the threshold potential, fast Na+ channels open allowing for fast influx of Na+ into the cytosol
- The previously negative cytosol becomes more positive and closer in charge to that of the ECF
- This causes the membrane to be less polar = **depolarization**



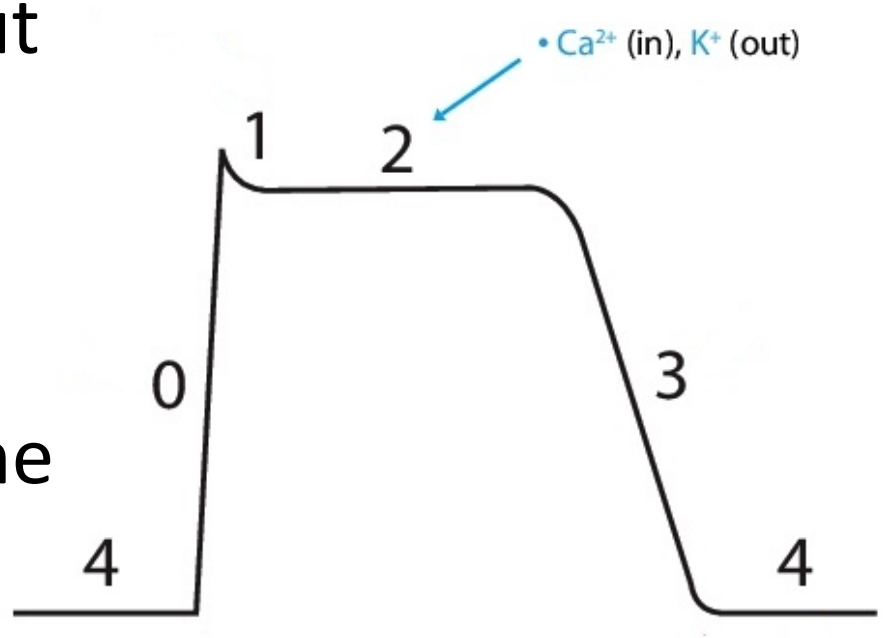
Phase 1
Early Repolarization Phase

- After the large influx of Na+ into the cytosol, the membrane potential has now increased to become slightly positive
- This means there is now more positive charge in the cytosol compared to the ECF
- This voltage change causes K^+ channels to open and increases movement of K^+ from the cytosol to the ECF
- This movement starts the membrane back towards the RMP and therefore is **repolarization**



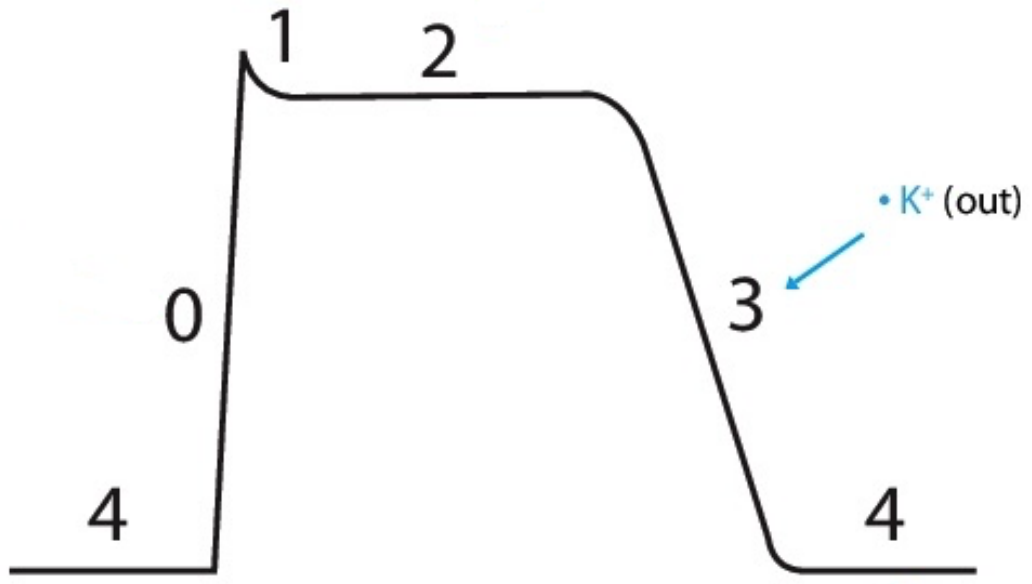
Phase 2
Plateau Phase

- Ca^{2+} channels open and Ca^{2+} starts to enter the cell
- This keeps the inside of the cell positive longer, prolonging the process of repolarization
- During this time, K^+ is still also leaking out of the cell
- This movement of positive charge in (Ca^{2+}) and positive charge out (K^+) counteract each other and the membrane potential is unchanged (plateau)



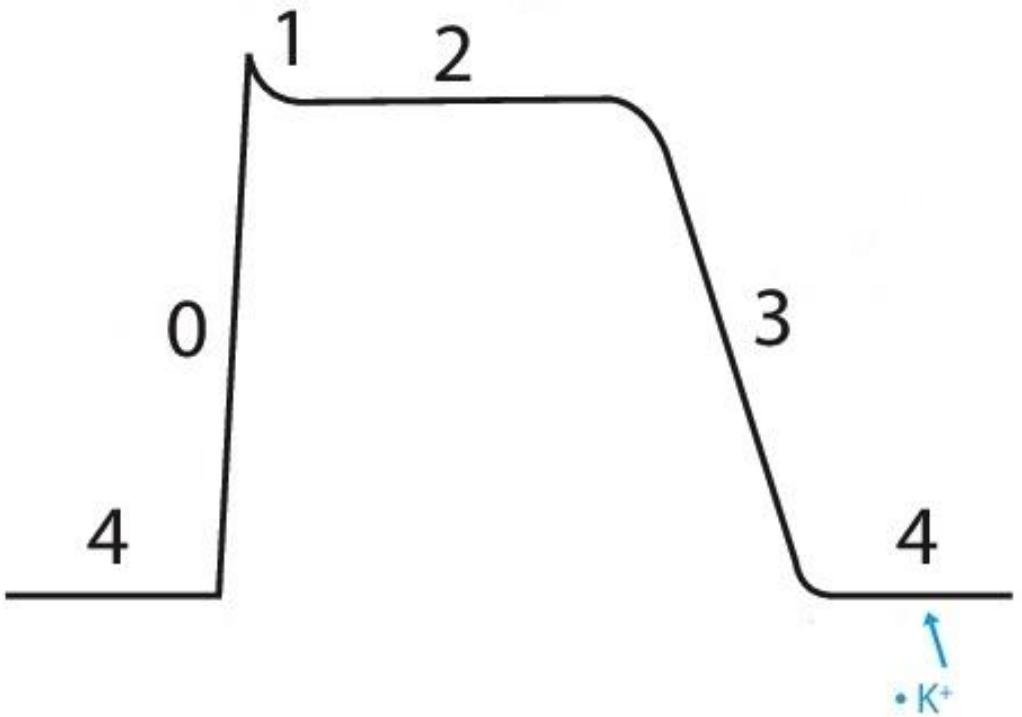
Phase 3
Terminal Repolarization Phase

- Ca^{2+} channels close and membrane becomes even more permeable to K^+
- Causes large decrease in positive charge in the Cytosol
- Results in the membrane potential returning back toward a negative value
- Ends when membrane potential returns to RMP and the membrane is once again polar



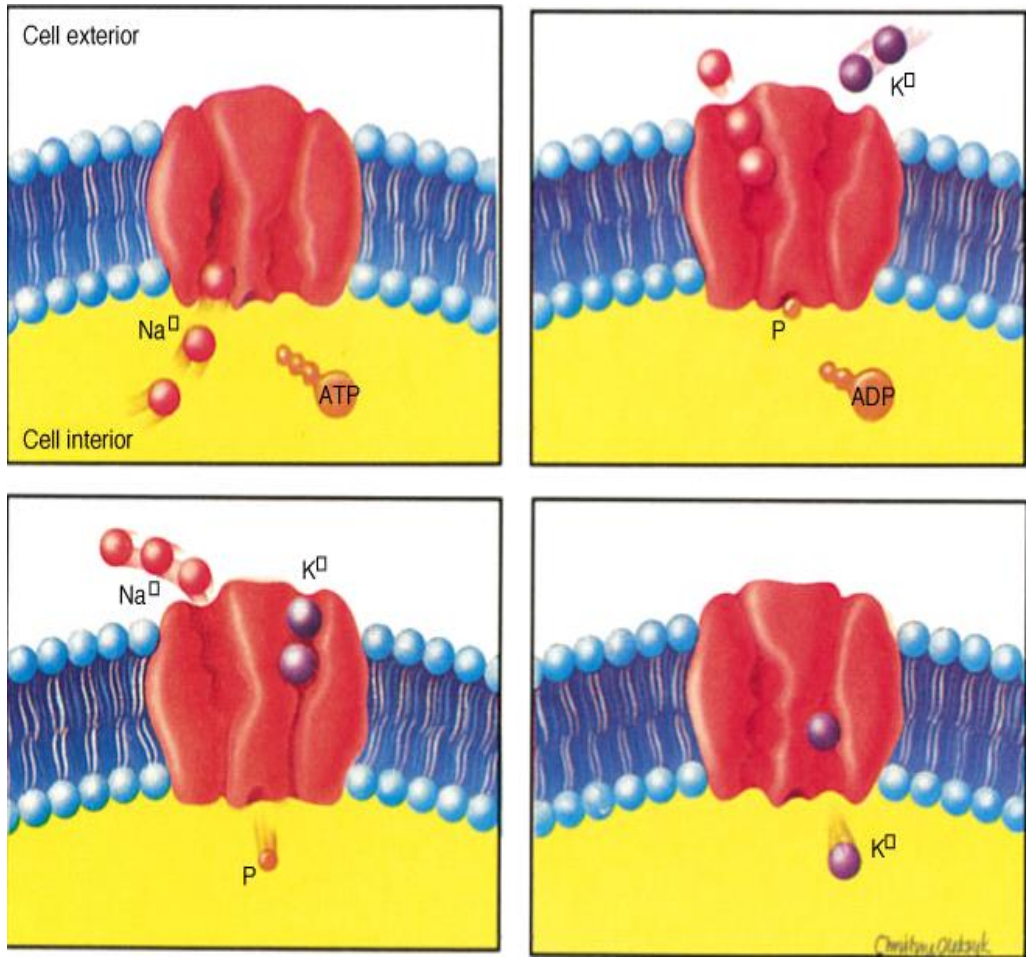
Phase 4
Resting phase

- At the end of an action potential, the membrane is back to RMP, however the electrolytes are not in their proper locations
- Na^+ and Ca^{2+} are primarily in the Cytosol and K^+ is primarily in the ECF
- During this phase, 3 pumps exchange electrolytes across the membrane to restore them to the correct locations

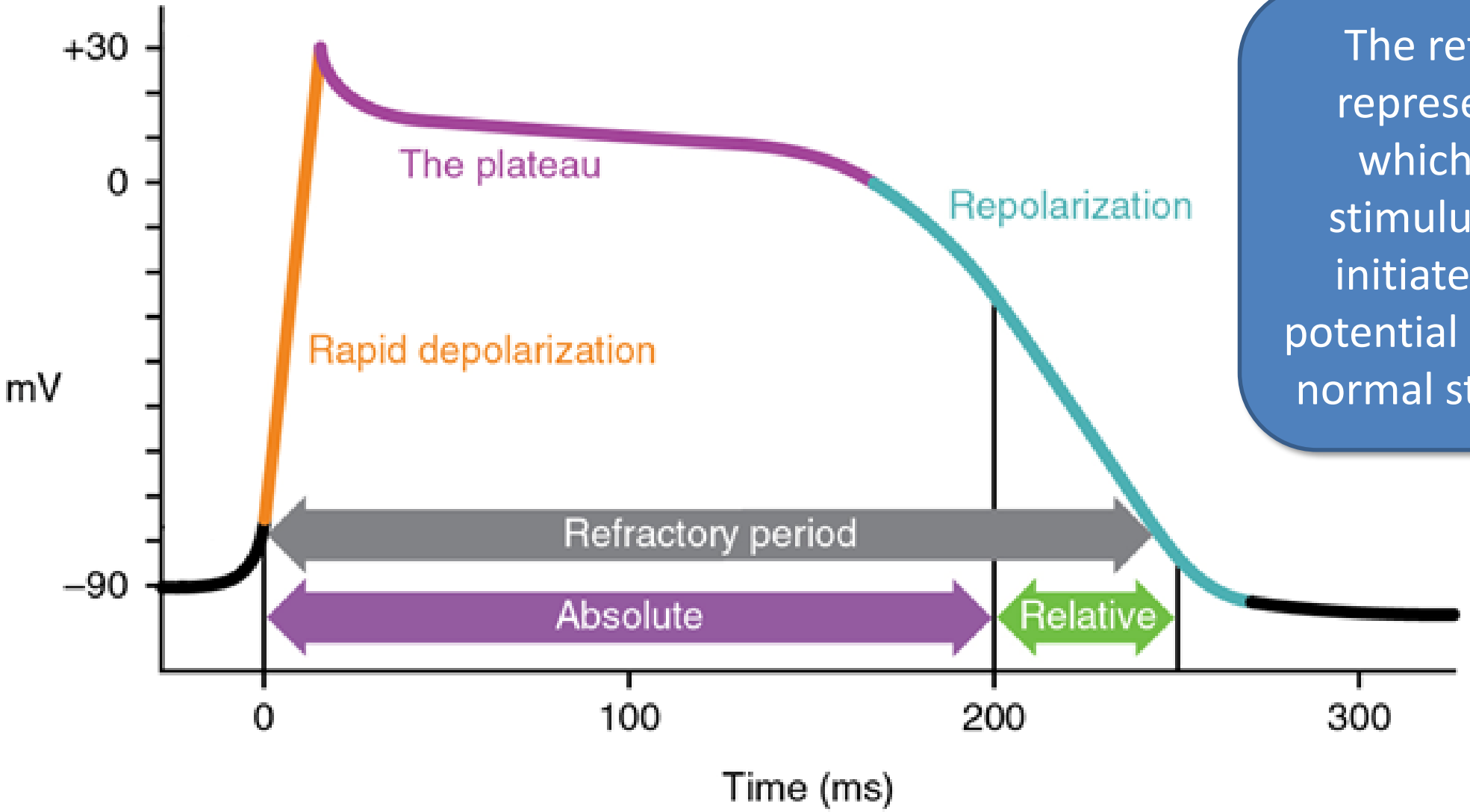


Phase 4
Na-K Pump (Na+/K+-ATPase)

- Na^+/Ca^{2+} exchanger moves Na^+ and Ca^{2+} back into ECF
- Ca^{2+} ATPase moves Ca^{2+} back into ECF
- Na^+/K^+ ATPase moves Na^+ back into ECF and K^+ back into the Cytosol

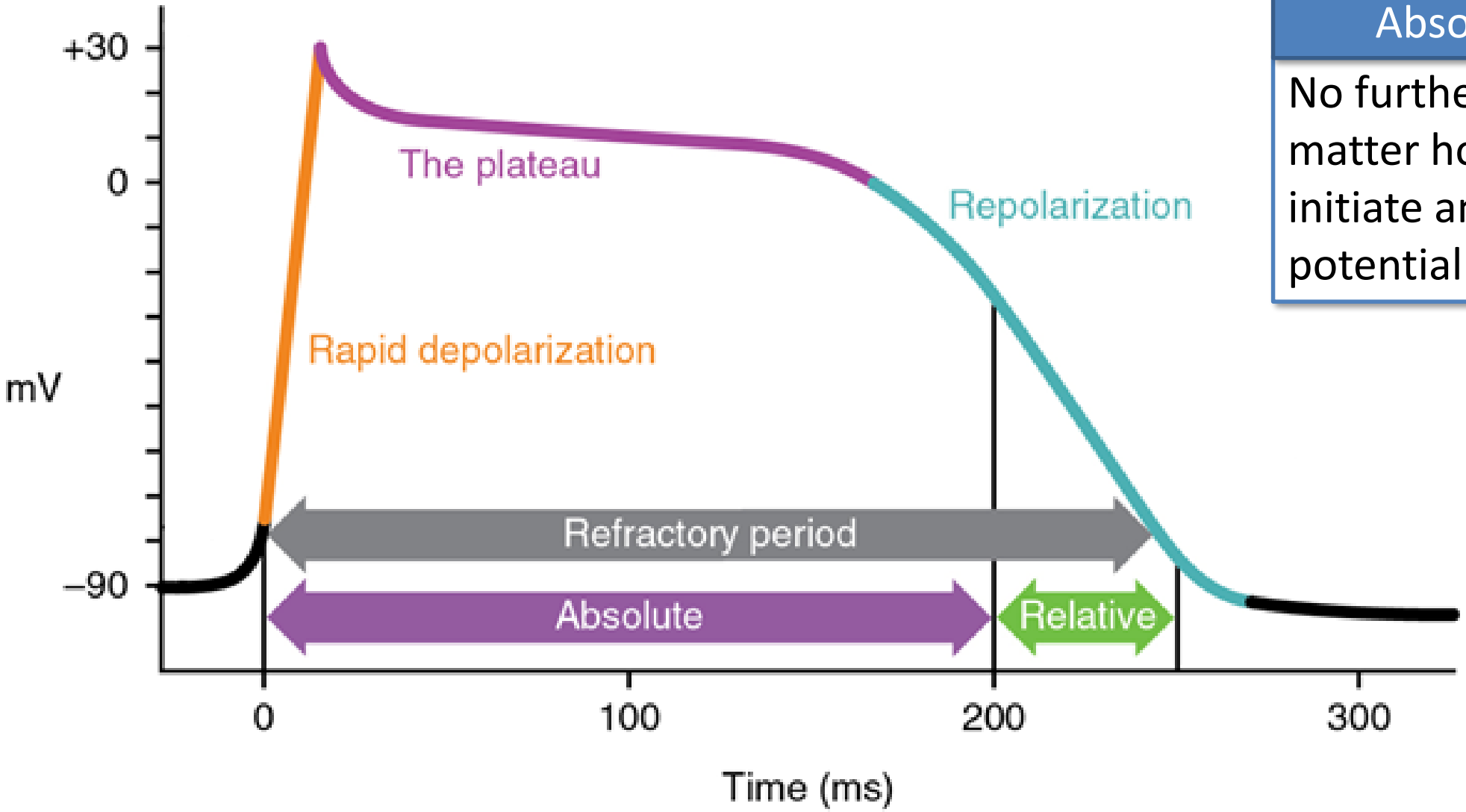


Refractory Period



The refractory period represents the time in which a subsequent stimulus will either not initiate another action potential or a stronger than normal stimulus is needed

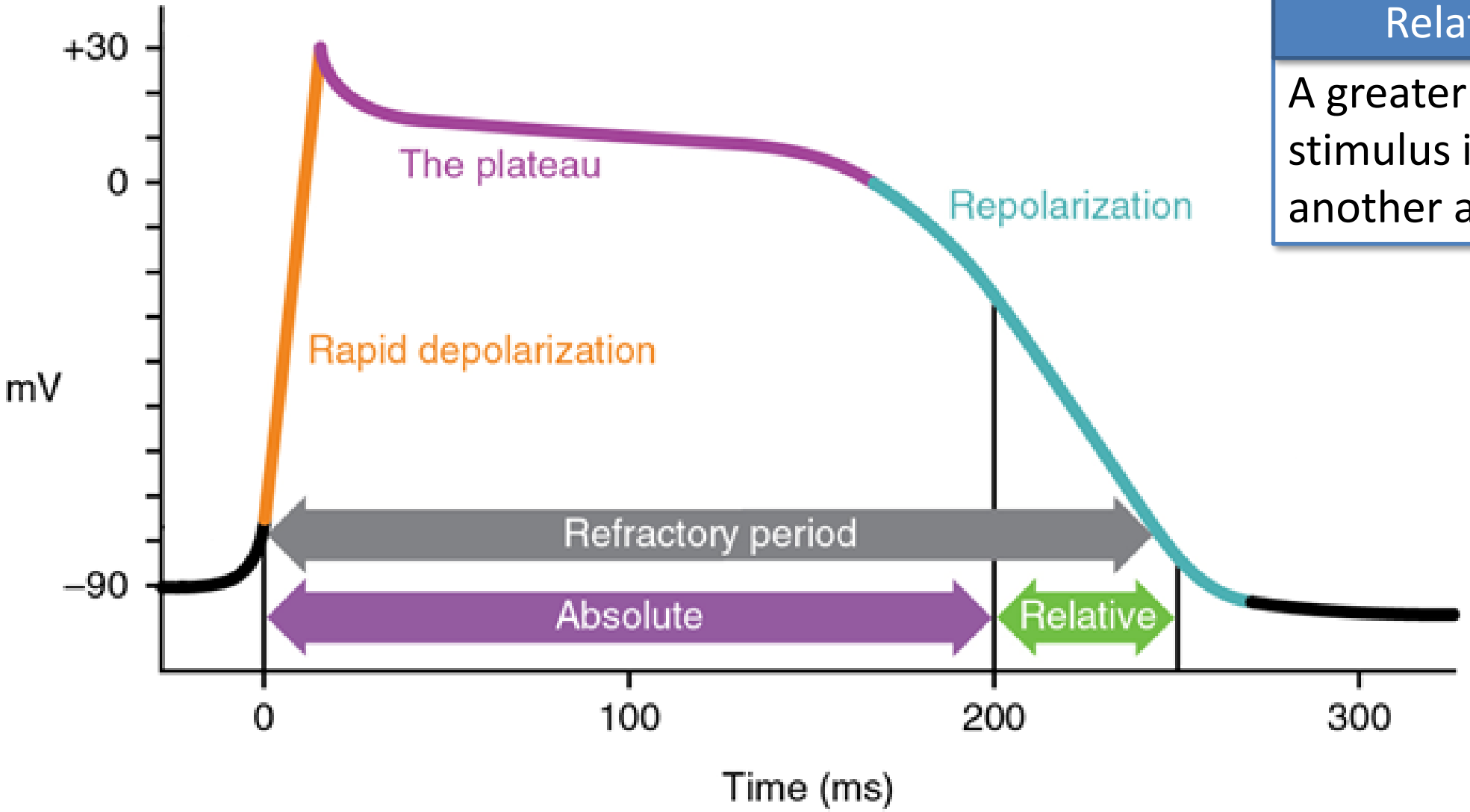
Refractory Period



Absolute Refractory

No further stimulus, no matter how strong, will initiate another action potential

Refractory Period



Relative Refractory

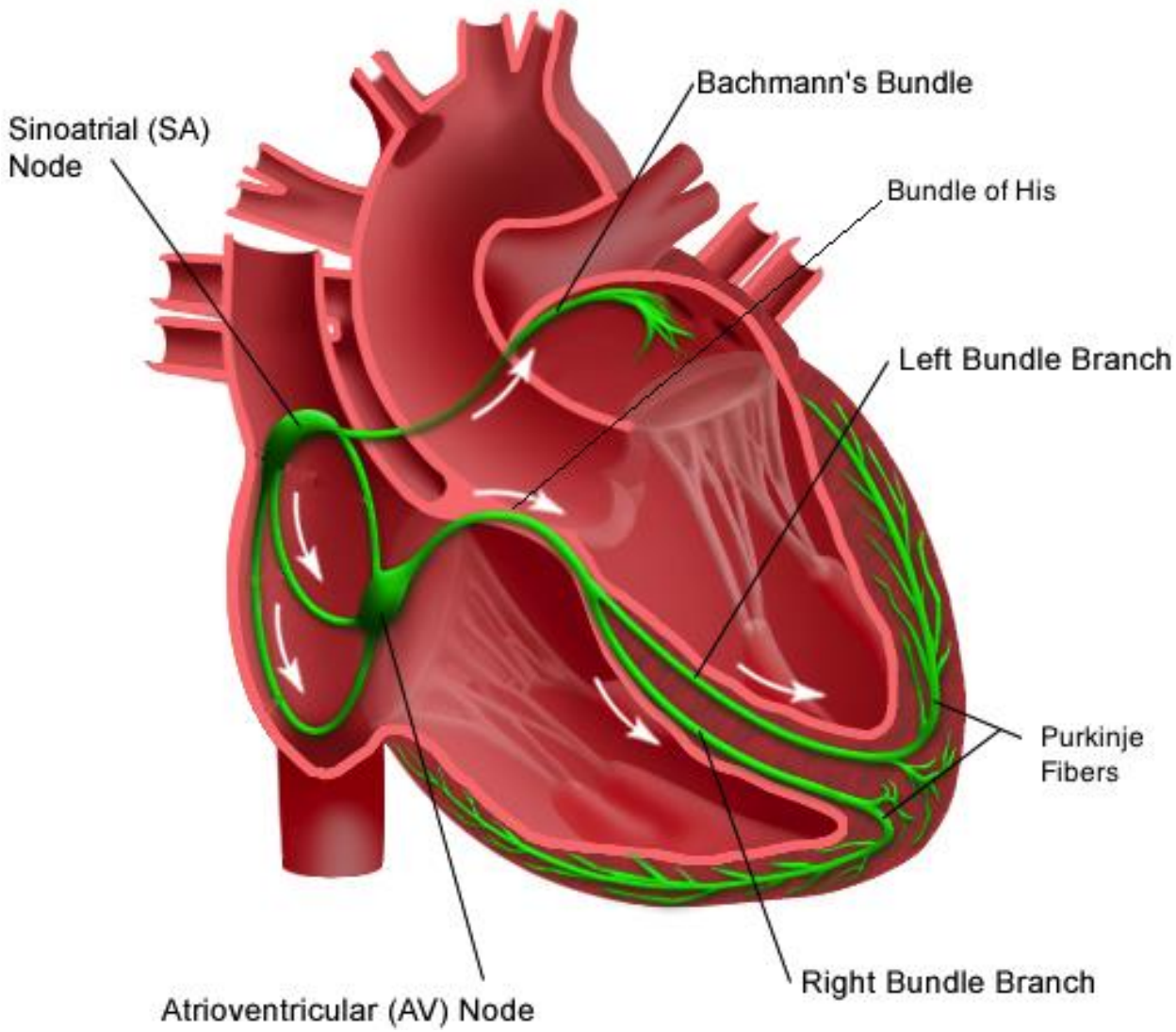
A greater than normal stimulus is needed to initiate another action potential

Cardiovascular Electrophysiology

COMPONENTS OF AN ELECTROCARDIOGRAM

Electrical Conduction System

- SA Node
- AV Node
- Bundle of HIS
- Bundle Branches
- Purkinje Fibers

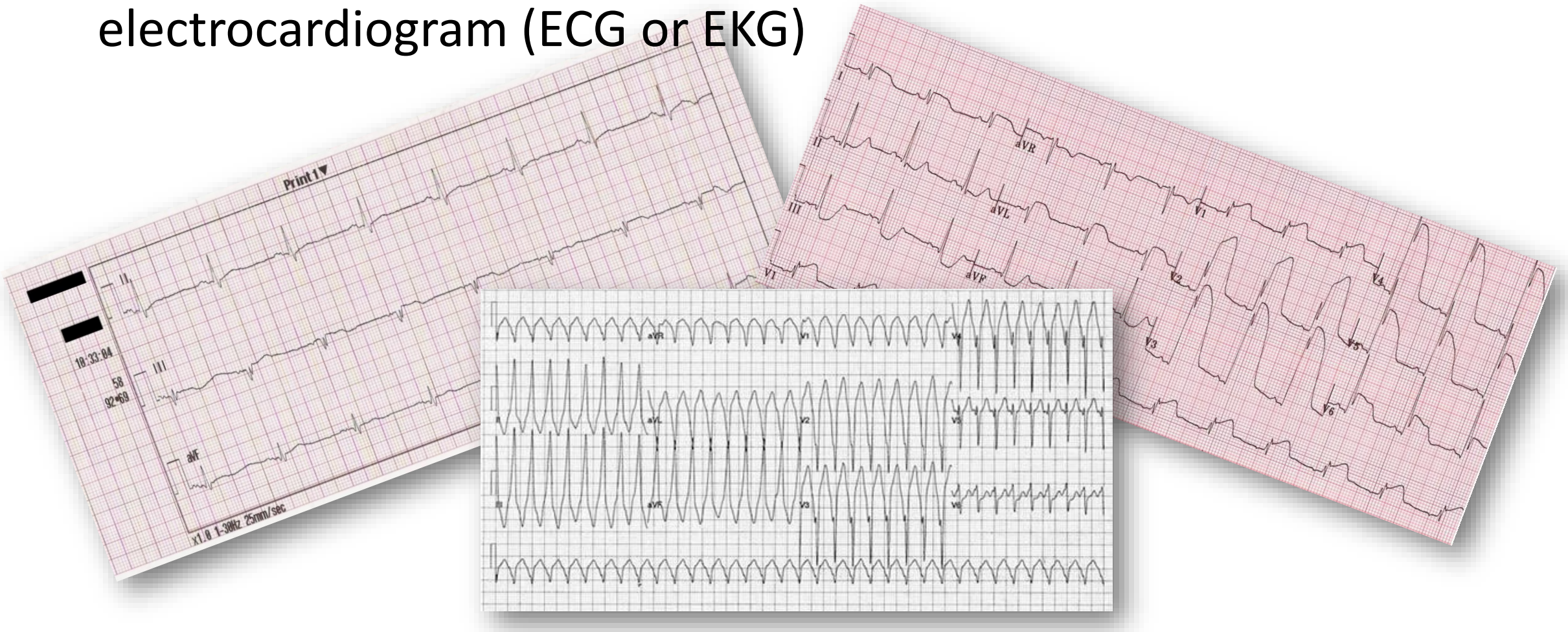


Electrocardiogram

- By placing electrodes on the skin, we can detect the electrical activity of the heart.
- Options include:
  - 3 lead
  - 12 lead
  - 15 lead
  - 18 lead

Electrocardiogram

- The electrical activity is recorded and displayed as an electrocardiogram (ECG or EKG)

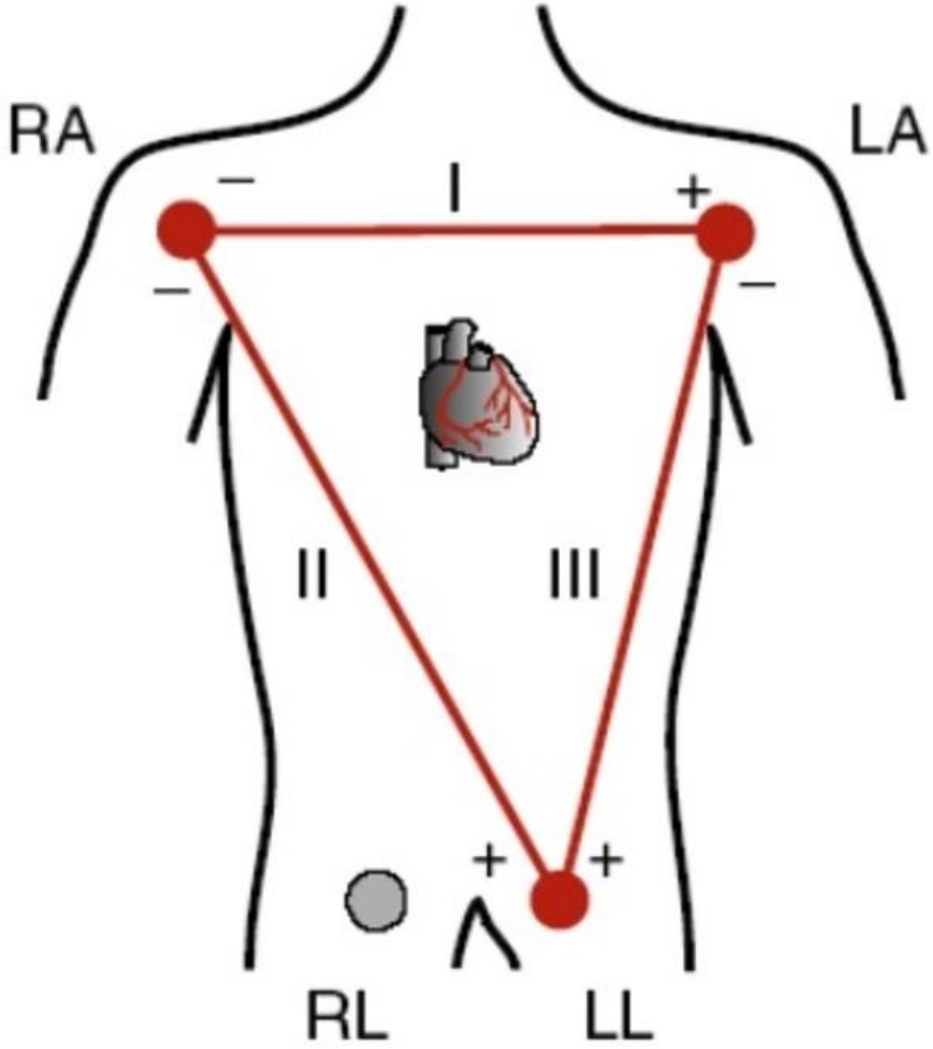


Willem Einthoven

- Dutch physician that studied and perfected the electrocardiogram in 1903
- Developed the technique that utilizes 3 leads to form equilateral triangle to detect the heart's electrical vector.
  - Later became known as Einthoven's Triangle
  - Gave rise to the three limb leads (I, II, III)

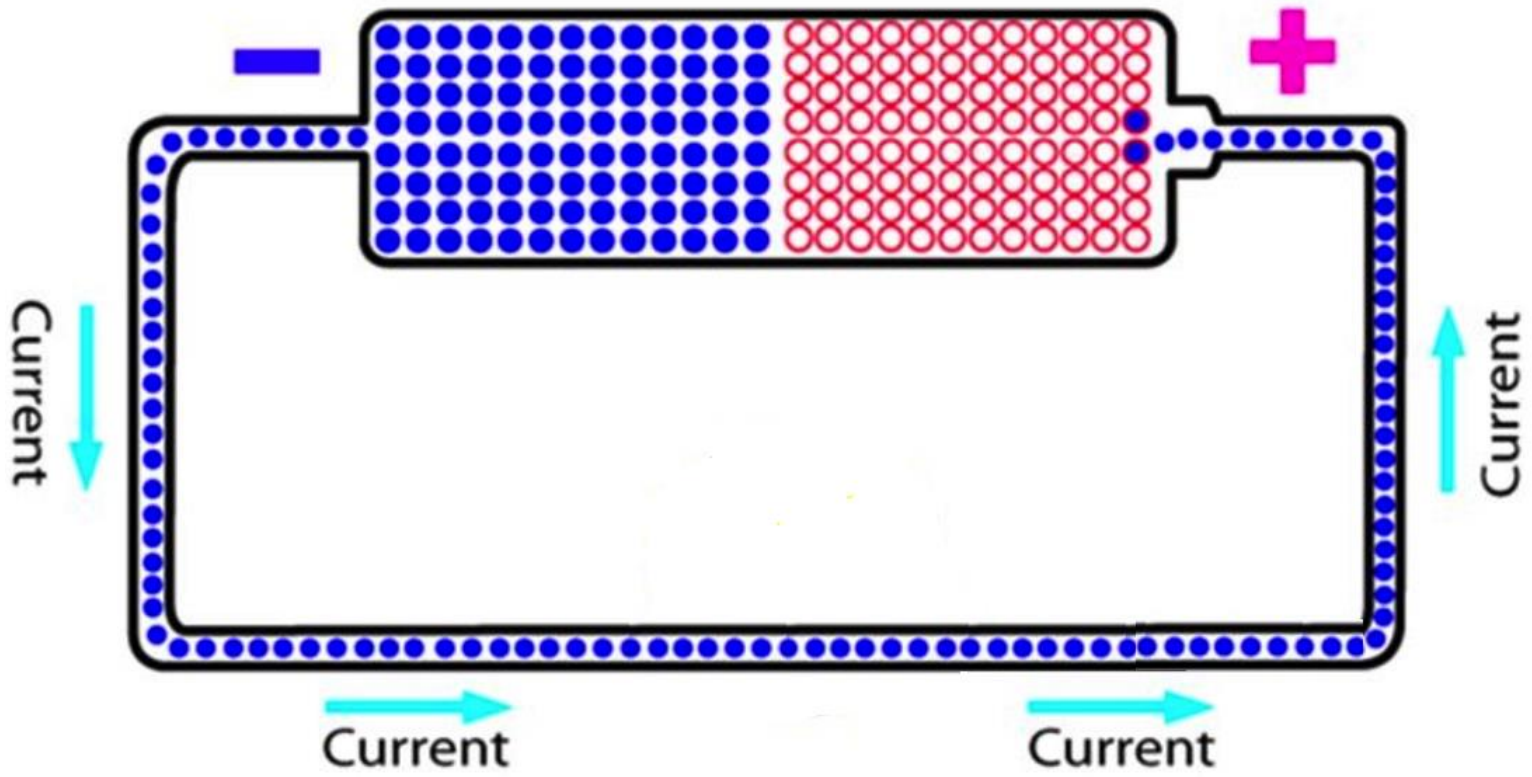
Einthoven's Triangle

- By placing electrodes on three limbs the heart's electrical vector can be recorded from 3 directions
- These electrodes are considered Bipolar leads as they can represent either a positive or negative electrode



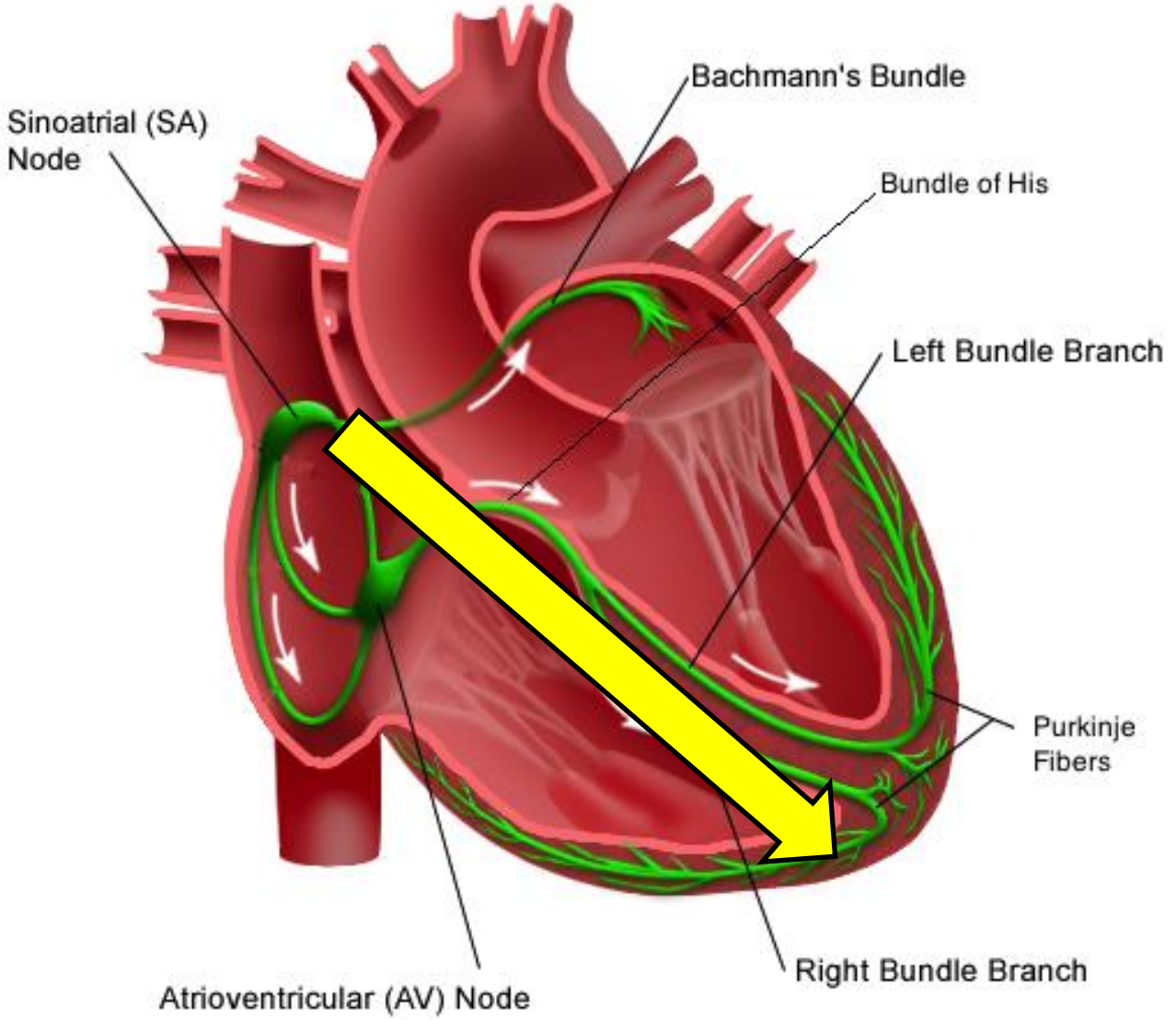
Electrical Current

- Electrical current is the movement of electrons between poles
- Electrons move from the negative pole to the positive pole



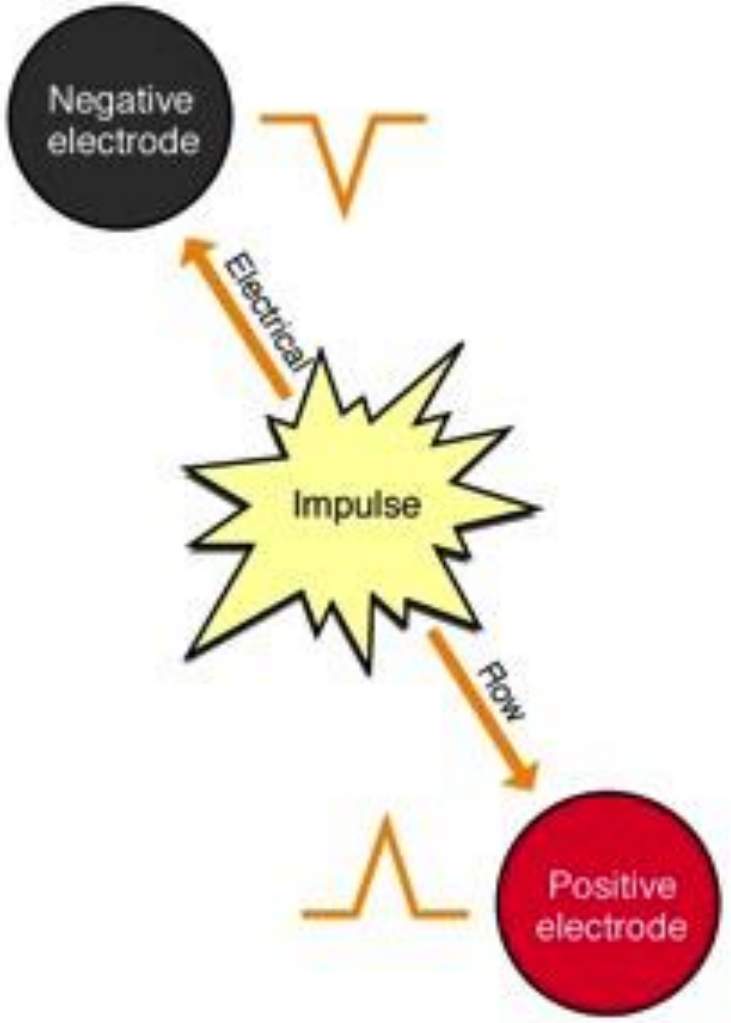
Electrical Current

- The overall movement of electrical current (electron flow) within the heart is downward and to the patient's left
- Using electrodes we can monitor this movement



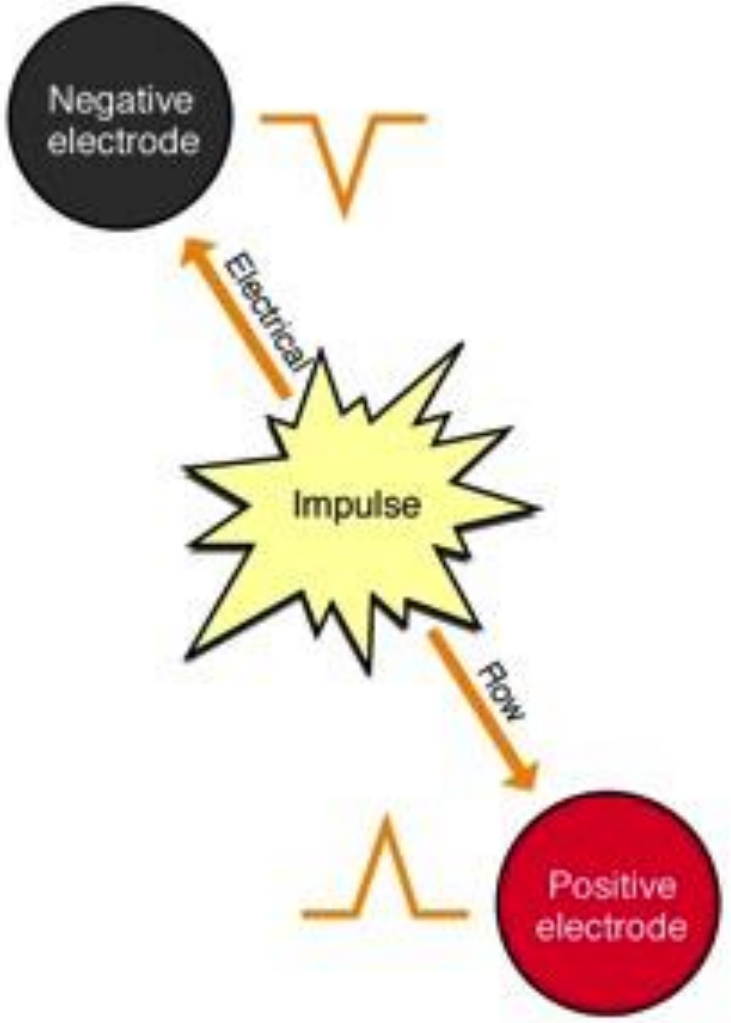
Electrical Current

- Since normally, electrons flow toward the positive electrode, we can use the positive electrode as an observation point.
- When looking at an ECG, the tracing will deflect above or below the horizontal based on whether the electrons are flowing toward or away from the positive electrode



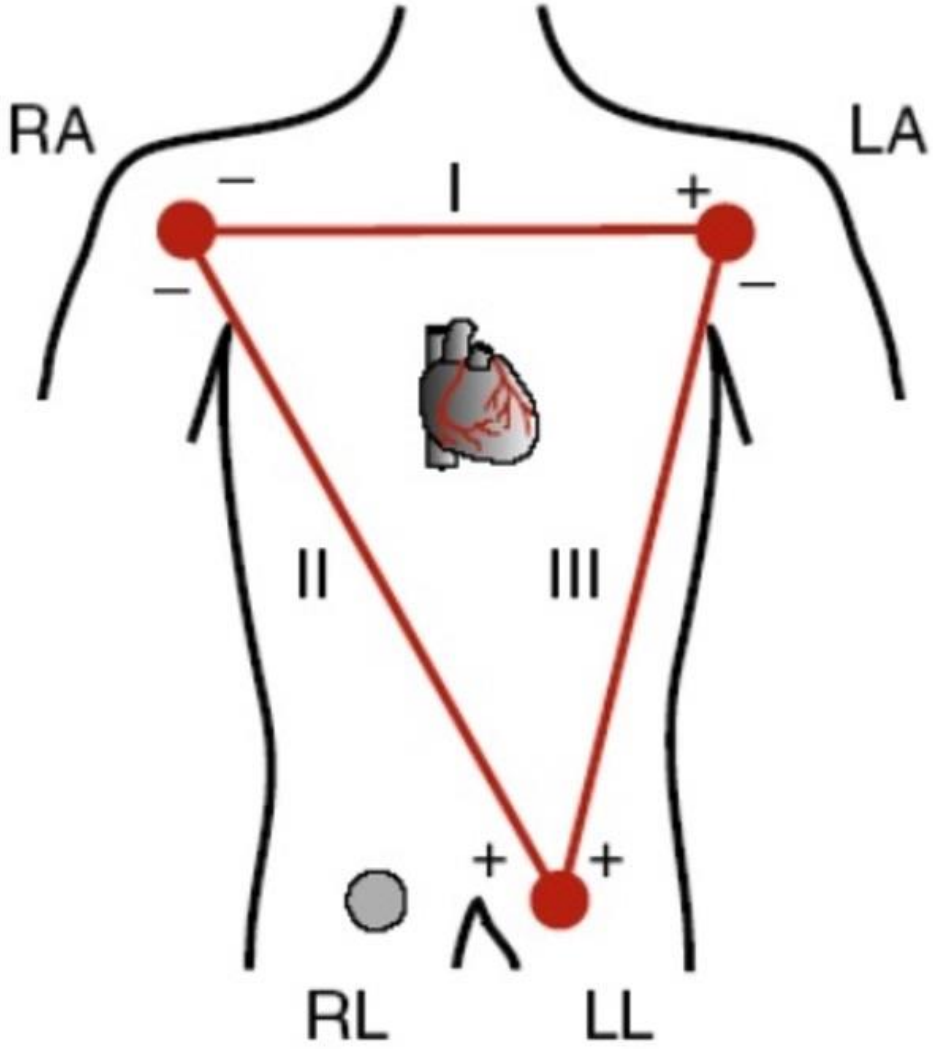
Electrical Current

- If electrons flow away from the positive electrode = negative deflection
- If electrons flow toward the positive electrode = positive deflection



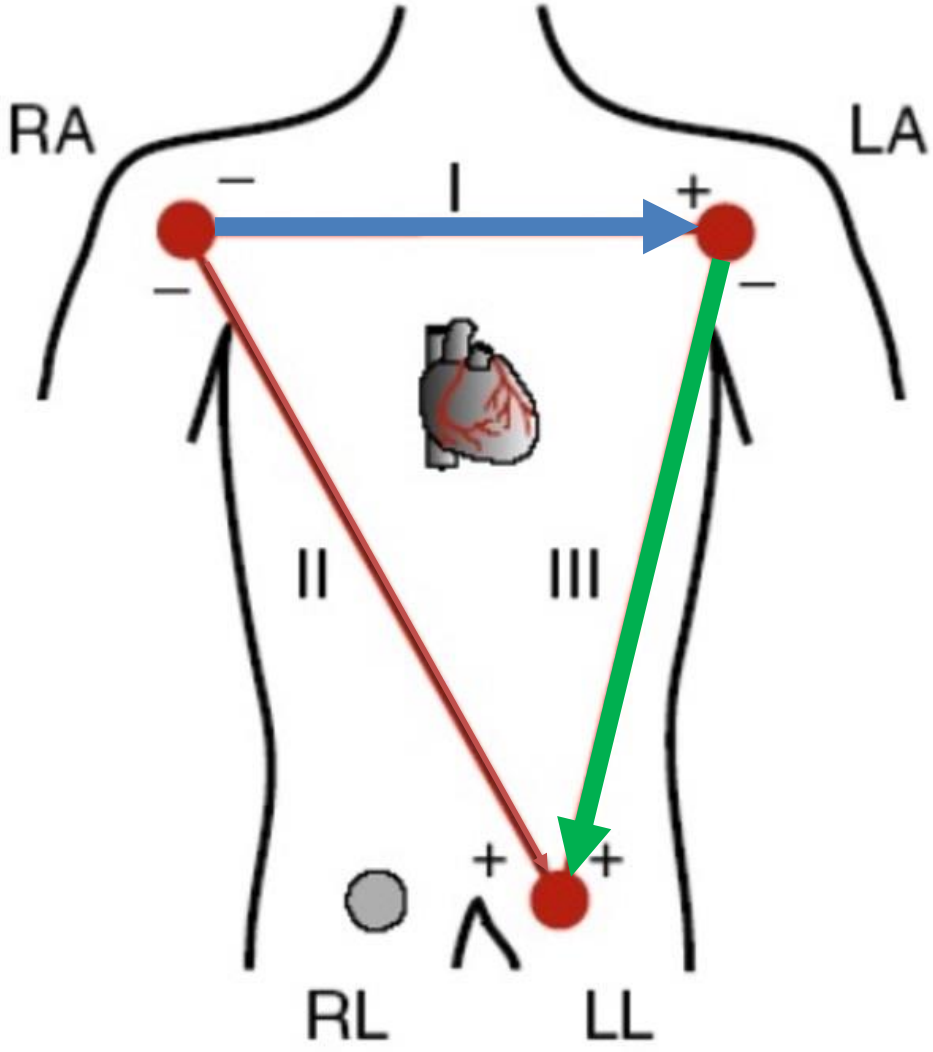
Einthoven's Triangle

- When obtaining a 3-lead ECG, we place bipolar electrodes on the Right Arm (RA), Left Arm (LA) and Left Leg (LL) then can obtain various "views" of the heart's electrical current



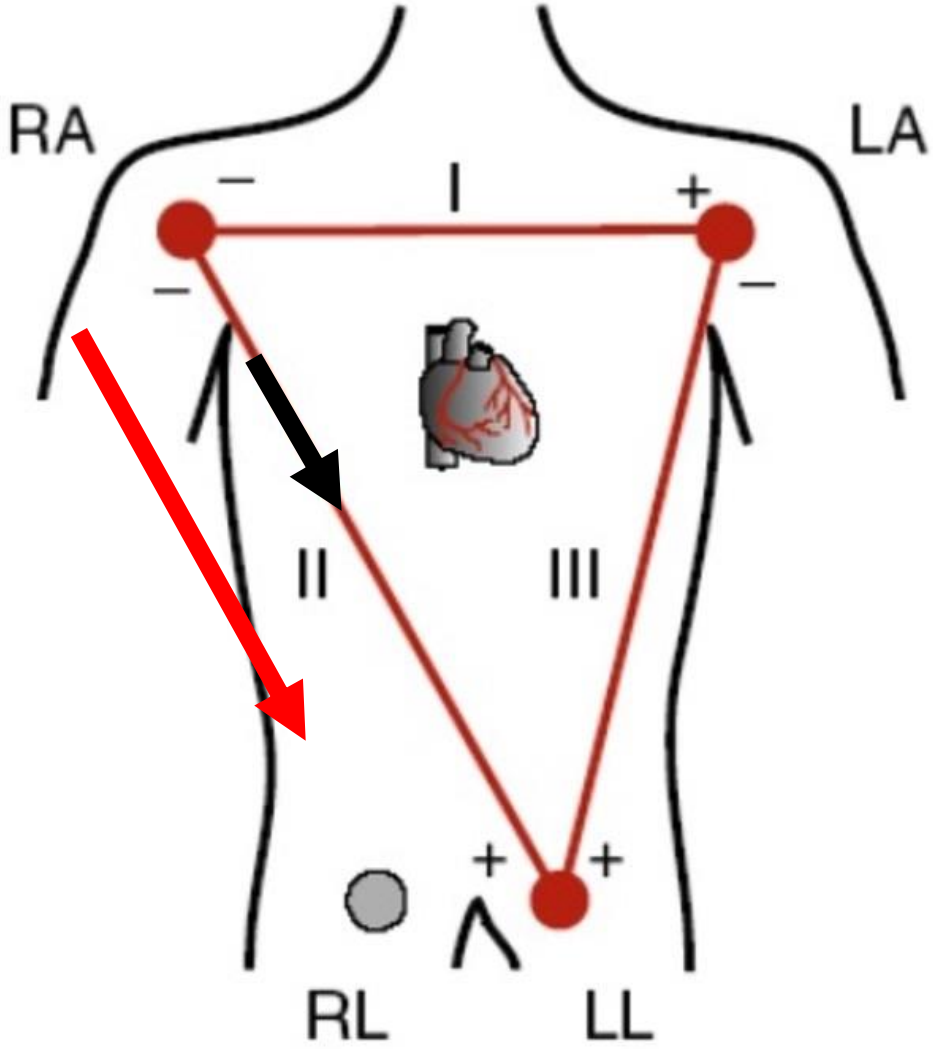
Einthoven's Triangle

Lead I	When RA is a negative electrode, and LA is a positive electrode
Lead II	When RA is a negative electrode, and LL is a positive electrode
Lead III	When LA is a negative electrode, and LL is a positive electrode



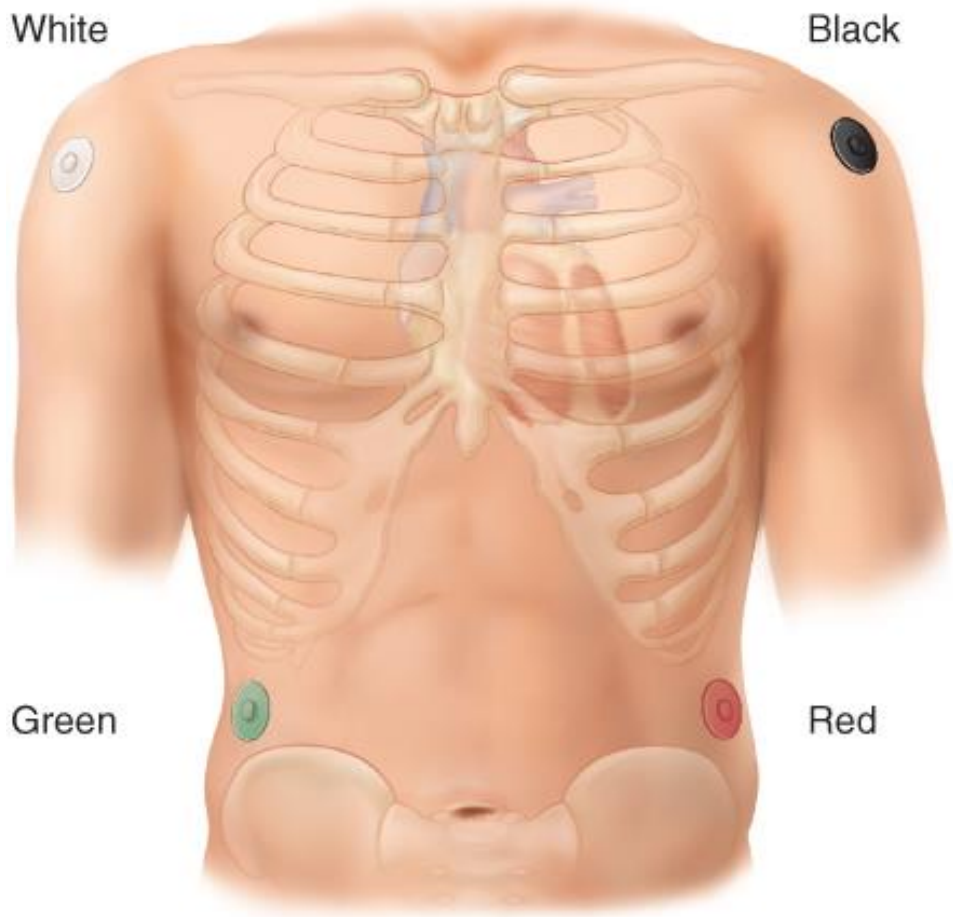
Einthoven's Triangle

- The direction of flow for lead II is closest to the heart's normal electrical current and as such is used as the primary lead in rhythm interpretation



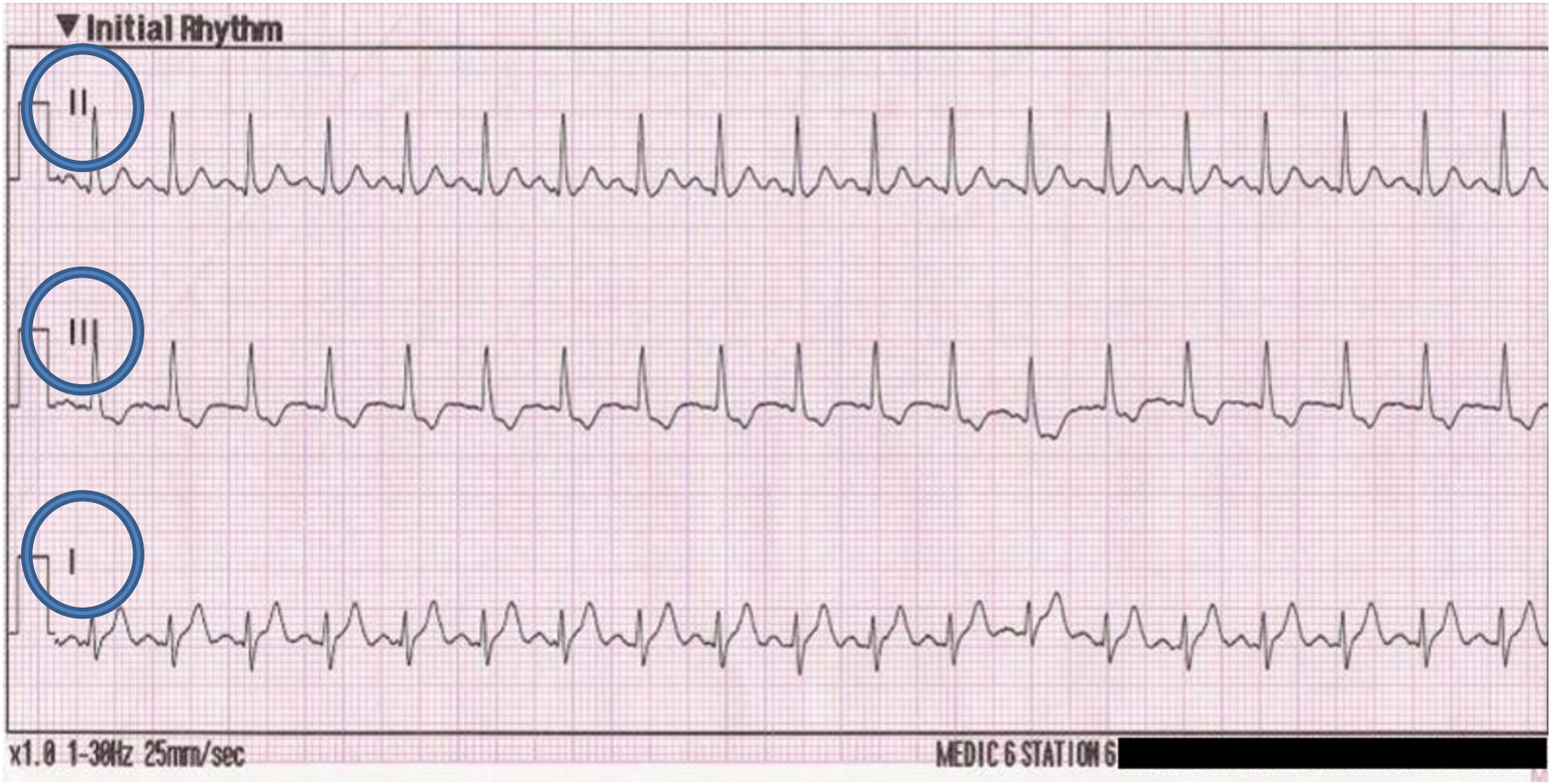
Electrode Placement for Cardiac Monitoring

- Electrodes
  - Generally adhesive
  - Have a gel centre to aid in skin contact
  - Diaphoretic electrode



3-lead ECG Tracing

- 3-lead ECG showing 3 different views at the same time of the heart's electrical activity



Extra Views

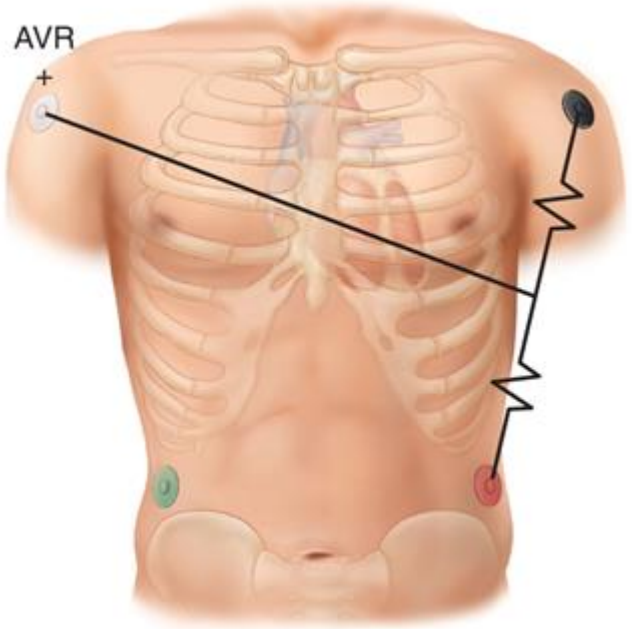
- In addition to the bipolar electrodes providing the three limb lead views, the ECG machine can use these same electrodes to create three different views
- The ECG machine can computationally use the heart's center as a negative pole and then use each bipolar electrode as a the positive pole
- This gives rise to three new views referred to as Augmented leads

Extra Views

- Augmented leads are named based on the positive electrode

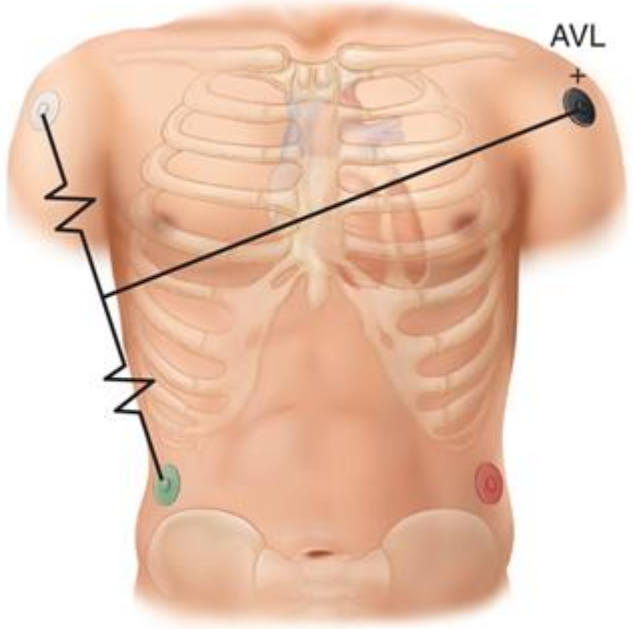
aVR

Augmented vector right because RA is used as positive electrode



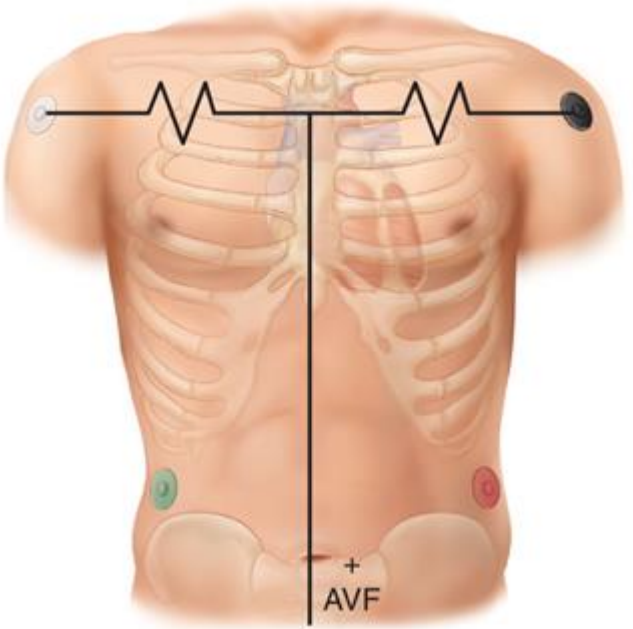
aVL

Augmented vector left because LA is used as positive electrode



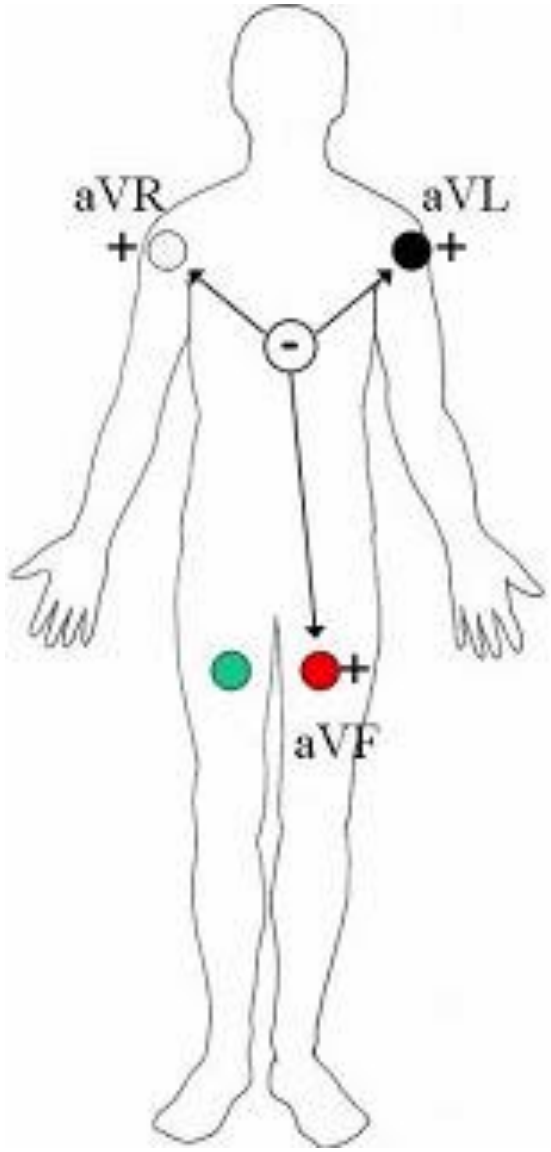
aVF

Augmented vector foot because LL is used as positive electrode



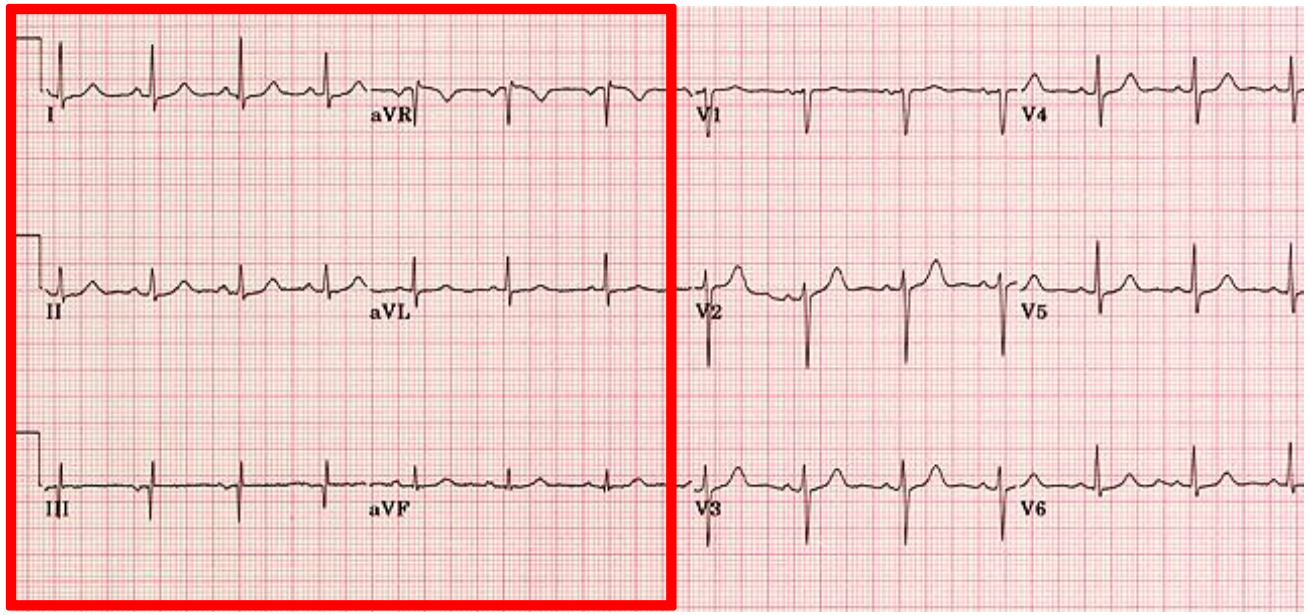
Extra Views

- The corresponding ECG tracings these augmented leads produce follow the same principles as the limb leads
  - i.e. if flow of current moves toward positive electrode the ECG will show positive deflection
- Therefore, when looking at the positive electrode of aVR, the normal current of the heart moves directly away from it
  - Therefore, aVR should be negatively deflected on an ECG



ECG Tracing

- As a result of correctly placing the 3 limb leads, we can obtain 6 different views of the heart's electrical current
  - Leads I, II & III, aVR, aVL, aVF
  - This provides us with half of the 12 views of a 12-lead ECG



12-lead ECG Tracing

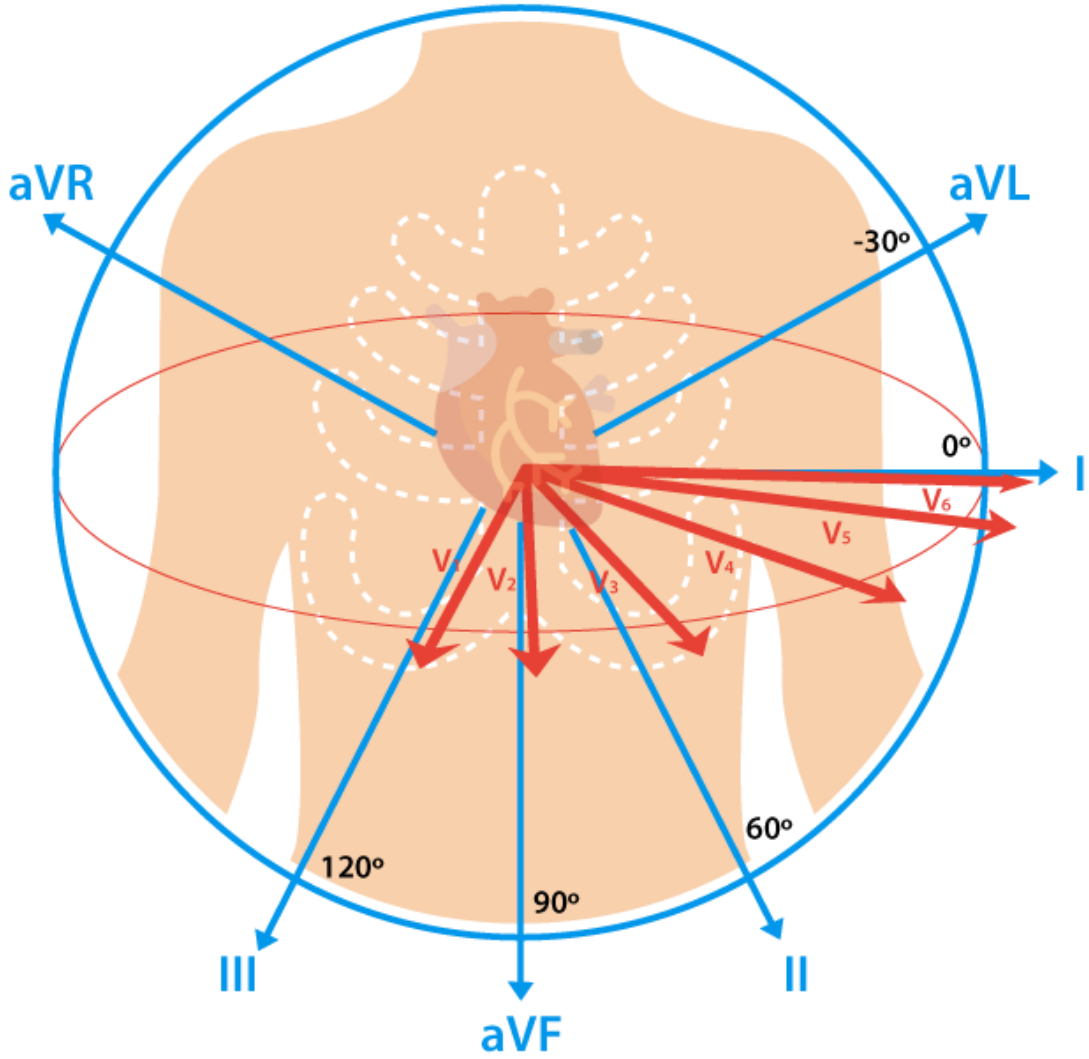
- In order to obtain the final 6 views of a 12-lead ECG we must place 6 more electrodes on the patient
- These 6 electrodes provide us with 6 more views known as the precordial leads

Precordial Leads

- Similar to the augmented leads, the precordial leads use the heart's center as the negative electrode and each precordial electrode acts as the positive
- The difference, however, is that the precordial leads view the heart on a different axis than the limb and augmented leads

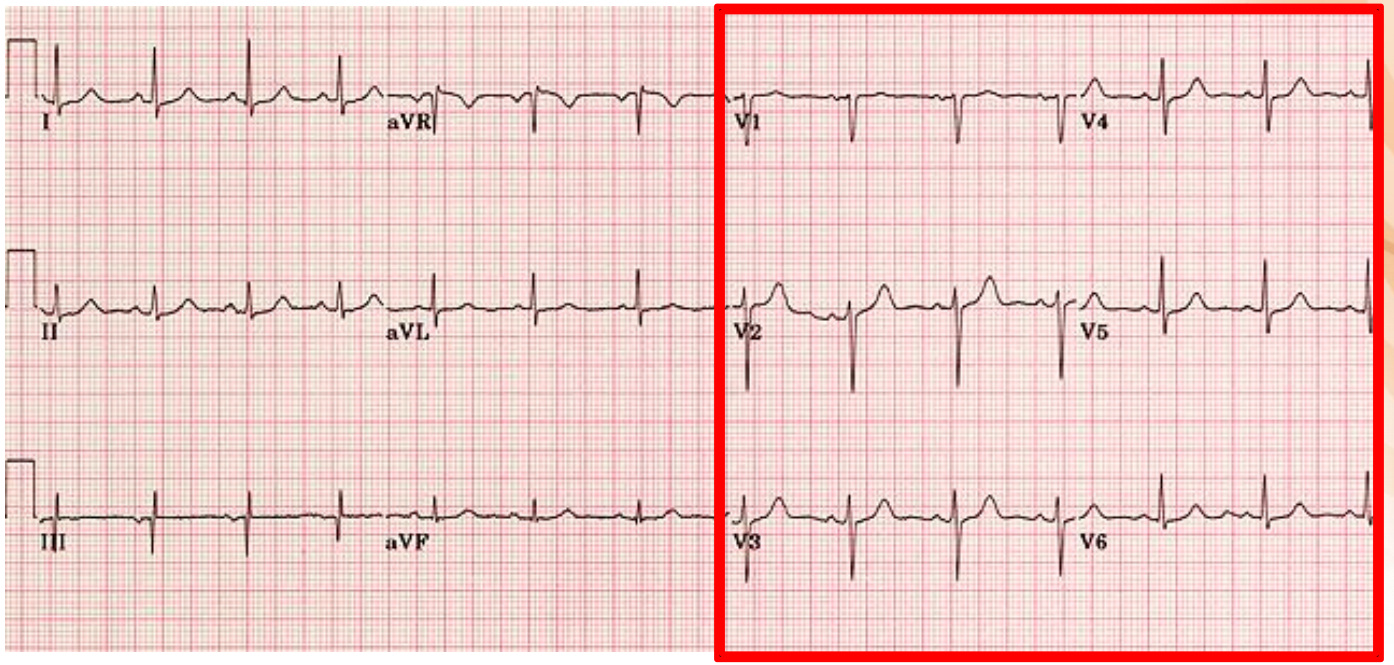
Precordial Leads

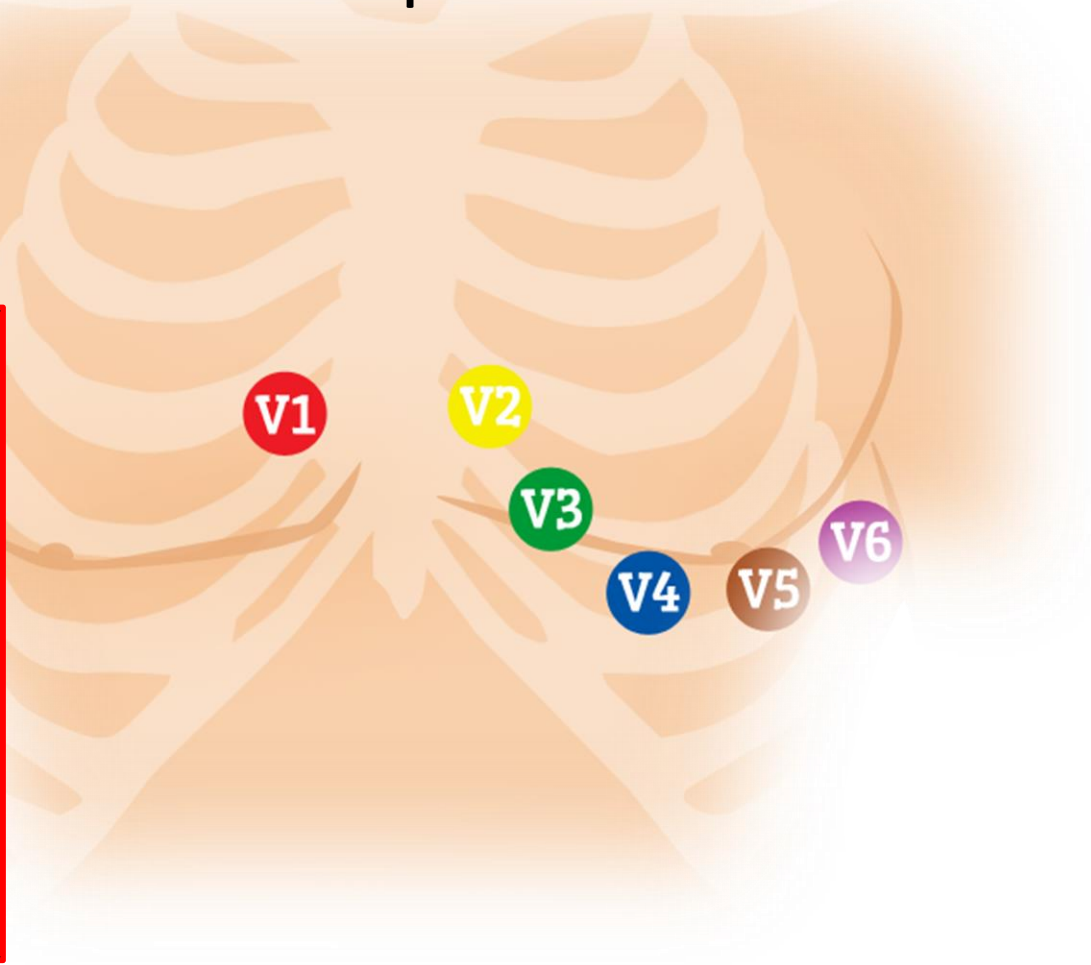
- The limb & augmented leads view the heart in a vertical (frontal) axis
- The precordial leads view the heart in a horizontal (transverse) axis



Precordial Leads

- The precordial leads are labelled V1 – V6 and provide the final 6 views of the 12-lead ECG.





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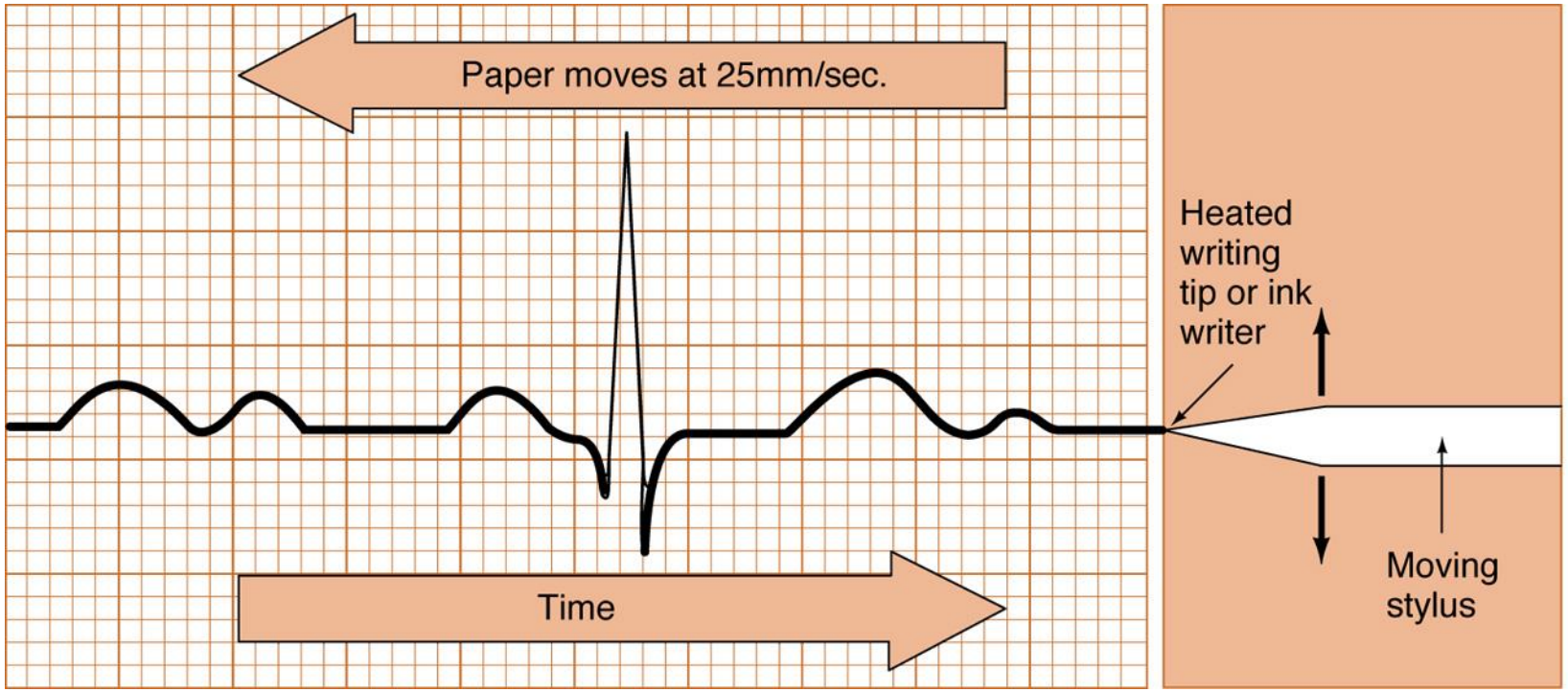
Cardiovascular Electrophysiology

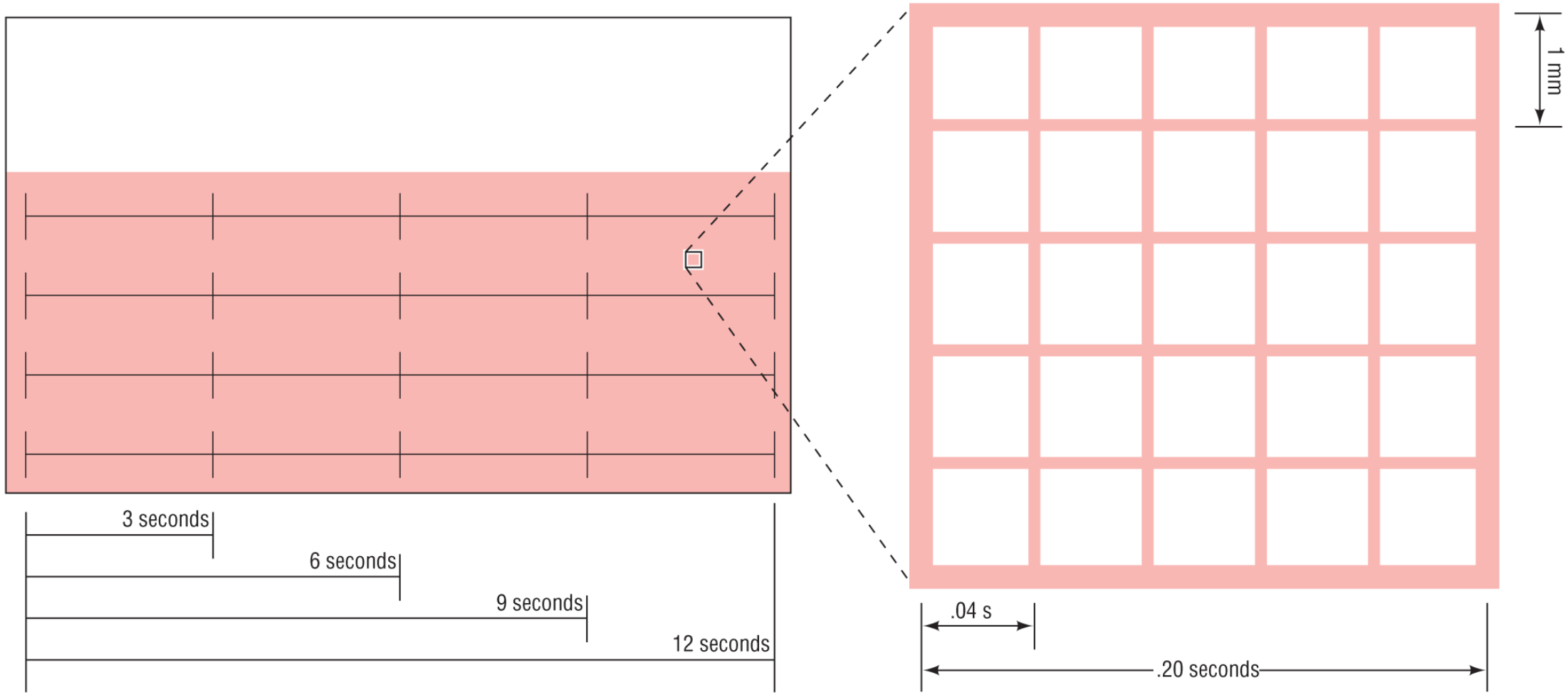
3-LEAD ECG INTERPRETATION

ECG Paper

- Speed and amplitude are standardized to allow for comparative analysis

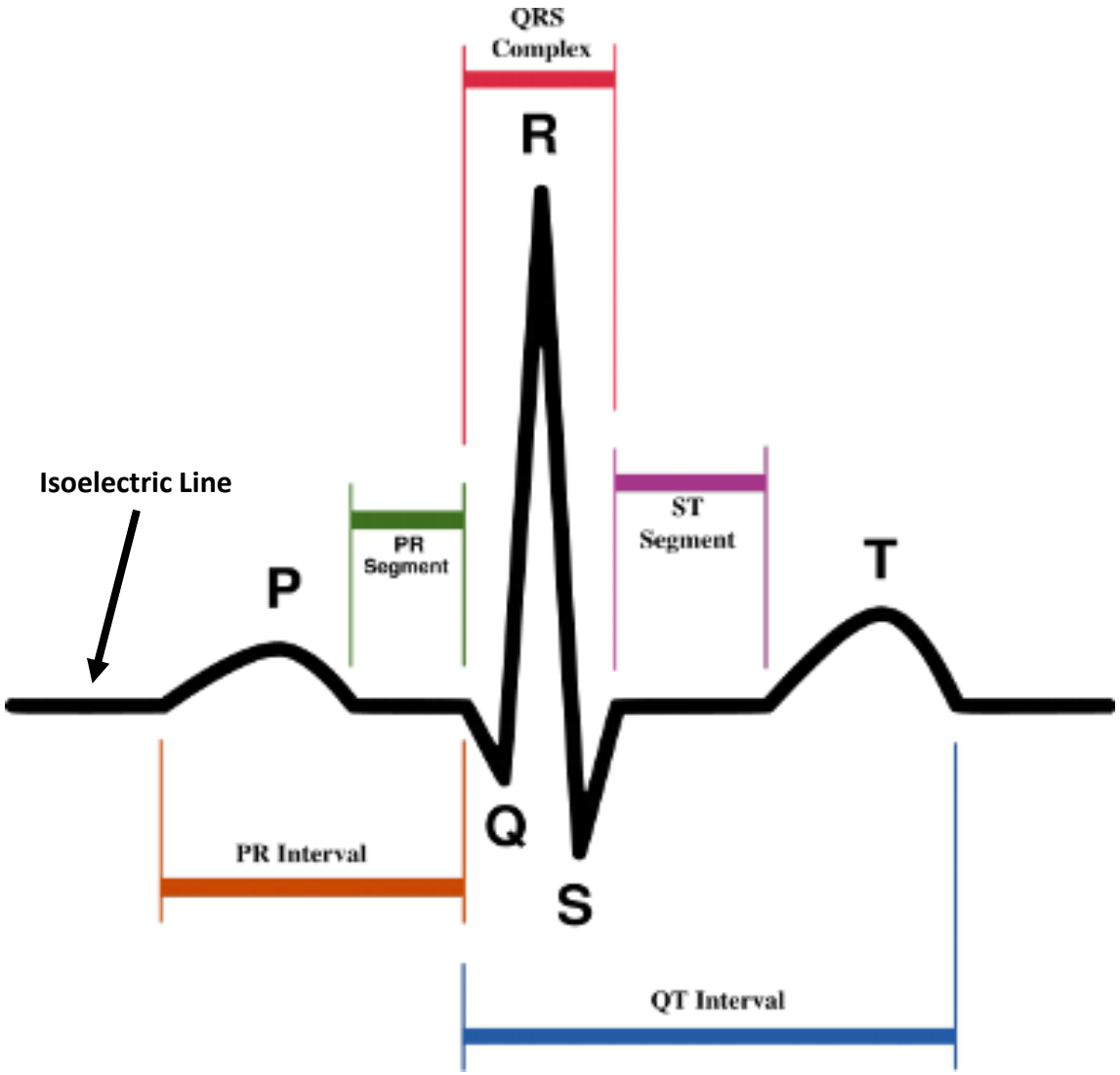


ECG Paper



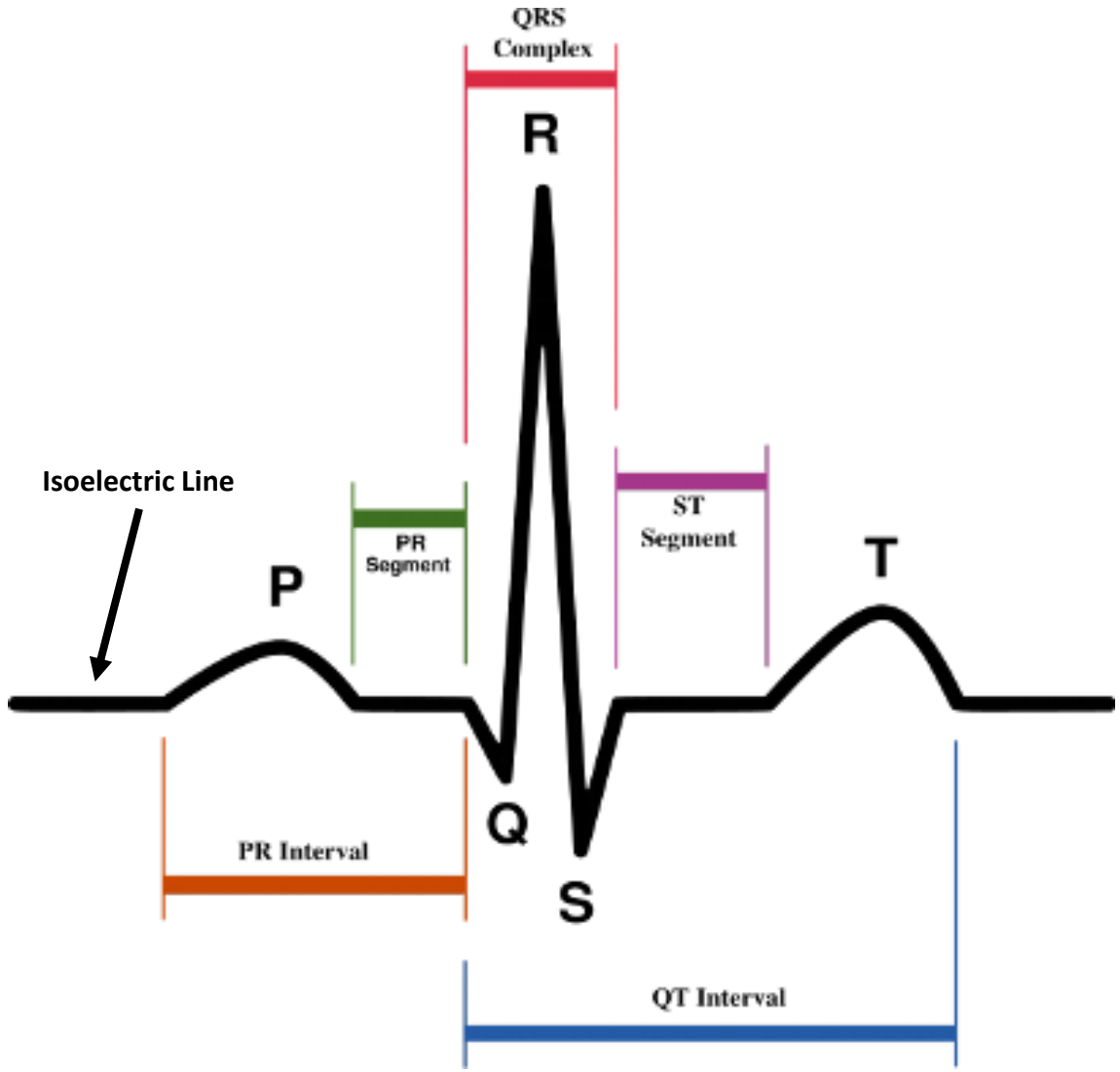
Components of an ECG Complex

- As the electrical current of the heart passes through the conduction system, it depolarizes the cardiomyocytes
- The positive and negative deflections on the ECG represent depolarization and repolarization of various parts of the heart



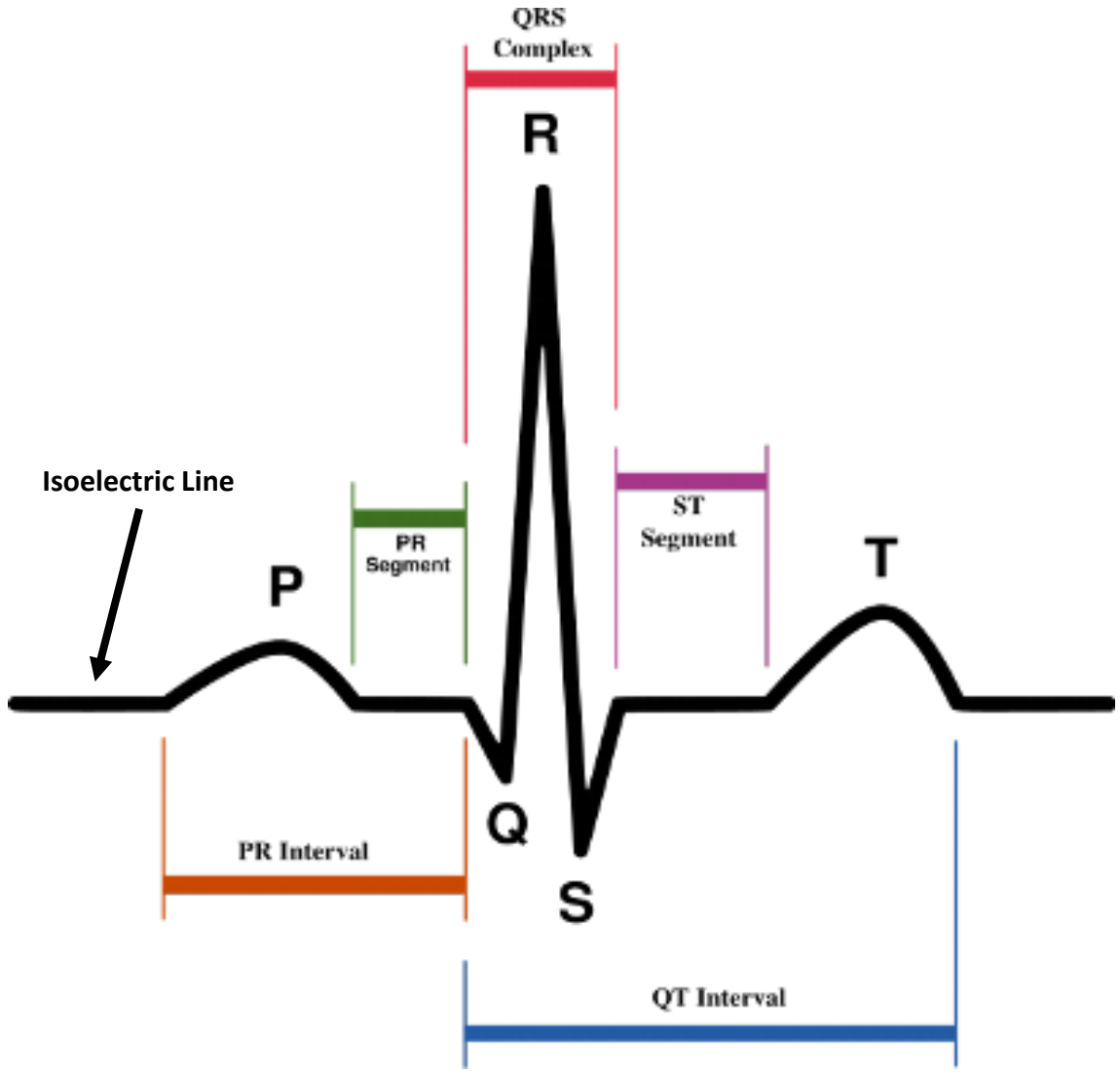
Components of an ECG Complex

- The baseline of the tracing is known as the **isoelectric line**
  - **P wave** = depolarization of the atria
  - **QRS complex** = depolarization of the ventricles
  - **T wave** = repolarization of the ventricles



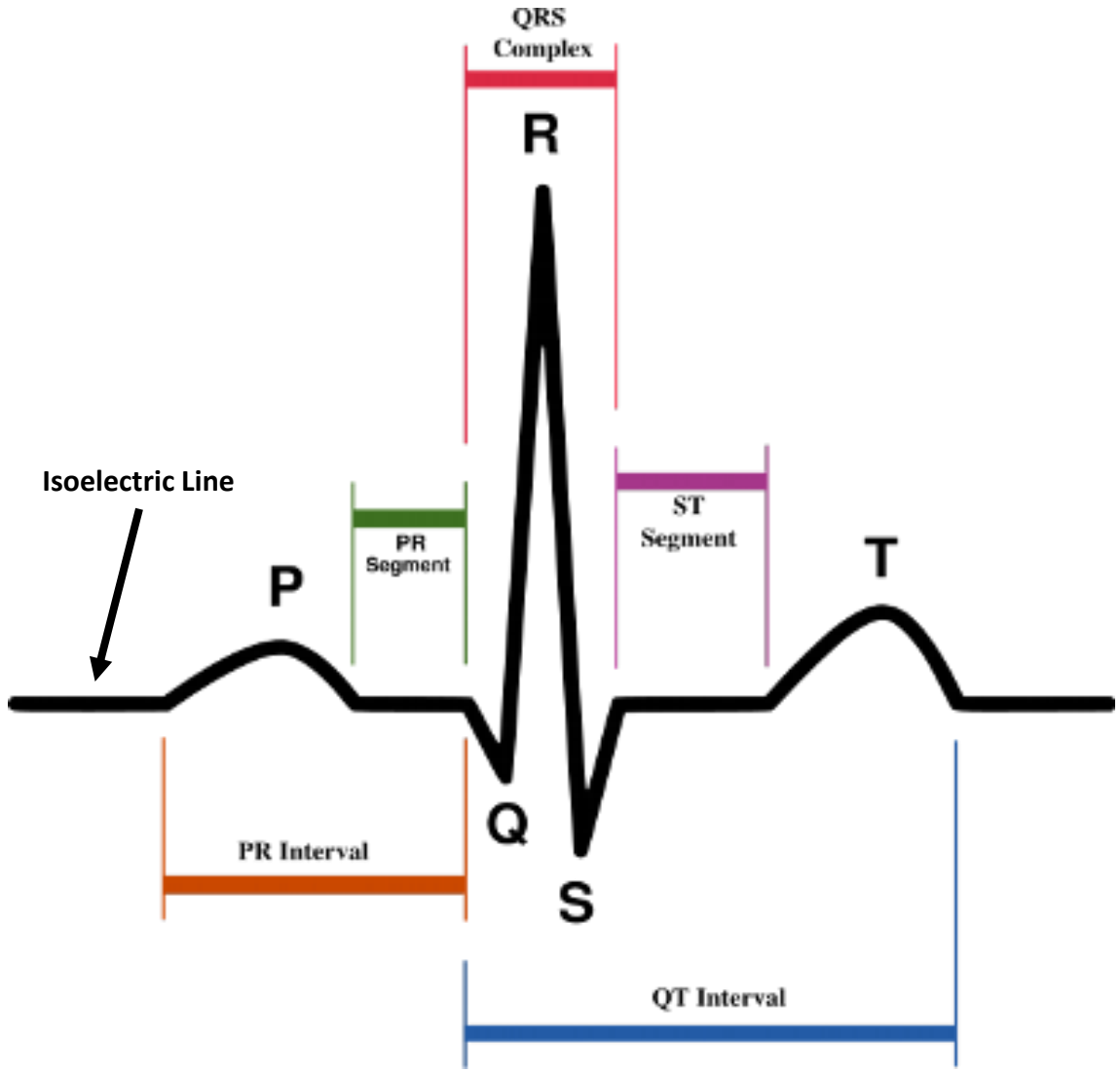
Components of an ECG Complex

- **PR Interval:** represents the time from the start of atrial depolarization to start of ventricular depolarization
- **QT Interval:** represents the time from the start of ventricular depolarization to the end of ventricular repolarization



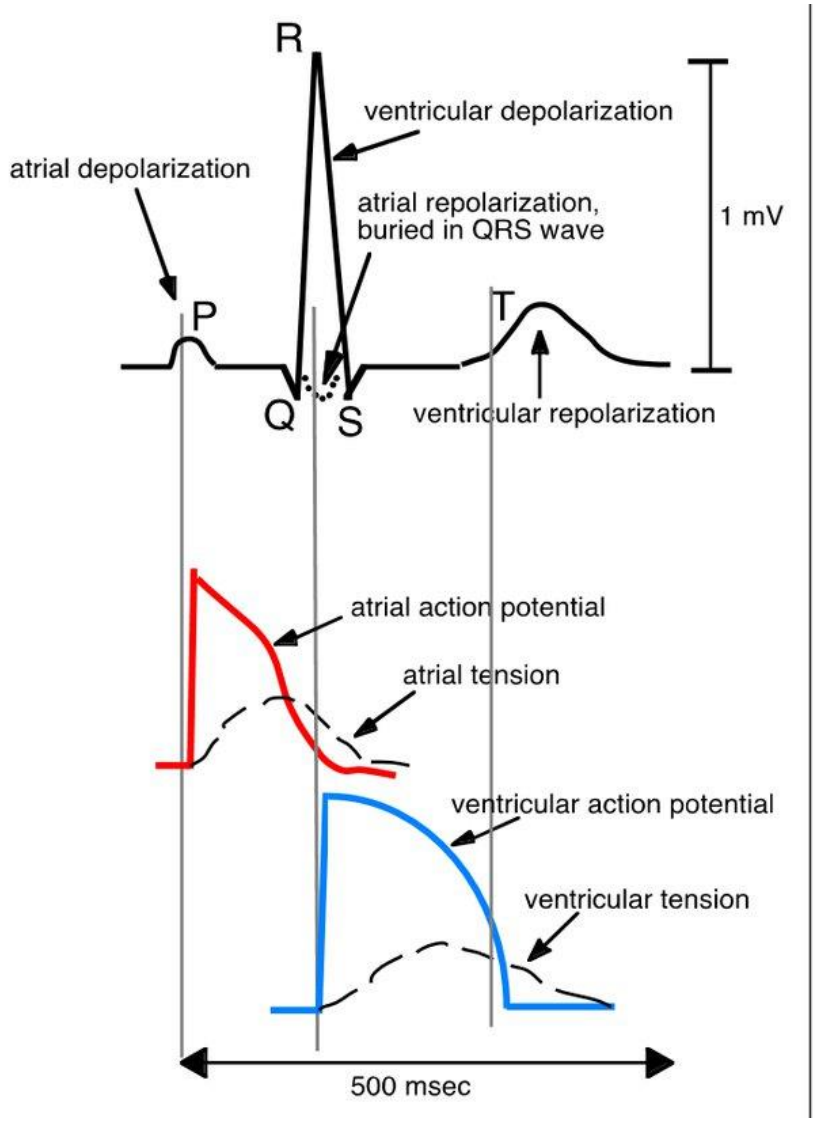
Components of an ECG Complex

- **PR Segment:** represents the time from the end of atrial depolarization to start of ventricular depolarization
- **ST Segment:** represents the time from the end of ventricular depolarization to the start of ventricular repolarization



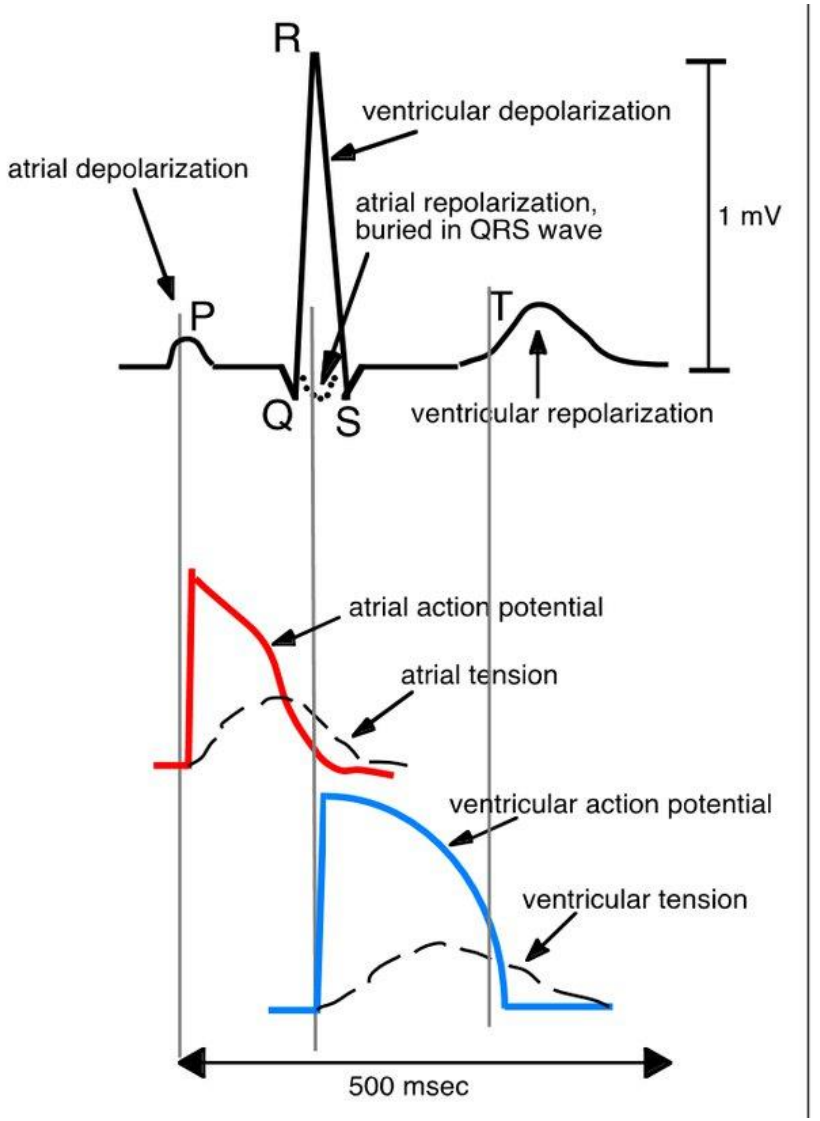
Action Potential

- When we overlap the action potential graph we can see that phase 0 of the atria (depolarization) corresponds to the start of the P wave
- Phase 0 of the ventricles corresponds to the start of the QRS complex
- Note: due to very low amplitude, the repolarization of the atria does not cause deflection on the ECG tracing



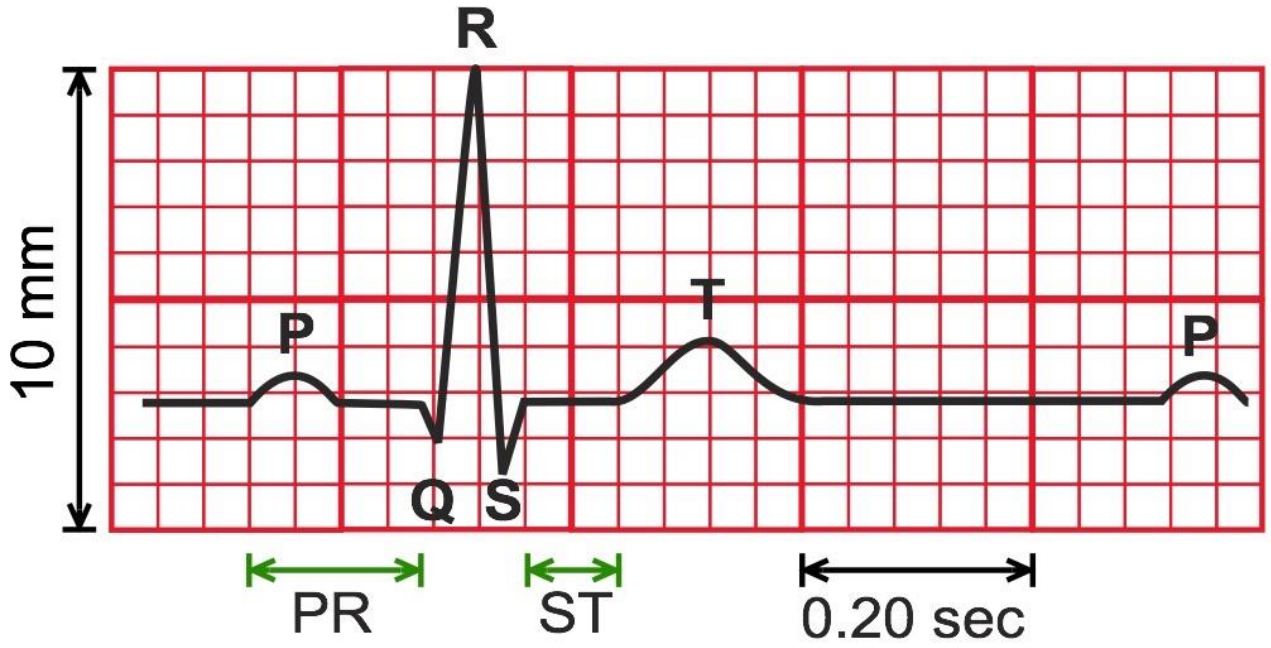
Action Potential

- As a result of depolarization, the cardiomyocytes contract
- Therefore we can see that atrial contraction occurs just after the start of the P wave and ventricular contraction just after the start of the QRS complex
- The delay between the two allows for complete filling of the ventricles prior to contraction
  - corresponds to the PR segment

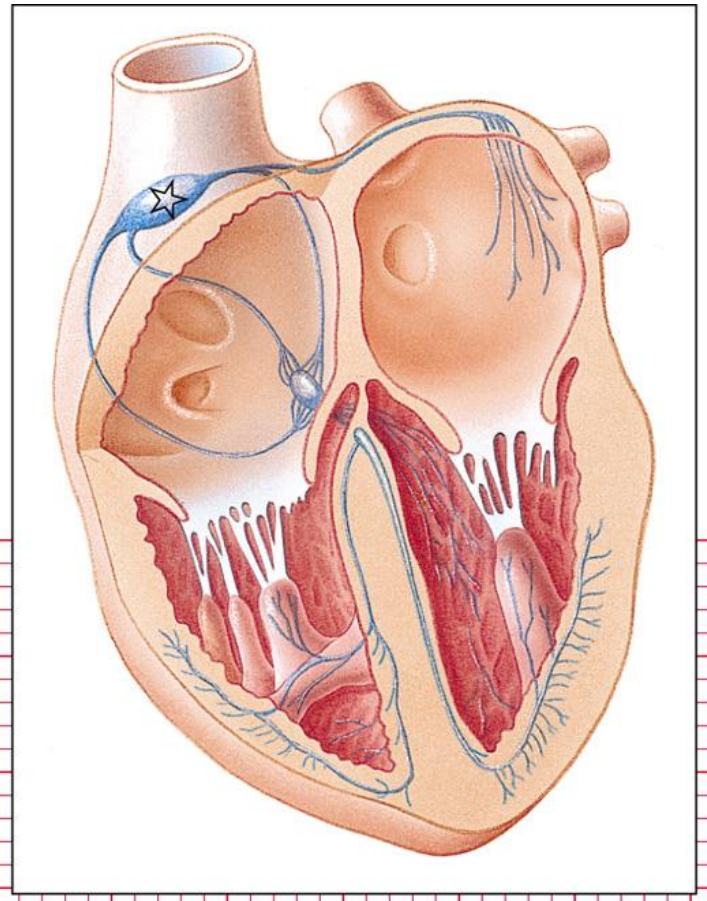


Normal Values

- Typical ranges for a normal heart:
  - PRI = 0.12 – 0.20 seconds (3-5 small boxes)
  - QRS Interval = 0.04 – 0.12 seconds (1-3 small boxes)

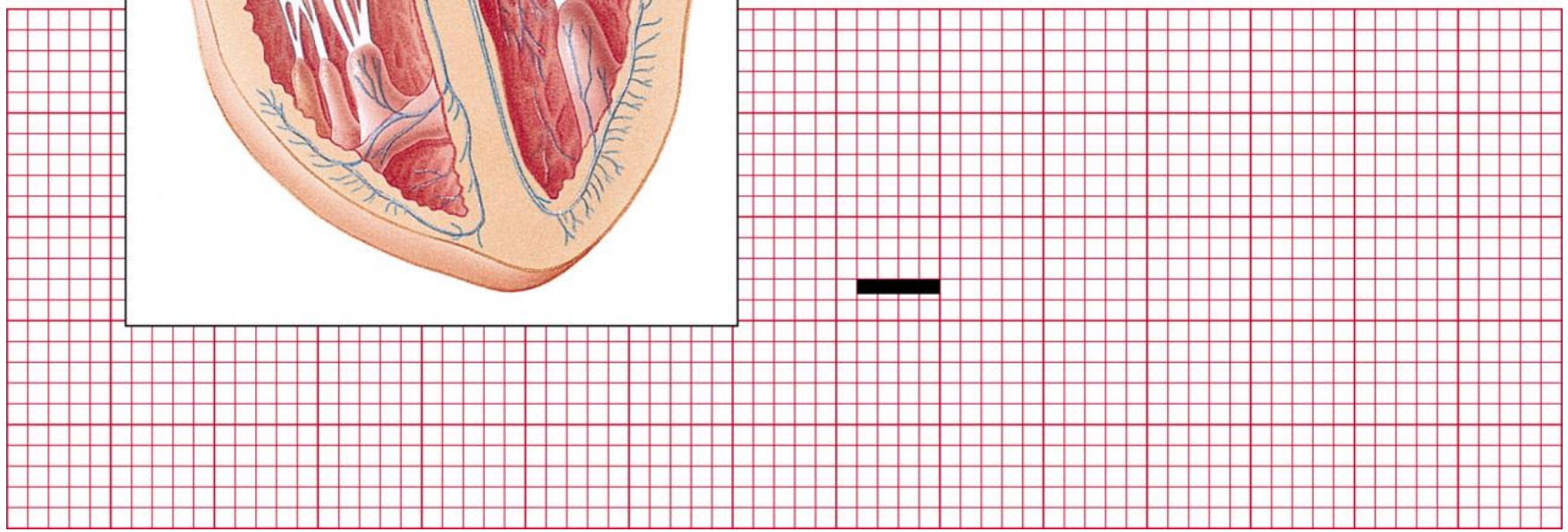


The Electrocardiogram

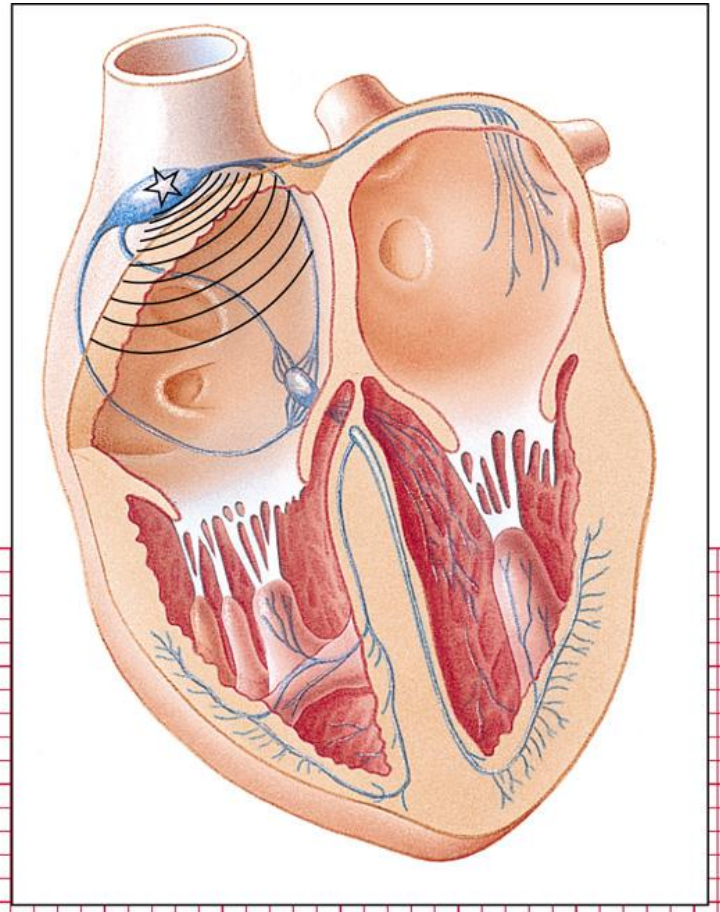


P Wave (upright in lead II)

Impulse initiated in the sinus node

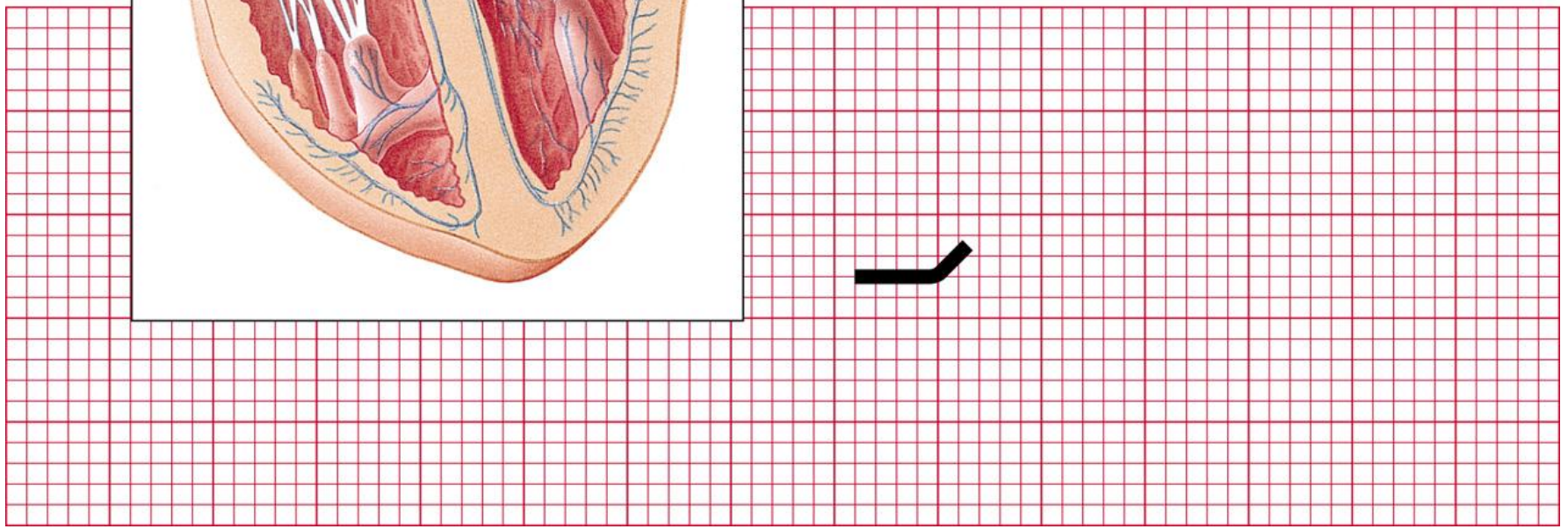


The Electrocardiogram

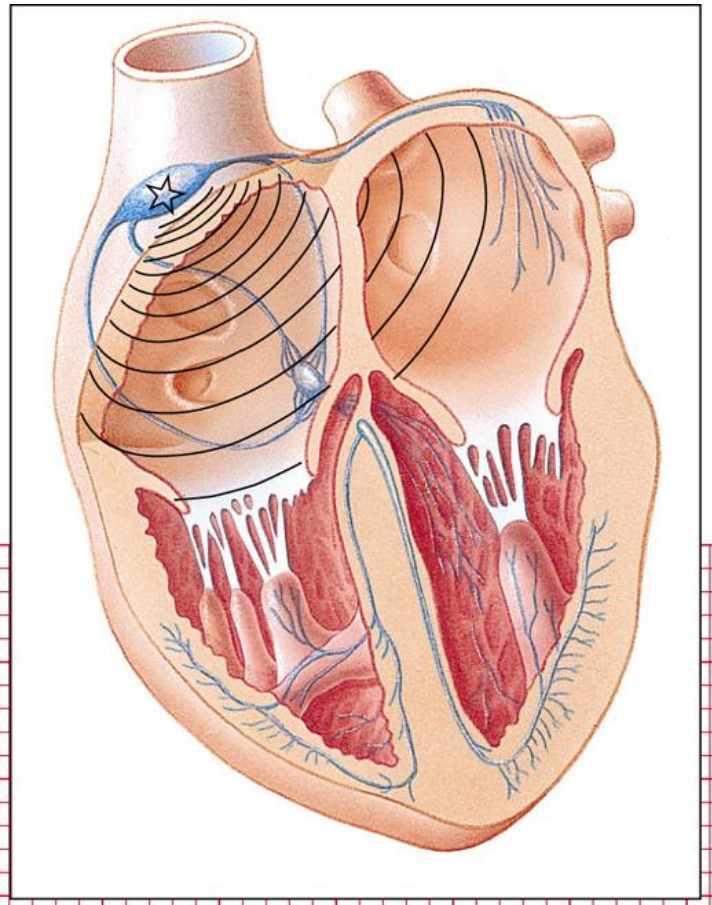


P Wave

Beginning of artial excitation

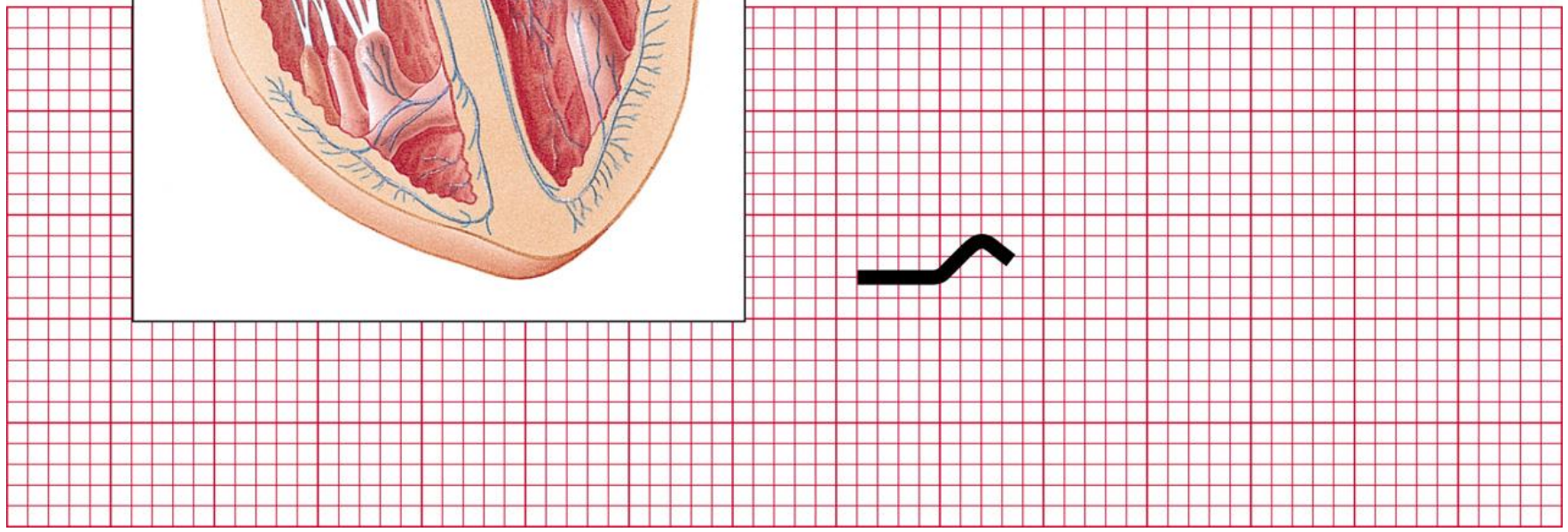


The Electrocardiogram

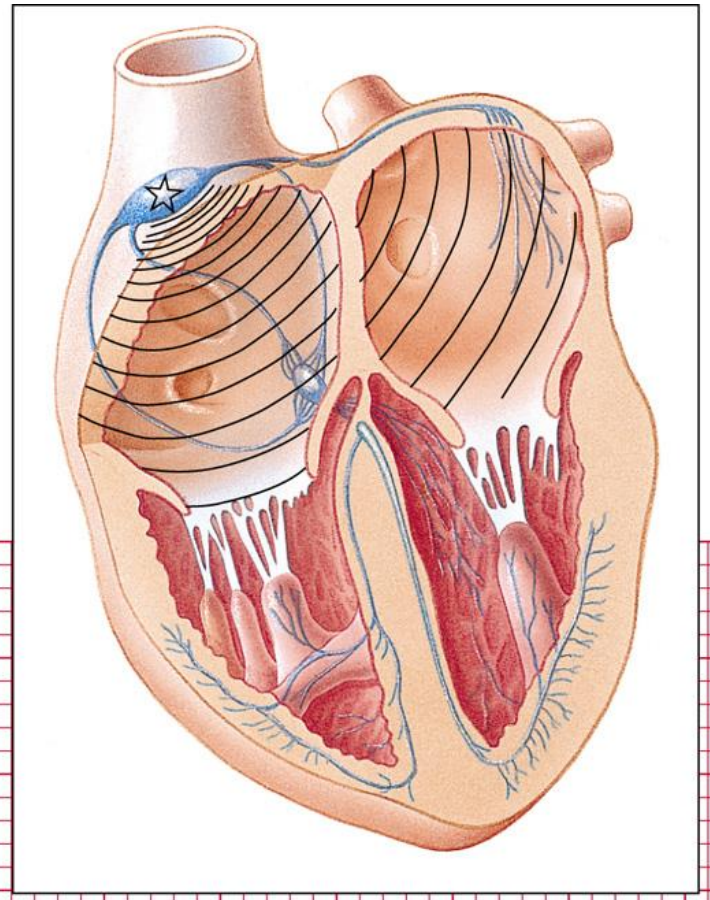


P Wave

Atrial excitation

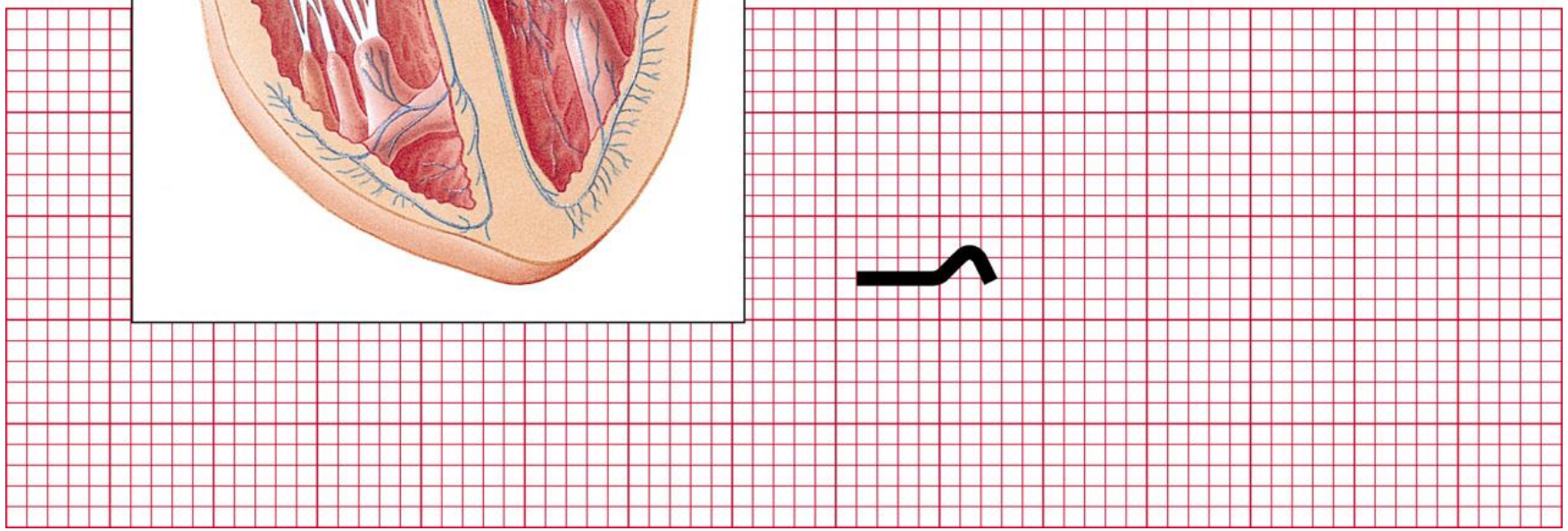


The Electrocardiogram

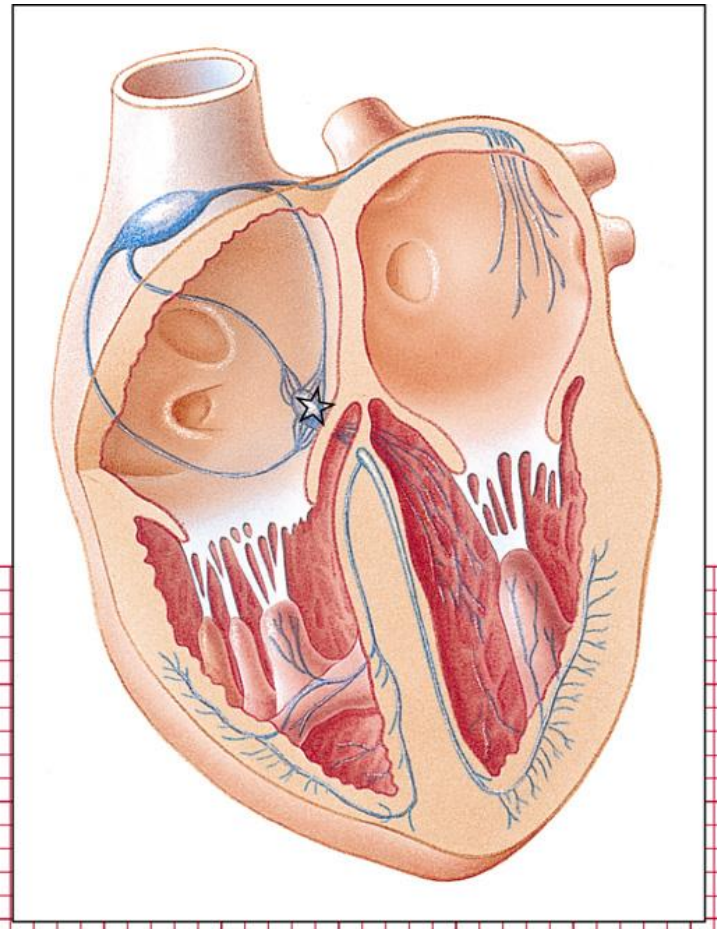


P Wave

Completion of atrial excitation

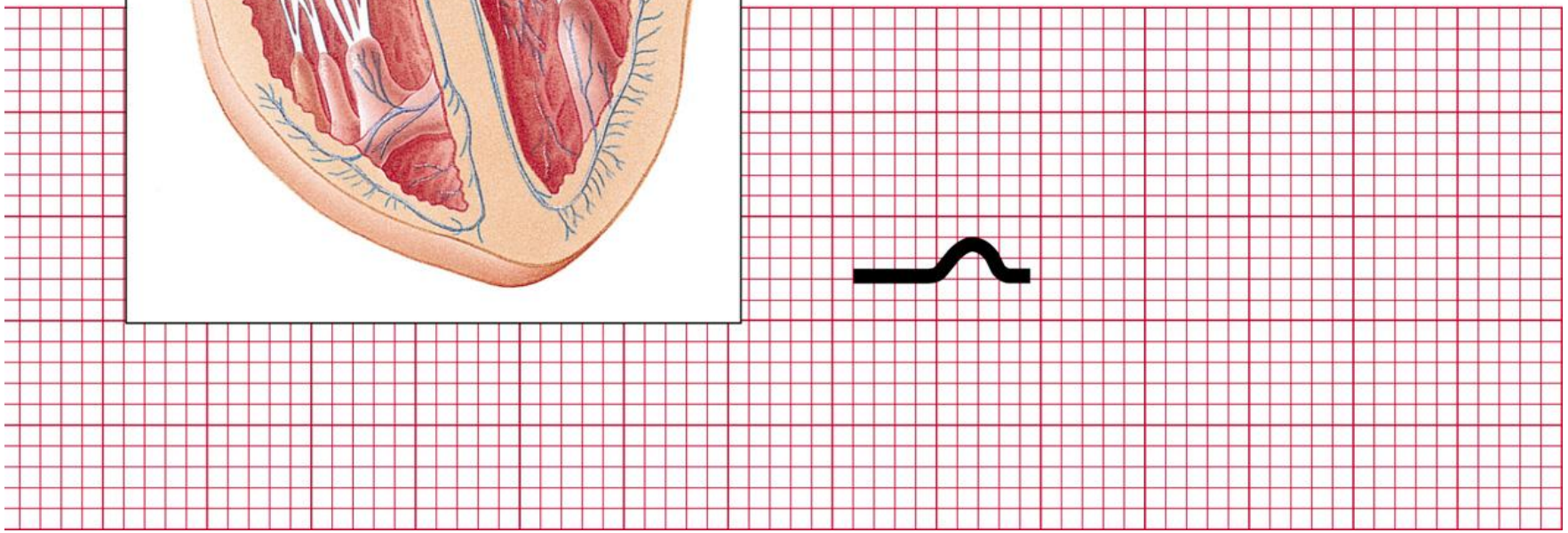


The Electrocardiogram

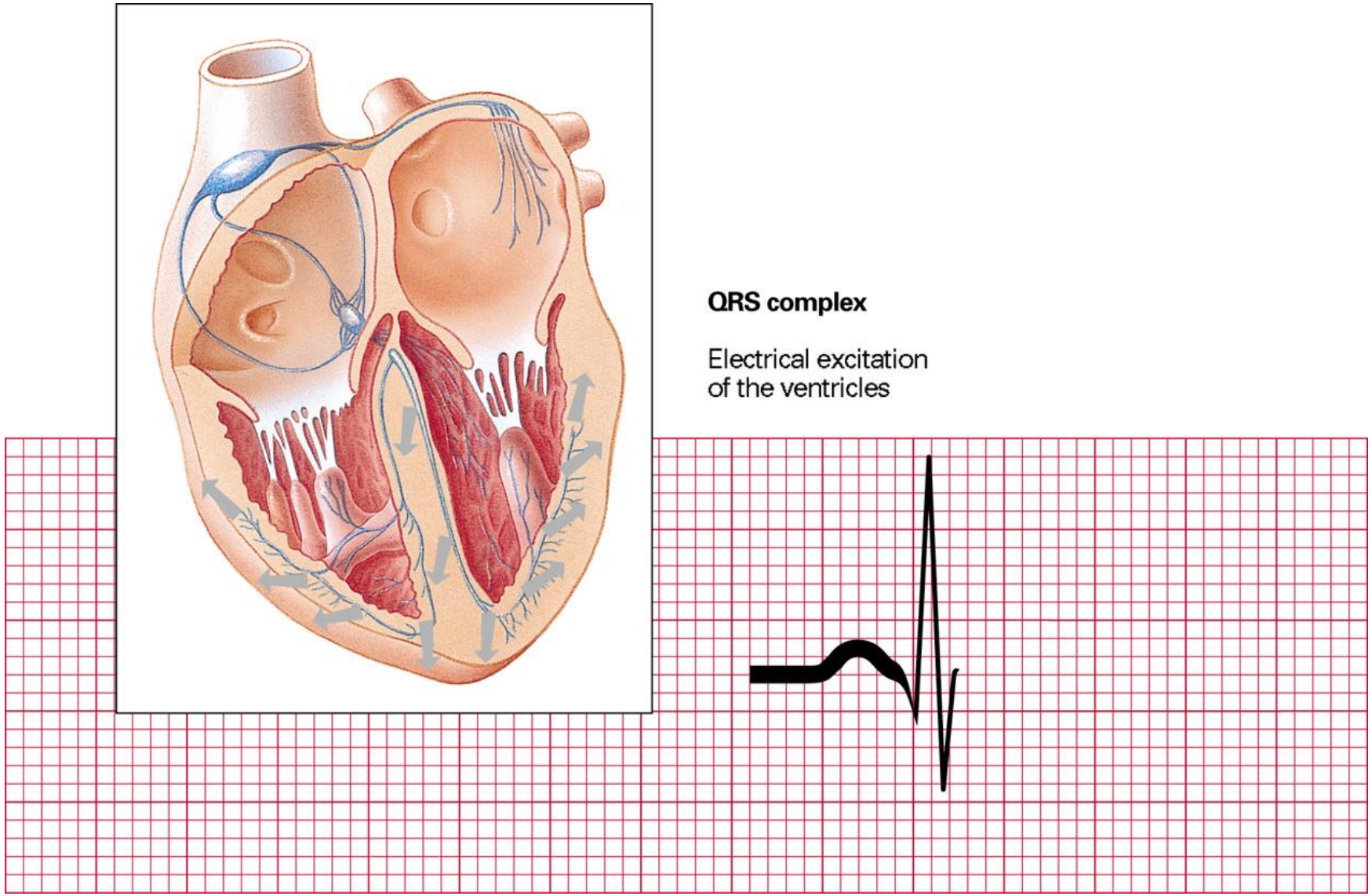


P-R Interval

Impulse delay at AV junction



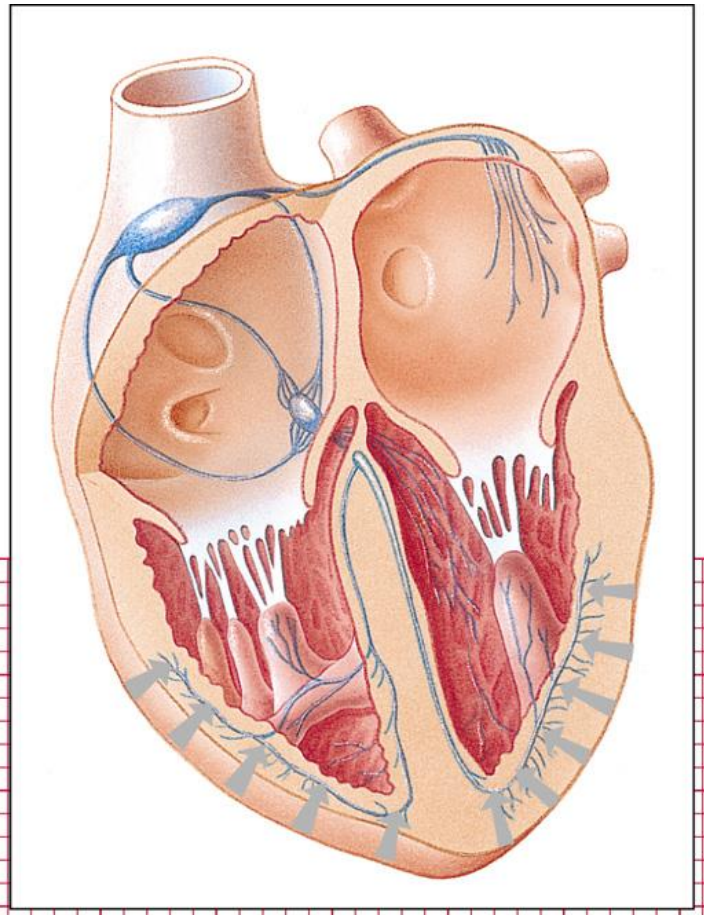
The Electrocardiogram



QRS complex

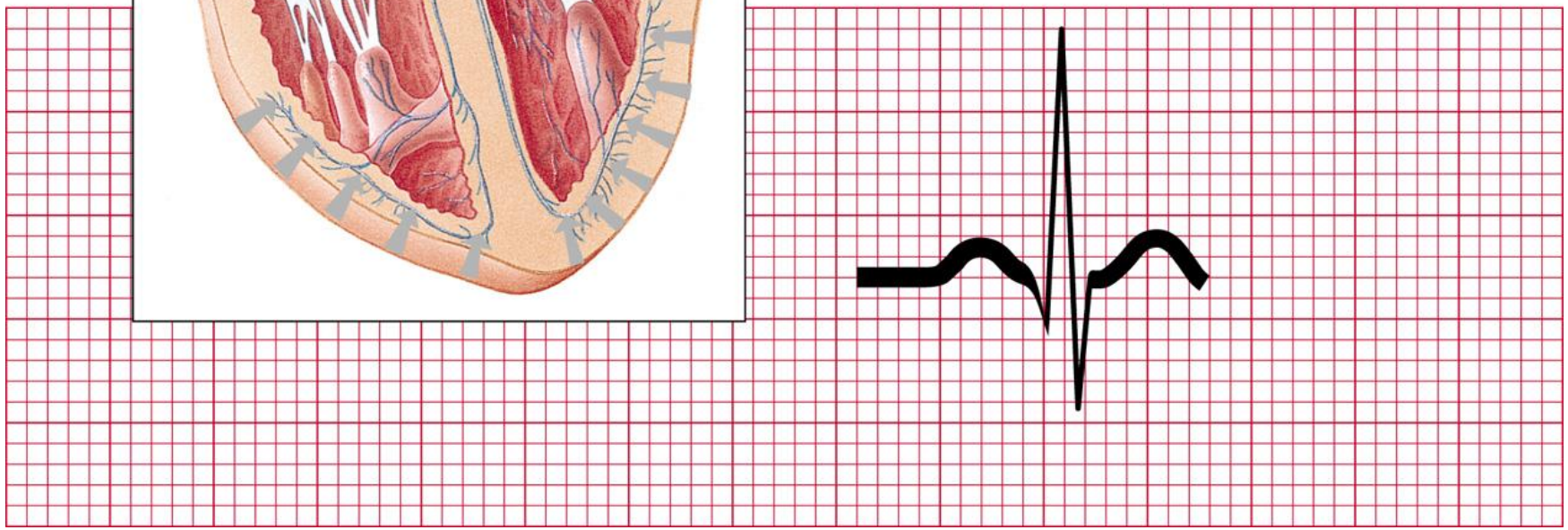
Electrical excitation
of the ventricles

The Electrocardiogram



T Wave

Ventricular repolarization



Rhythm Interpretation

- The use of 3-lead ECGs is mainly for underlying rhythm interpretation
- In order to efficiently interpret tracings, follow the same process each time

Rhythm Interpretation

- Rate
- Rhythm
- P Wave
- PRI
- QRS

Rate Calculations

- At this point, don't need to determine exact HR, just get approximation
- Can utilize various methods:
  - Heart Rate Rulers
  - Six-Second Method
  - R–R Interval
  - Triplicate Method

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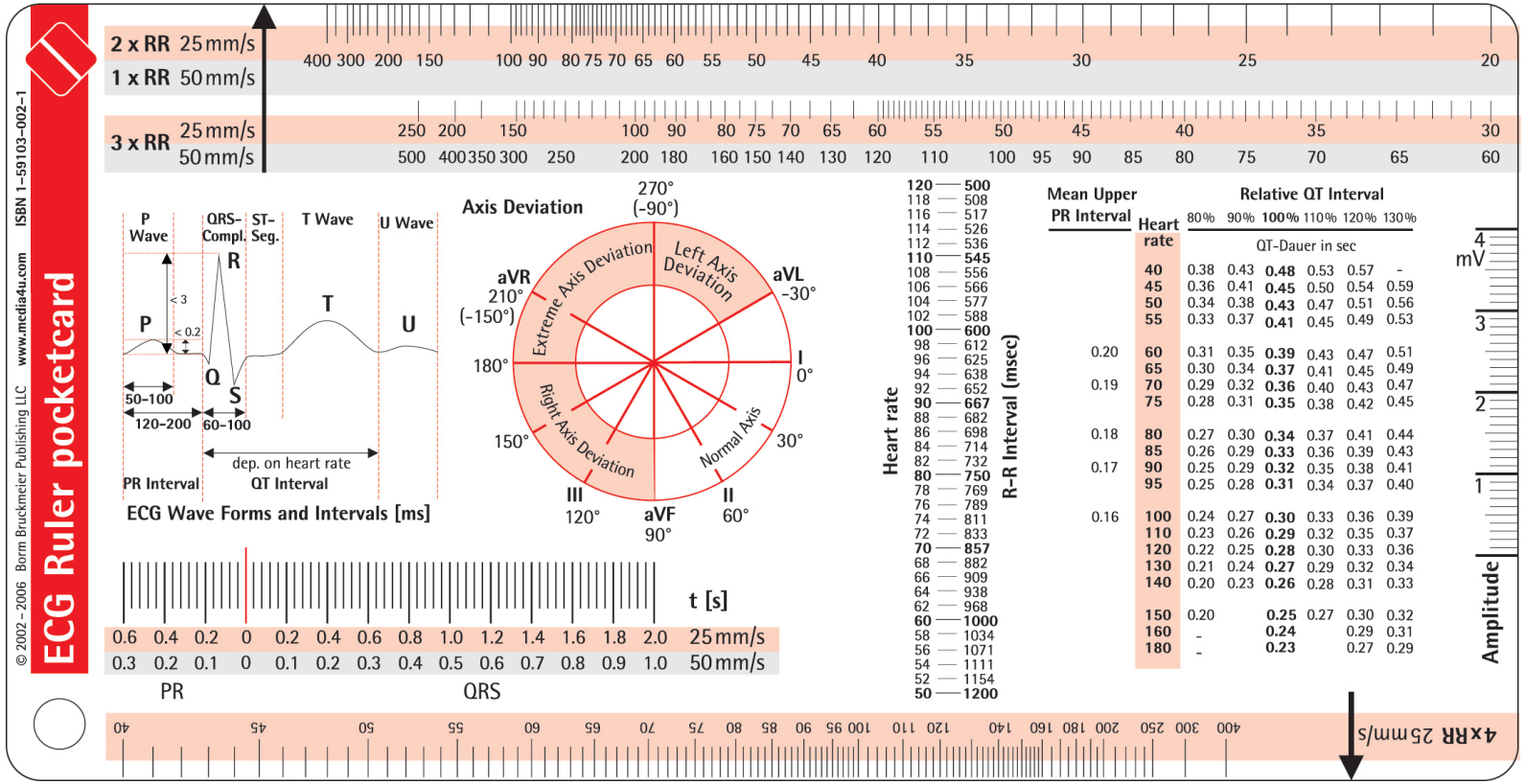
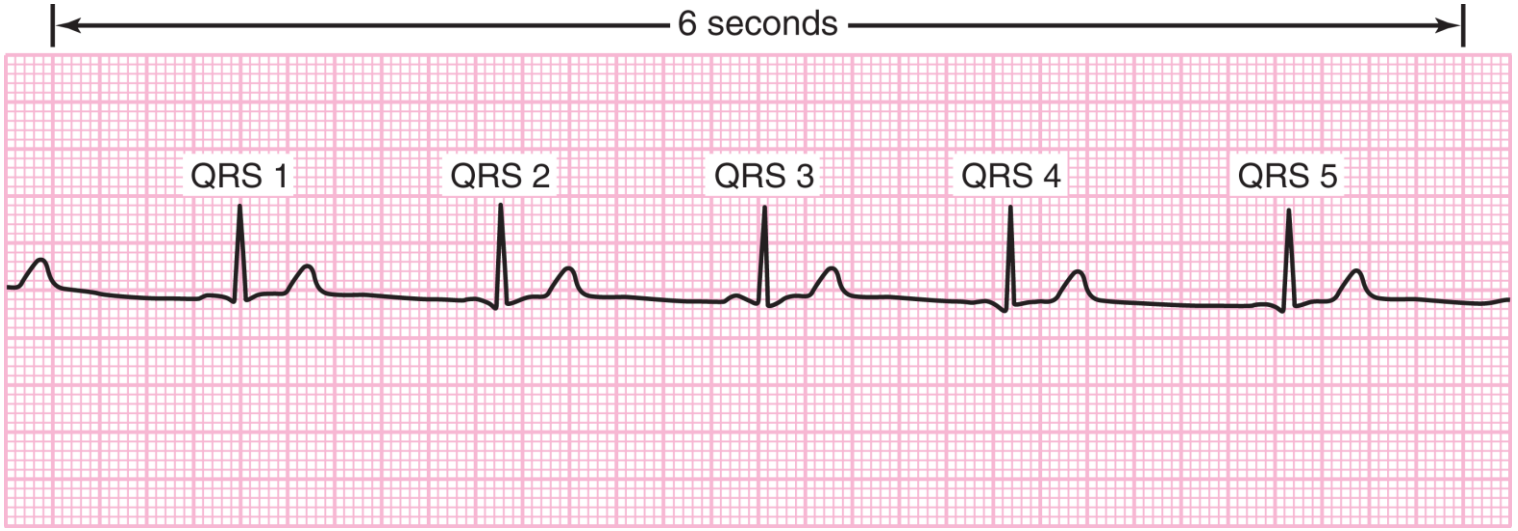
Rate Calculations

- Heart Rate Rulers



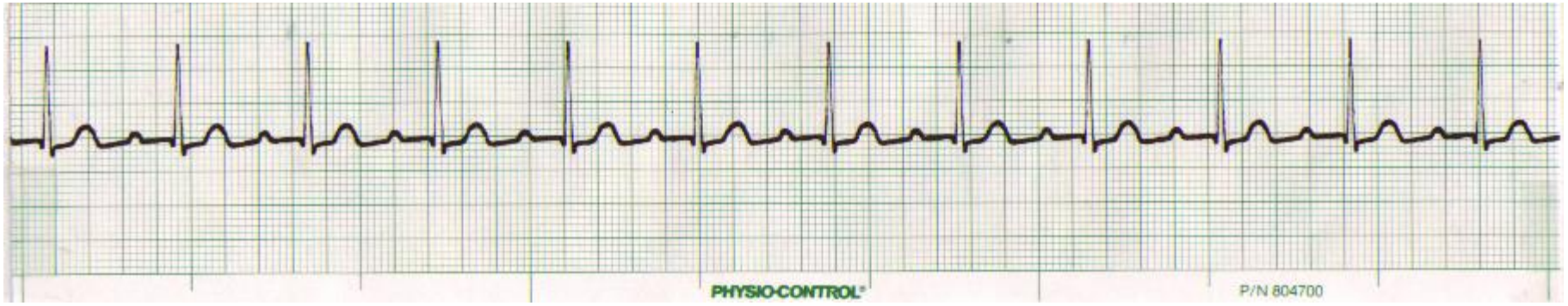
Rate Calculations

- Six Second Rule
  - Count the # of QRS complexes in 6 seconds and multiply by 10
    - Ex. 6 QRS complexes in 6 seconds = HR approx. 60 bpm
    - Works well for normal to bradycardic rhythms



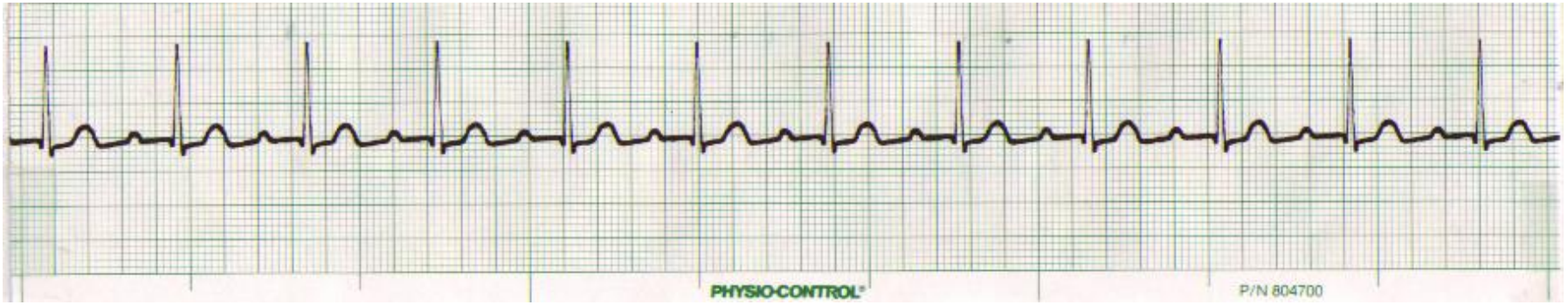
Rate Calculations

- Six Second Rule
  - If 3-second tick marks aren't visible, recall that:
    - 5 large boxes = 1 sec
    - 15 large boxes = 3 sec



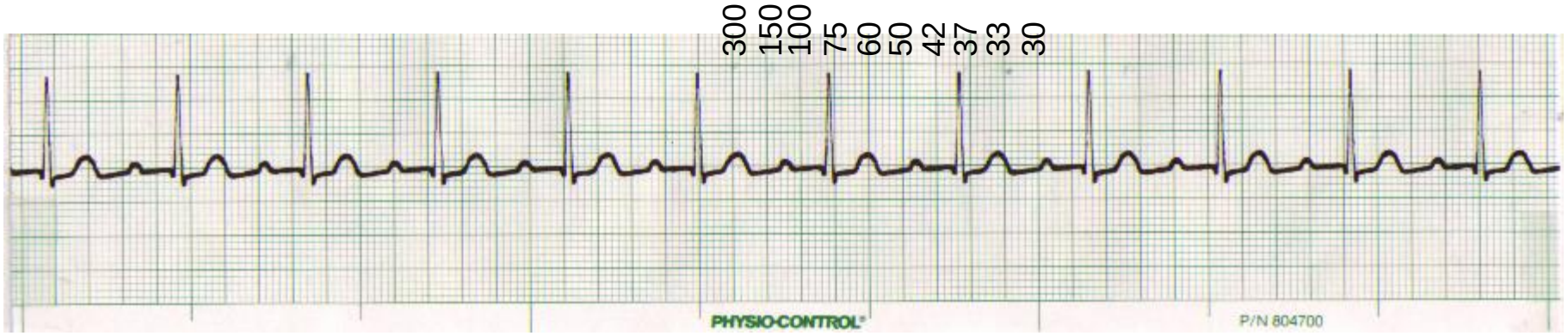
Rate Calculations

- R-R Rule
  - Works only if regular rhythm
  - Measure R-R Interval 3 ways:
    - Divide 60 by R-R in seconds (60/0.72 sec = 83)
    - Divide 300 by # of large squares in R-R (300/4 = 75)
    - Divide 1500 by # of small squares in R-R (1500/19 = 79)



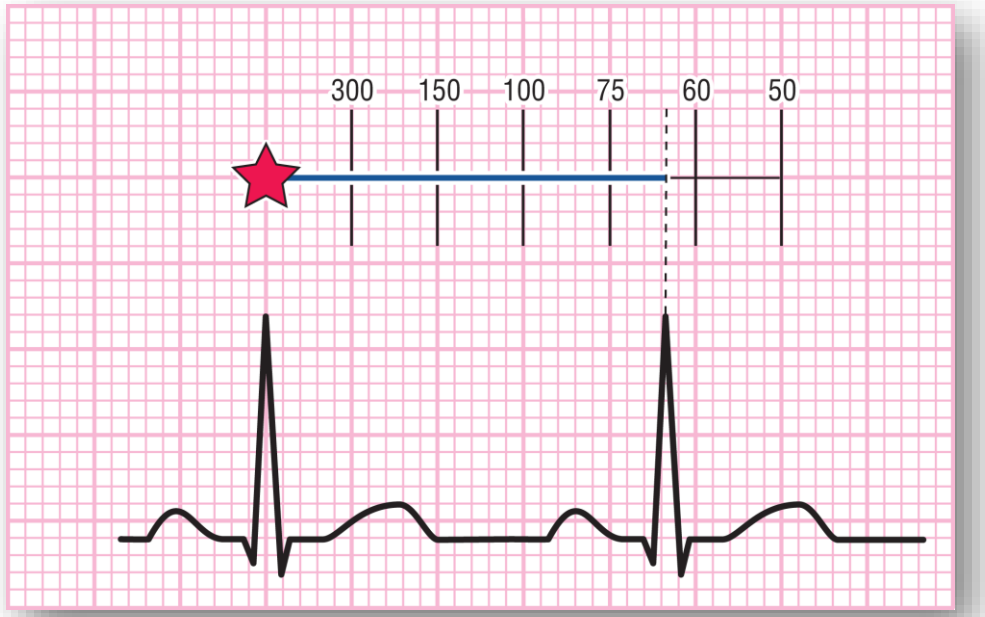
Rate Calculations

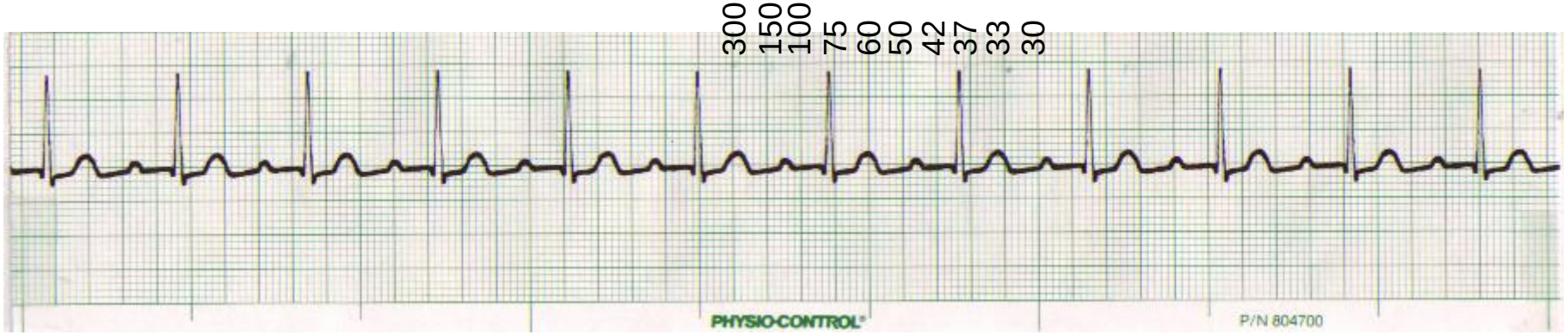
- Triplicate Method
  - Works only if regular rhythm
  - Better for faster rhythms
  - Required memorization of below numbers



Rate Calculations

- Triplicate Method
  - Locate a QRS peak that falls on thick line
  - Then locate the next QRS segment and determine its corresponding rate



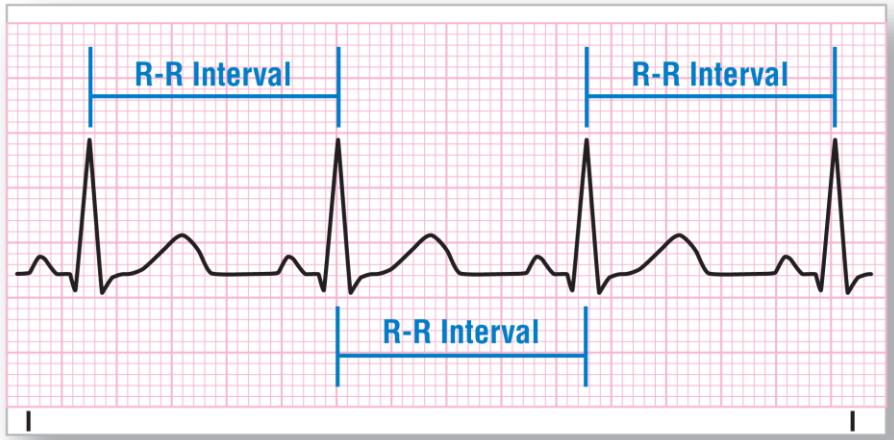


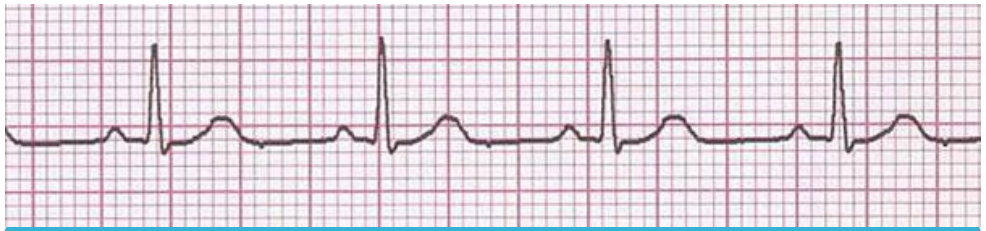
Rhythm Interpretation

- Rate
- Rhythm
- P Wave
- PRI
- QRS

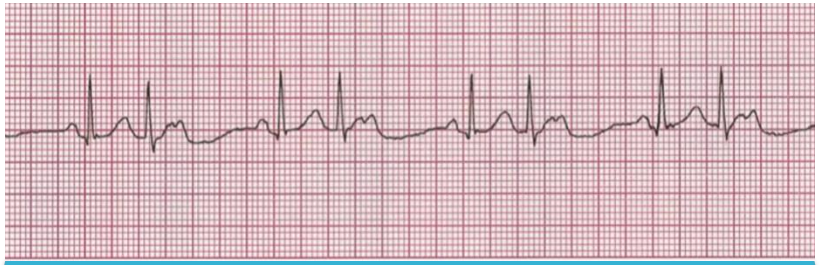
Rhythm

- Analyzing Rhythm
  - Determine the regularity of the rhythm

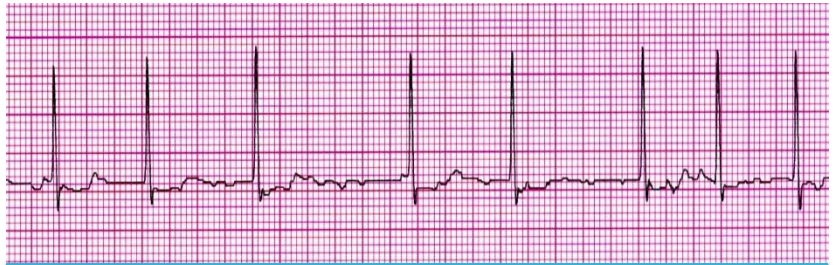




Regular



Regularly Irregular



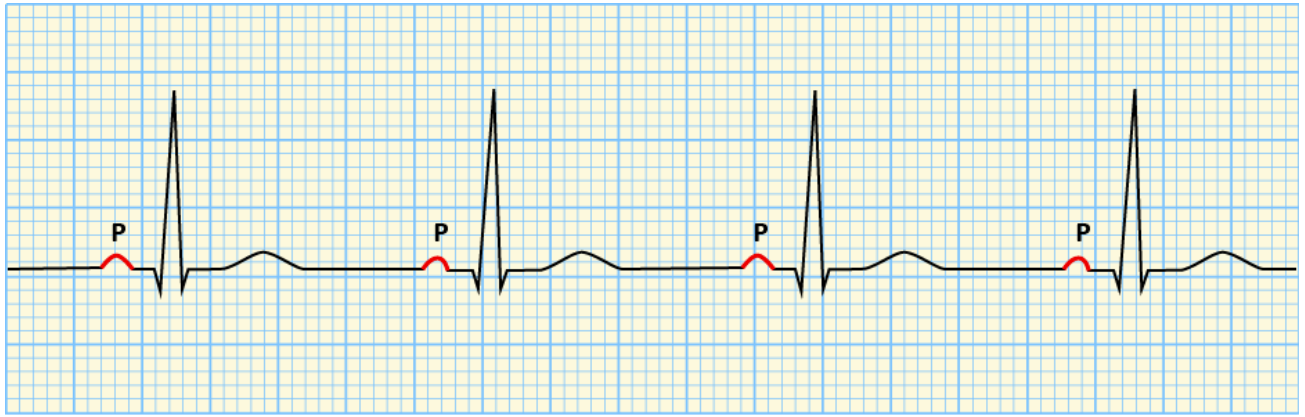
Irregularly Irregular

Rhythm Interpretation

- Rate
- Rhythm
- P Wave
- PRI
- QRS

P Waves

- When analyzing P Waves ask yourself:
  - Are P waves present?
  - Are the P waves regular in appearance?
  - Is there one P wave for each QRS complex?
  - Are the P waves upright or inverted?
  - Do all the P waves look alike?



P Waves

- What is there are no P waves?
  - No atrial depolarization
- What if there is more than one P wave for each QRS complex?
  - Possible AV block?
- What if the P wave is inverted?
  - Possible retrograde electrical movement from a junctional rhythm?
- What if there P waves with different appearance?
  - Depolarization occurring in different atrial locations = multiple atrial foci

Rhythm Interpretation

- Rate
- Rhythm
- P Wave
- PRI
- QRS

P-R Interval

- What is the P–R Interval?
  - Recall normal is 0.12 – 0.20 seconds (3-5 small boxes)
- What if it is shorter?
  - Means there is a shorter pause between atrial and ventricular depolarization
    - Possible finding with WPW
- What if it is longer?
  - Means there is a longer pause between atrial and ventricular depolarization
    - Possible finding with AV blocks

Rhythm Interpretation

- Rate
- Rhythm
- P Wave
- PRI
- QRS

QRS Complex

- What is the width of the QRS complex?
  - Recall normal is 0.04 - 0.12 seconds (1-3 small boxes)
- What if it is more narrow?
  - Means the depolarization of the ventricles is happening quicker than normal
    - Not a typical finding
- What if it is wider?
  - Means the depolarization of the ventricles is happening slower or depolarization of the R and L ventricles are not happening concurrently
    - Possible finding with ventricular rhythms
    - Could represent a BBB

Overdrive Suppression

- When the conduction system of the heart is functioning normally, the rate is paced by the SA node
  - This area paces the heart at a normal intrinsic rate of 60 - 100bpm
- As a result of this rate, the remaining regions of the conduction system are suppressed from pacing at their own intrinsic (and slower) rates
  - This is known as overdrive suppression

Overdrive Suppression

The possible pacemaking sites of the heart and their intrinsic rates are:		
SA node (Atria)	AV node (Junction)	Purkinje fibers (Ventricles)
60 – 100 bpm	40 – 60 bpm	20 – 40 bpm

- When the SA node is working properly it overdrives the junction and ventricles
  - If the SA node failed, the junction would take over pacemaking at it's intrinsic rate

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Cardiovascular Electrophysiology

DYSRHYTHMIAS

Dysrhythmias

- May or may not be clinically significant
- Evaluate the dysrhythmia in the context of the patient's overall clinical condition.
- Treat the patient and the monitor

Table 30-14 Causes of Cardiac Dysrhythmias

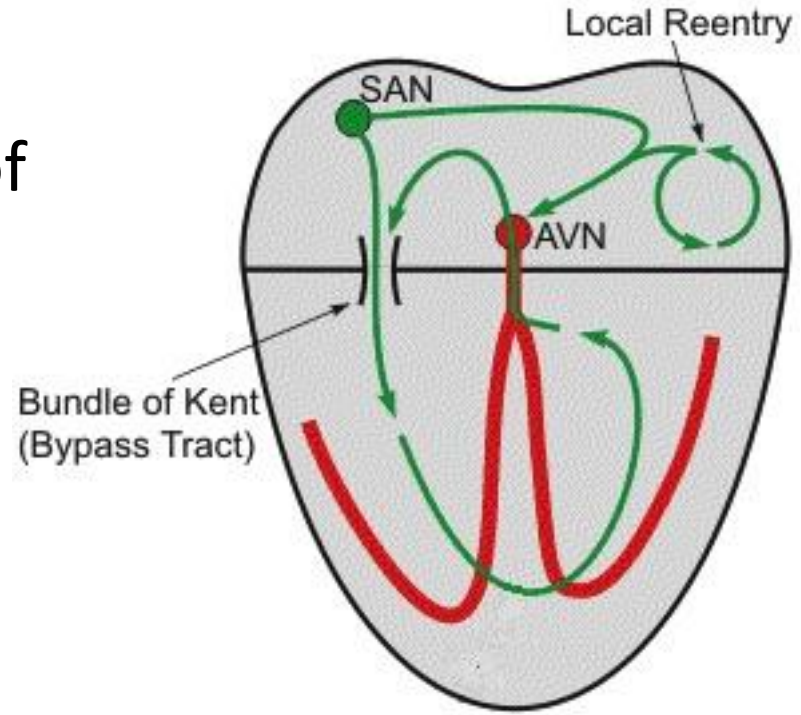
- Acid–base disturbance
- Autonomic nervous system imbalance
- Central nervous system damage
- Certain poisons (eg, organophosphate insecticides)
- Cor pulmonale (right ventricular failure caused by pulmonary disease)
- Distention of cardiac chambers (as in heart failure)
- Drug effects (phenothiazines, tricyclic antidepressants, and medications used to treat dysrhythmias)
- Electrolyte disturbances, especially those involving potassium, calcium, or magnesium
- Endocrine disorders (hyperthyroidism, hypothyroidism)
- Hypothermia
- Hypoxemia from any cause
- Increased sympathetic output
- Increased vagal (parasympathetic) tone
- Myocardial ischemia or infarction
- Normal variation
- Rheumatic heart disease
- Trauma (eg, cardiac contusion)

Impulse Formation

- Normally, cardiomyocytes in the conduction pathway of the heart conduct the impulse for depolarization
- However at times, other cardiomyocytes outside the conduction pathway can also form an impulse
  - When this occurs, these cardiomyocytes are known as **ectopic foci**
  - These irritable cells can produce a single extra beat = **ectopic beat**

Impulse Formation

- Other than ectopic foci, another impulse abnormality that can occur is re-entry
- Re-entry
  - Disease or ischemia produces two branches of a pathway
  - Impulses re-enter conduction pathway in opposite direction (local re-entry) or via a direct conduction path from the atria to the ventricles (global re-entry)



Classification of Dysrhythmias

- When interpreting rhythms, dysrhythmias are classified based on:
  - Nature of origin
    - Changes in automaticity versus disturbances in conduction
  - Magnitude
    - Major versus minor
  - Severity
    - Life threatening versus non-life threatening
  - Site of origin

Classification by Site of Origin

- Dysrhythmias originating in the SA Node
- Dysrhythmias originating in the atria
- Dysrhythmias originating within the AV junction
- Dysrhythmias originating in the ventricles
- Dysrhythmias resulting from disorders of conduction