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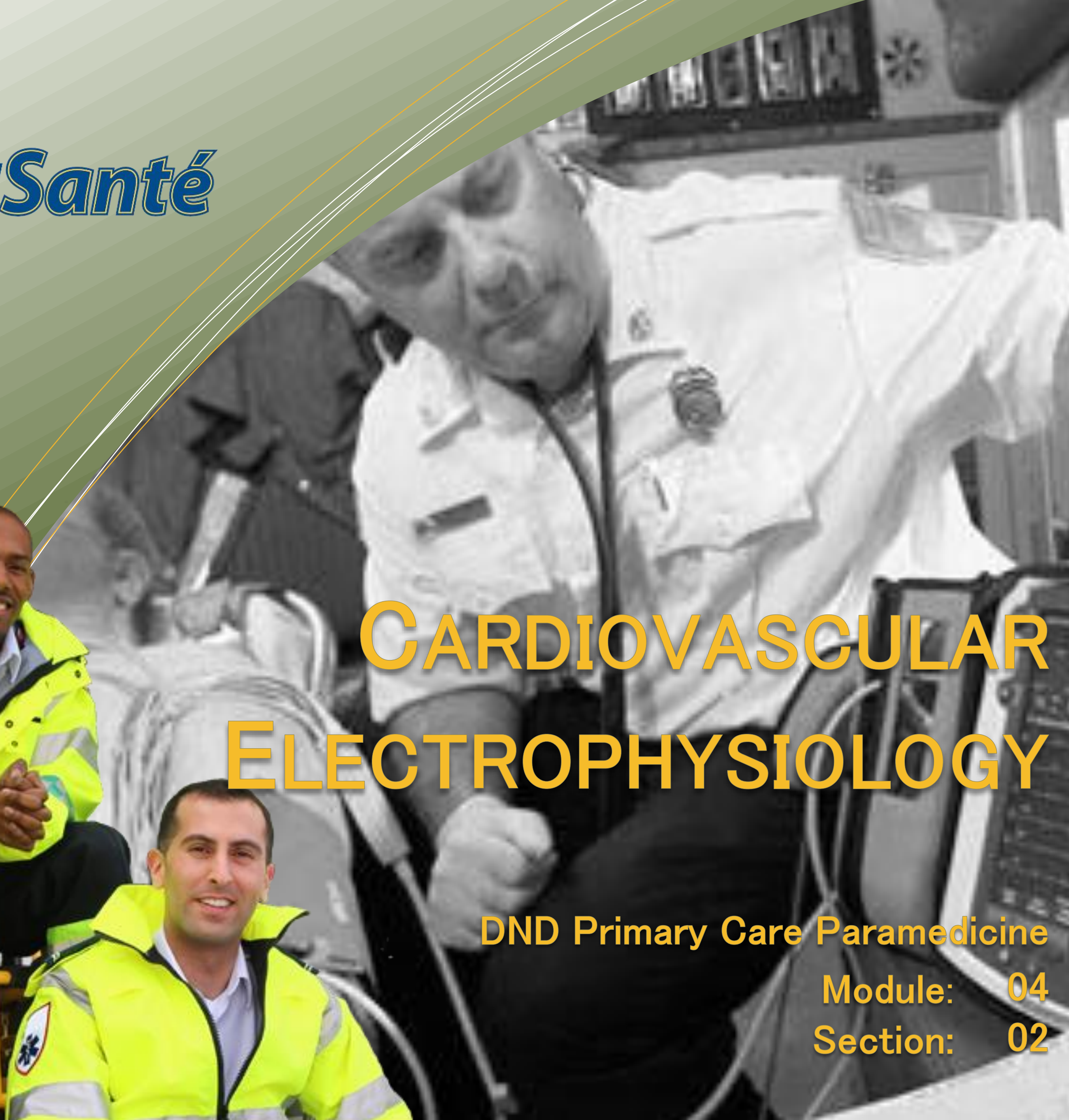

Cardiovascular Electrophysiology

DND Primary Care Paramedicine

Module: 04

Section: 02

Electrophysiology

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

Cardiovascular Electrophysiology

MYOCARDIAL ACTION POTENTIAL

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Myocardial Action Potential

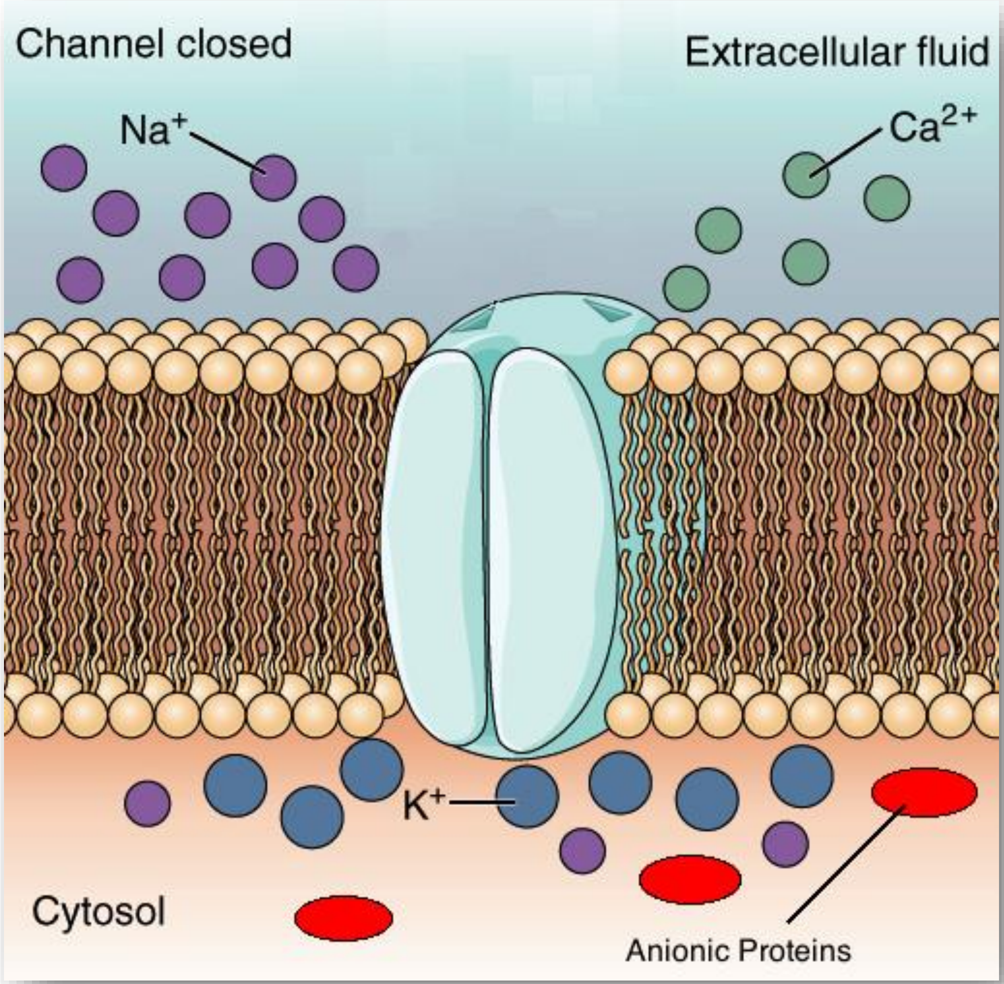
- Cardiac muscle tissue is comprised of unique muscle cells called cardiomyocytes
- Stimulation for contraction occurs in a similar fashion to that of skeletal or smooth muscle cells, however cardiac myocytes have some unique properties.
  - Prolonged action potential
  - Opening of Ca^{2+} channels

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**



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Resting Membrane Potential

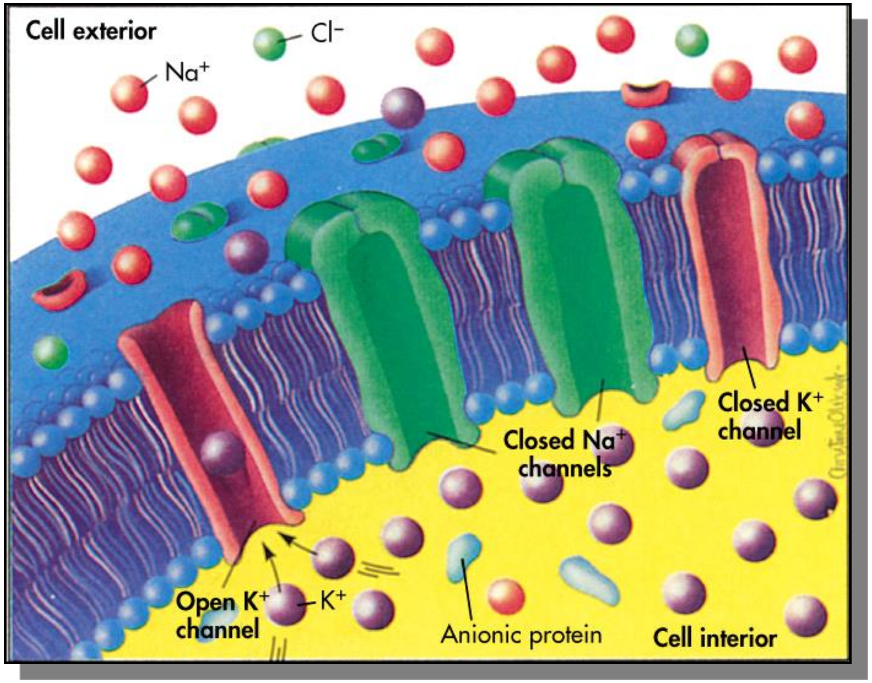
- When not stimulated, the cardiomyocyte is said to be at **Resting Membrane Potential**
- At this time the inside of the cell (cytosol) is more negatively charged than the outside (ECF)
  - The difference in charge from one side of the membrane to the other is -90 mV (RMP)
  - Cytosol negative due to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

Resting Membrane Potential

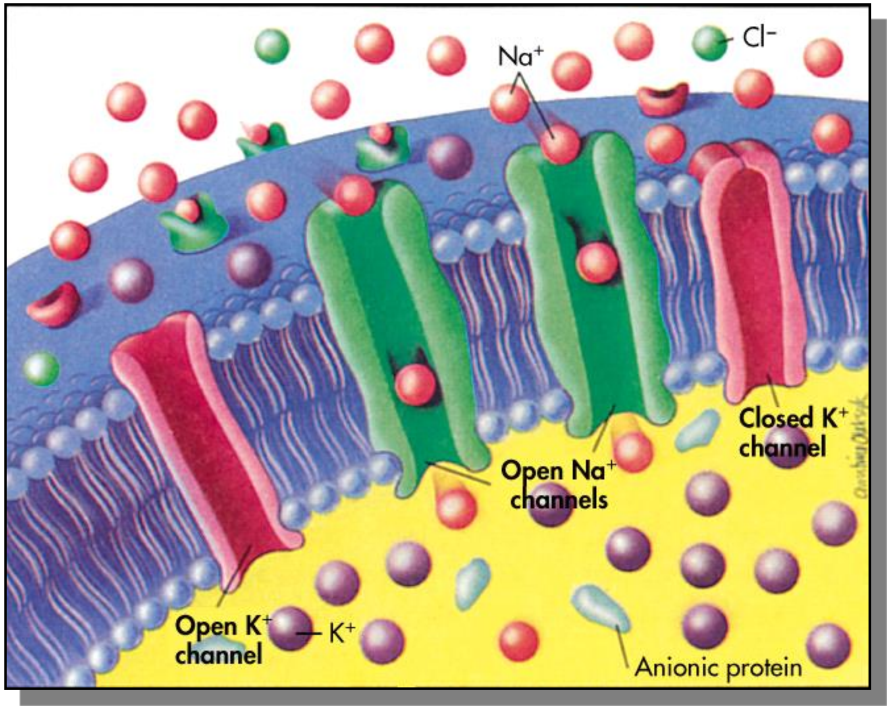
- With more positive charge in the ECF and more negative charge in the cytosol the membrane is now **polar**
- When the charges on either side of the membrane are equal the membrane is non polar.
- The process that changes the membrane from polar to non polar is called **depolarization**
- A process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



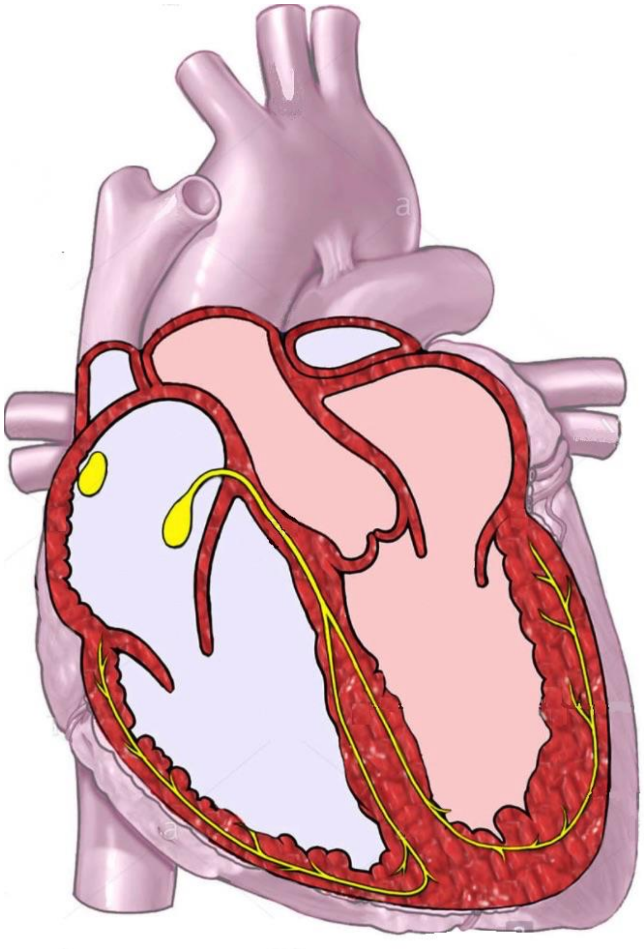
Ion Channels



- 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:
  1. Pacemaker cells
  2. 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

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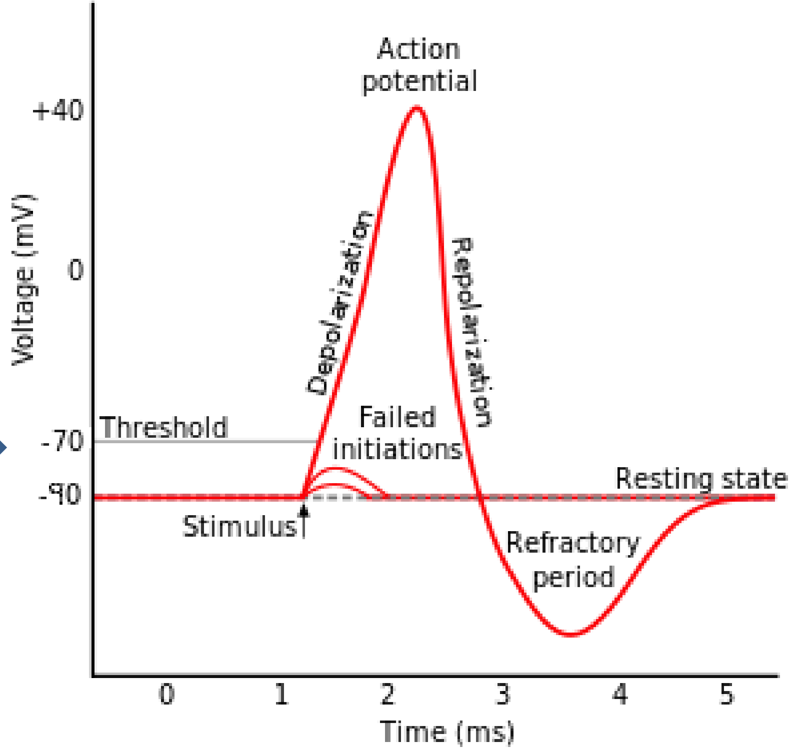
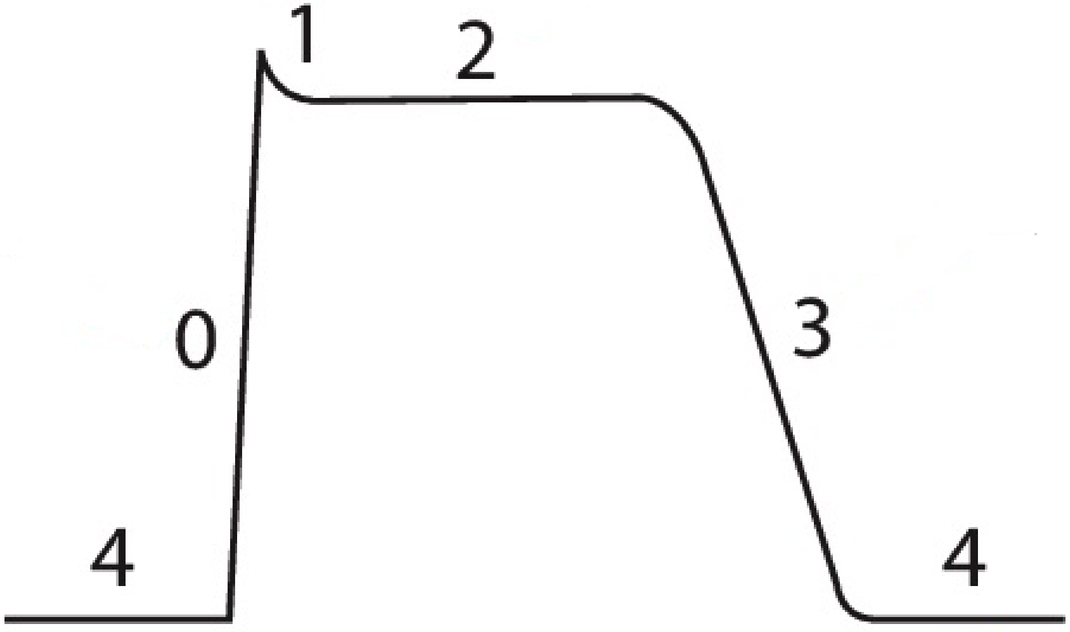
Threshold Potential

- 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



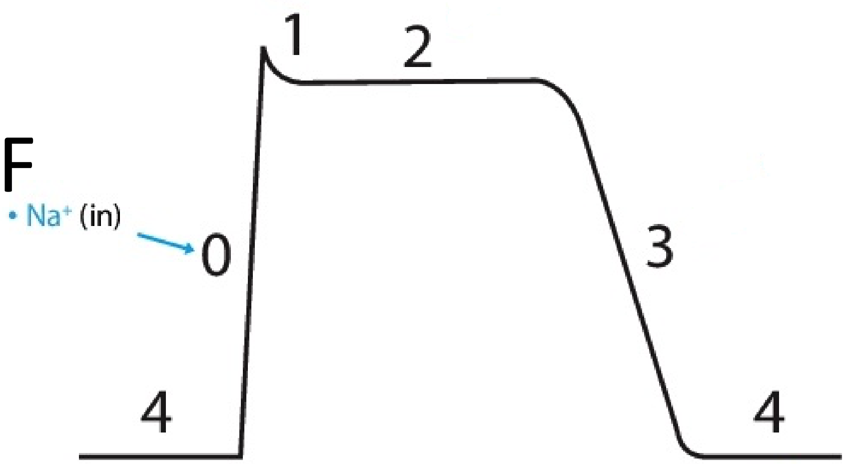
Cardiac Action Potential

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



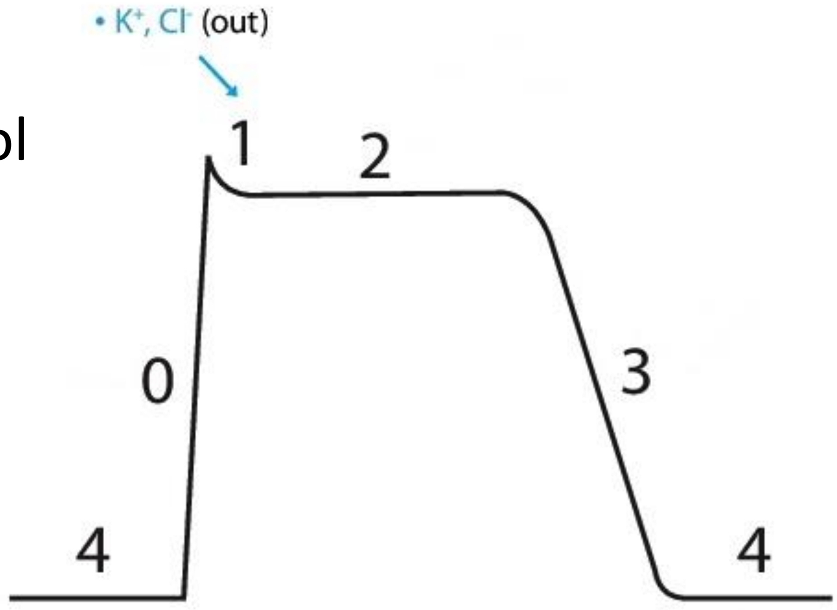
Phase 0
Rapid Depolarization Phase

- 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



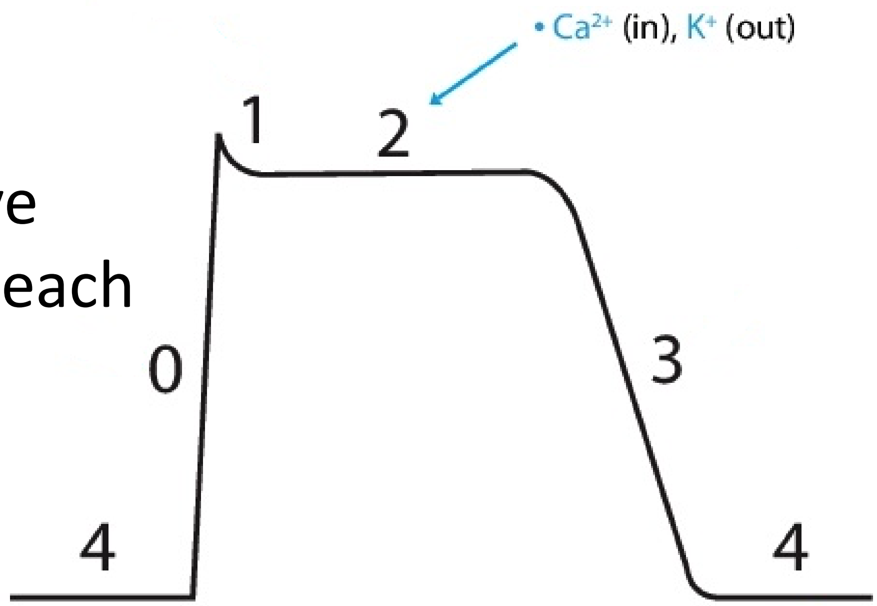
Phase 1
Early Repolarization Phase

- 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



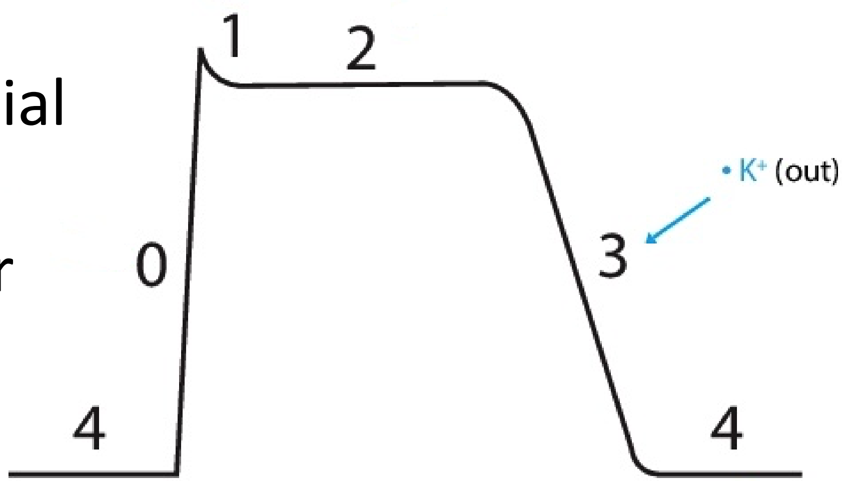
Phase 2
Plateau Phase

- 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)



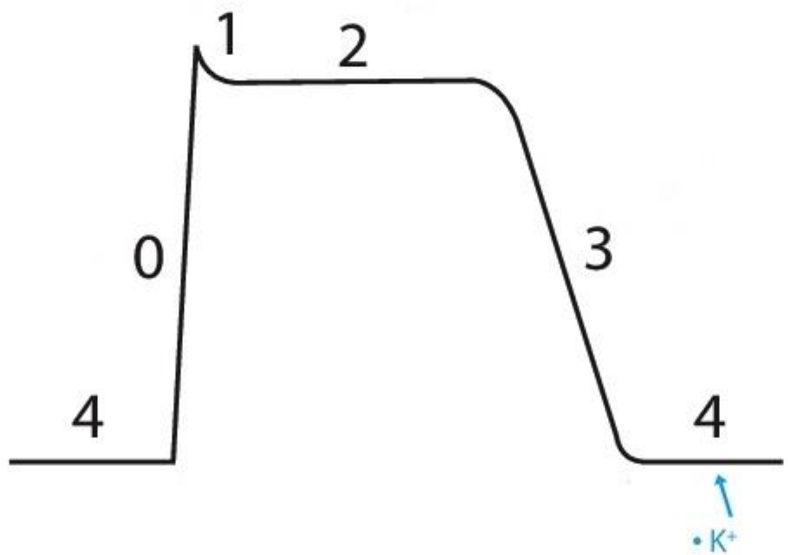
Phase 3
Terminal Repolarization Phase

- 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

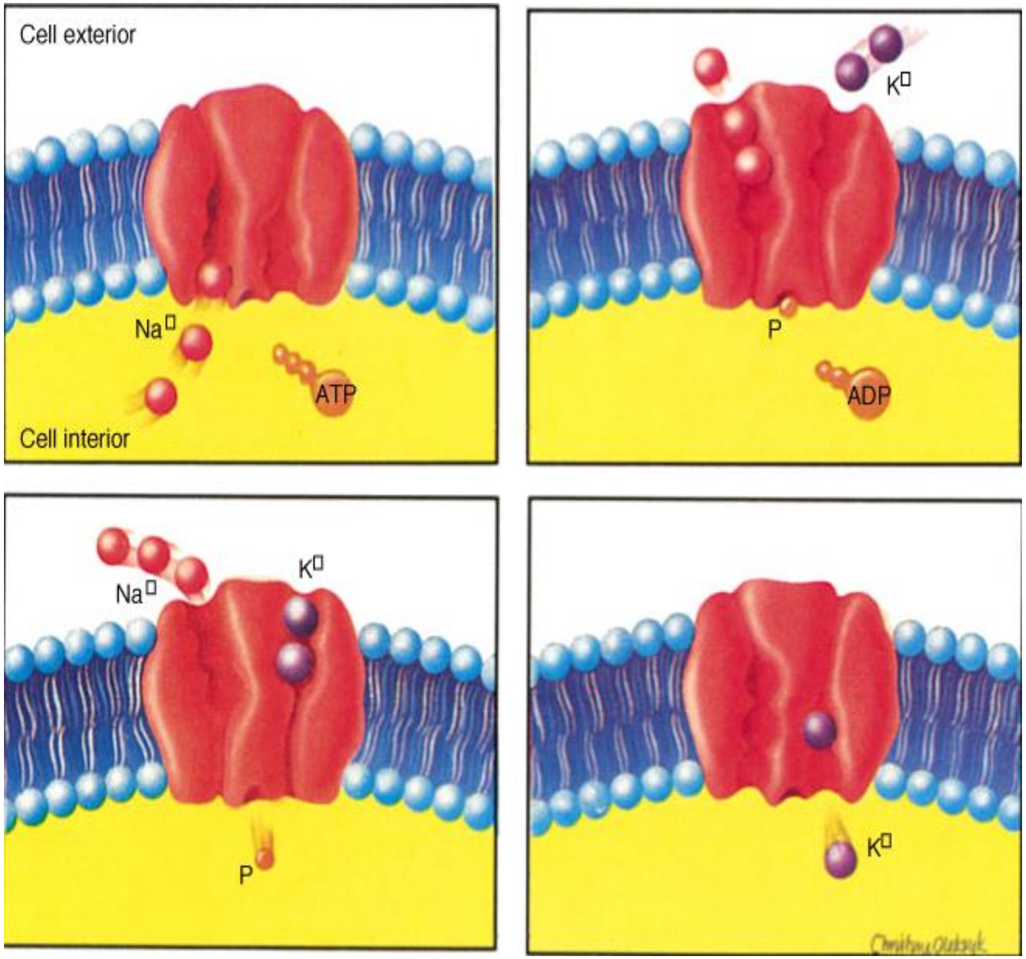


Phase 4
Resting phase

- At the end of an action potential, the membrane is back to RMP, however the electrolytes are not in their proper locations
- Na^+ and $Ca2^+$ 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



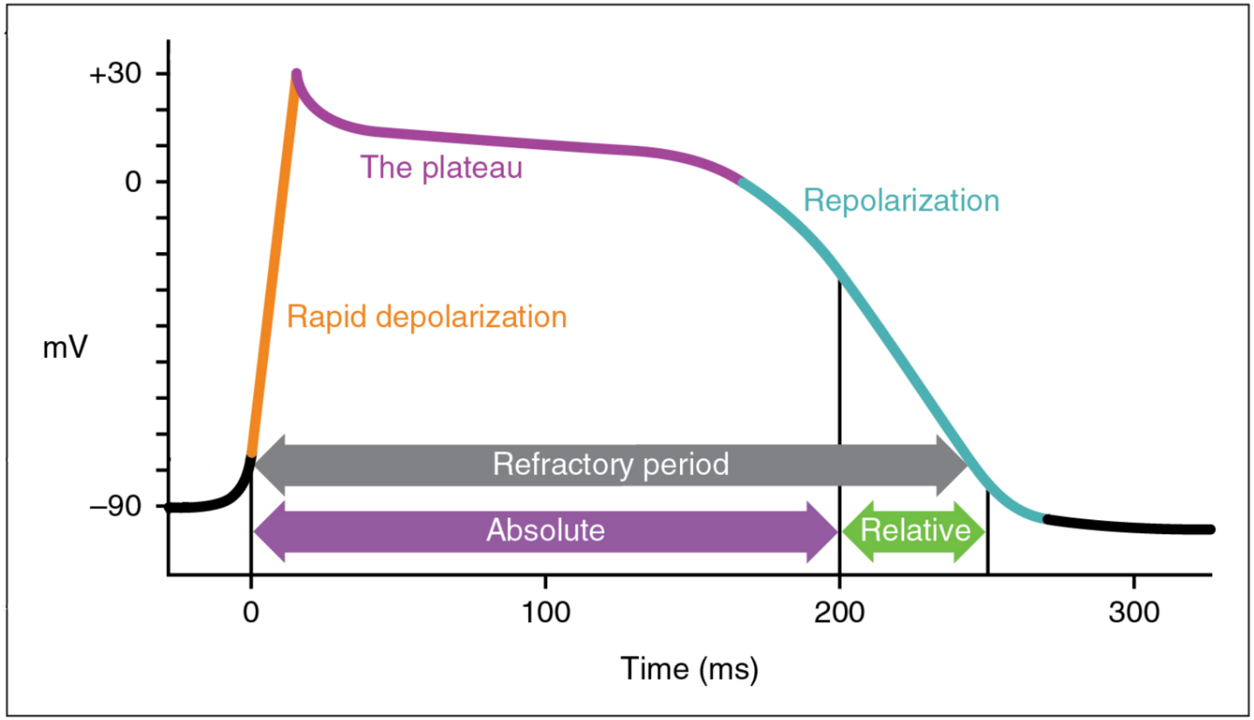
Phase 4
Na-K Pump (Na+/K+-ATPase)



- 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

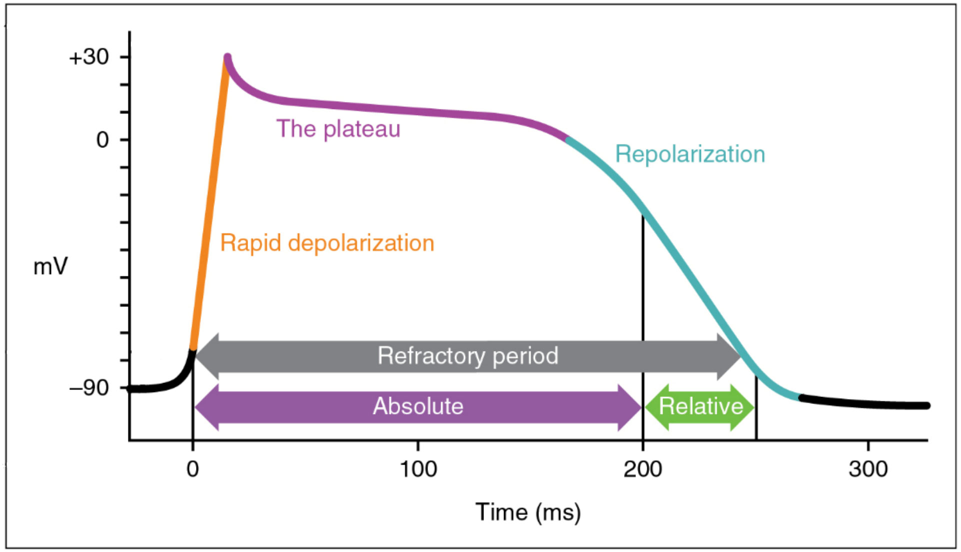
Refractory Period

- 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

- That refractory period can either be:
  1. Absolute Refractory
     - No further stimulus, no matter how strong, will initiate another action potential
  2. Relative Refractory
     - A greater than normal stimulus is needed to initiate another action potential

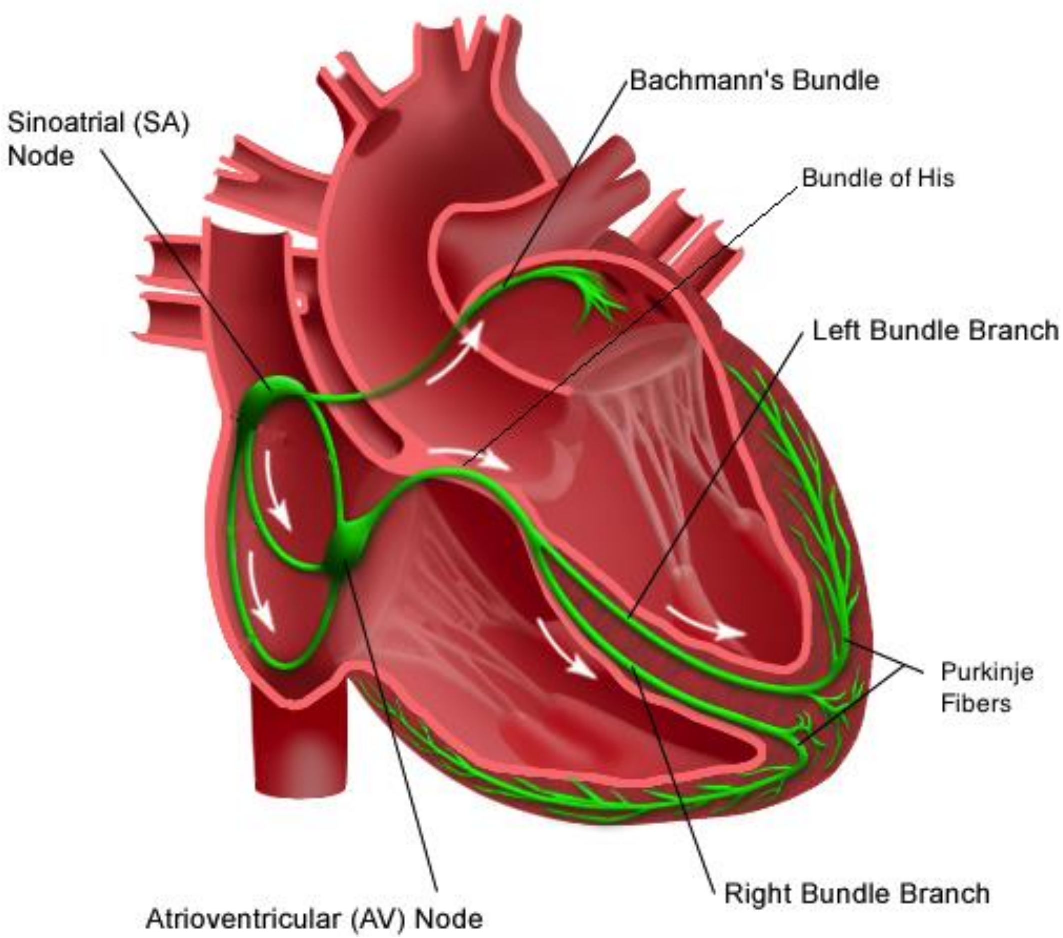


Cardiovascular Electrophysiology

COMPONENTS OF AN ELECTROCARDIOGRAM

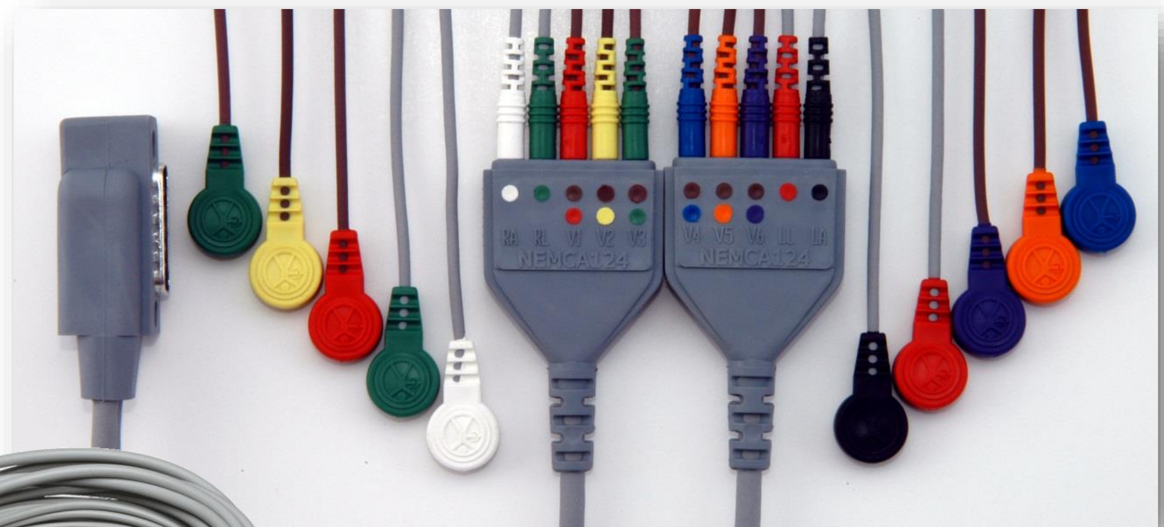
Electrical Conduction System

SA node→ AV node → Bundle of His→ Bundle Branches → Purkinje Fibers



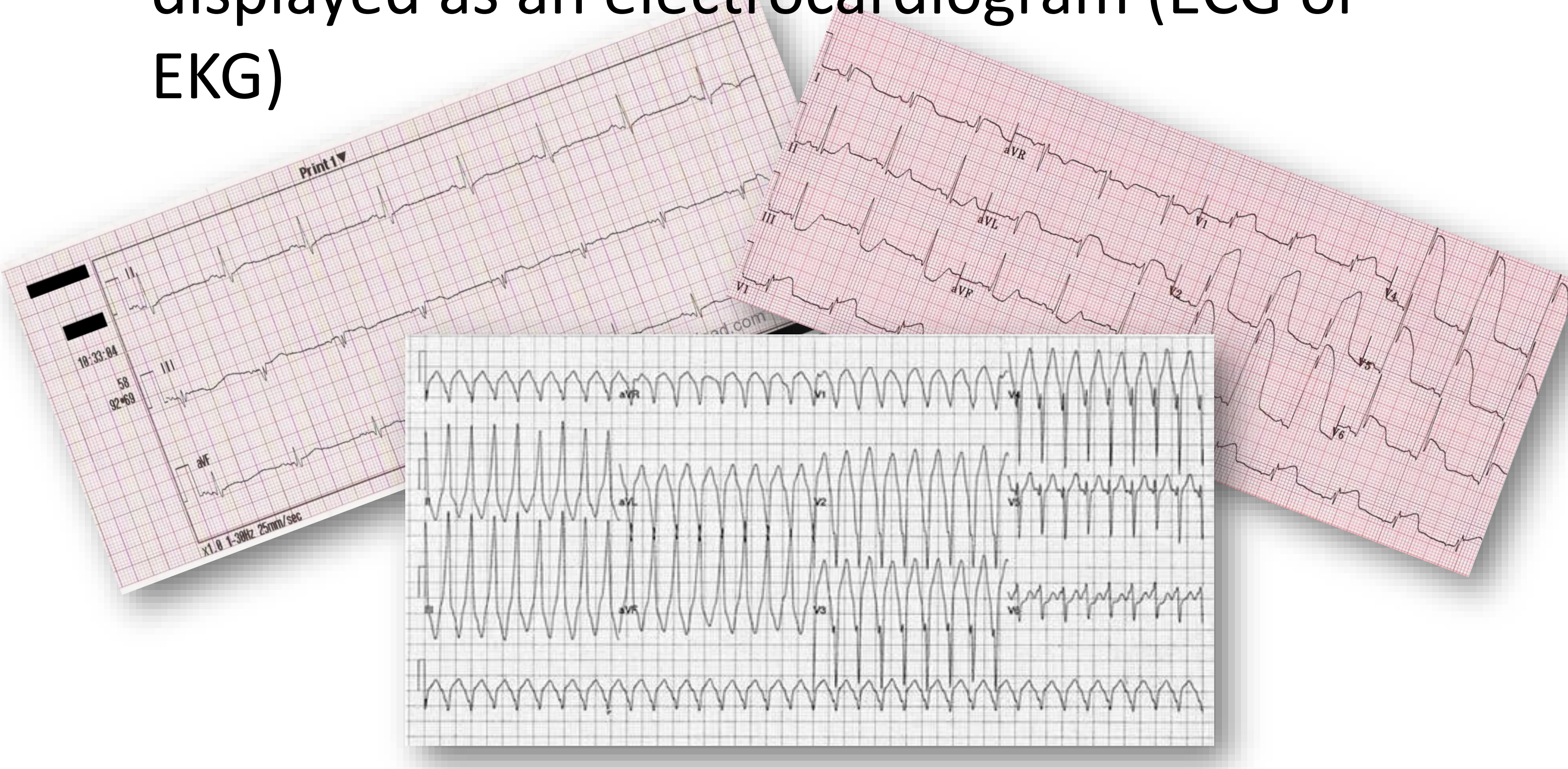
Electrocardiogram

- 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)

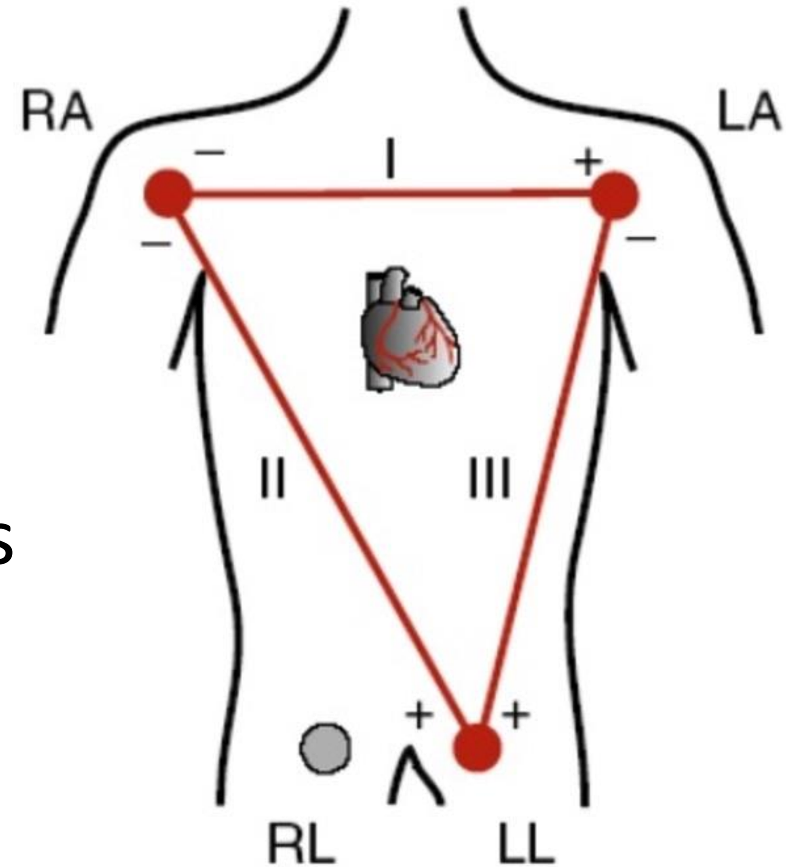


Willem Einthoven

- 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)

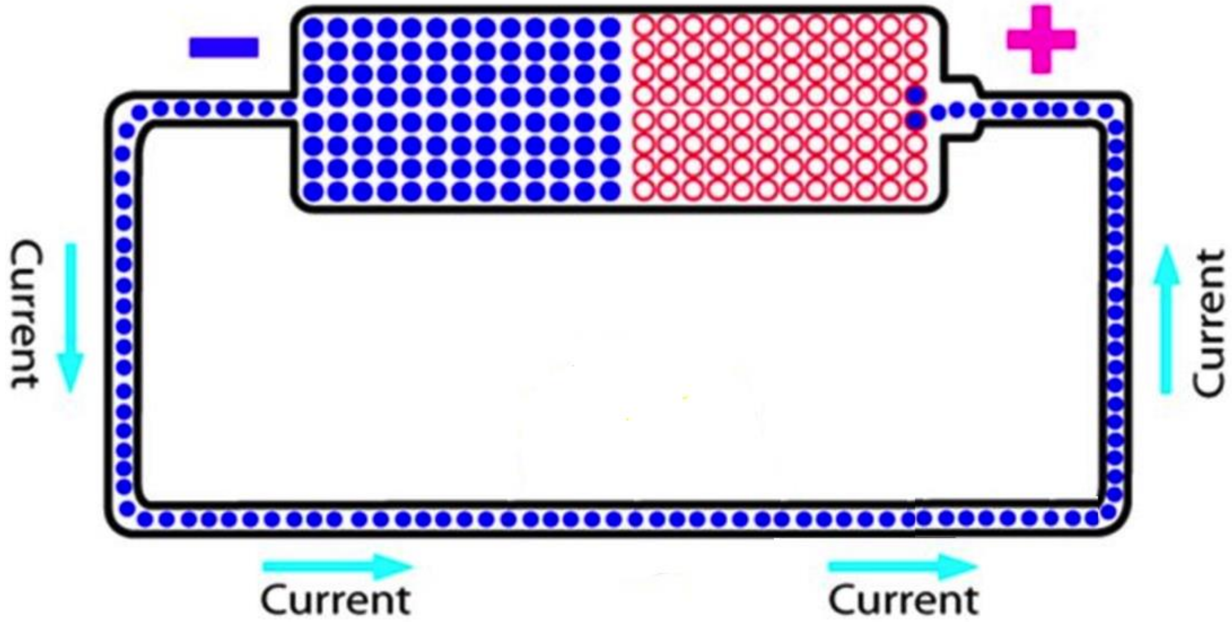
Einthoven's Triangle

- 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



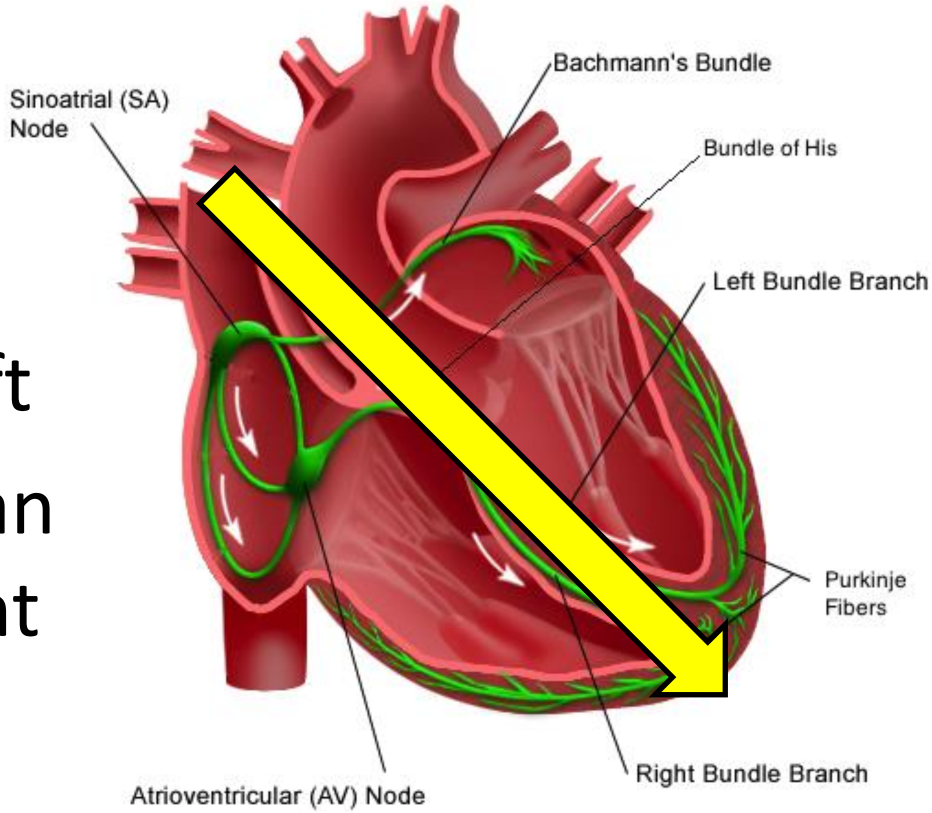
Electrical Current

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



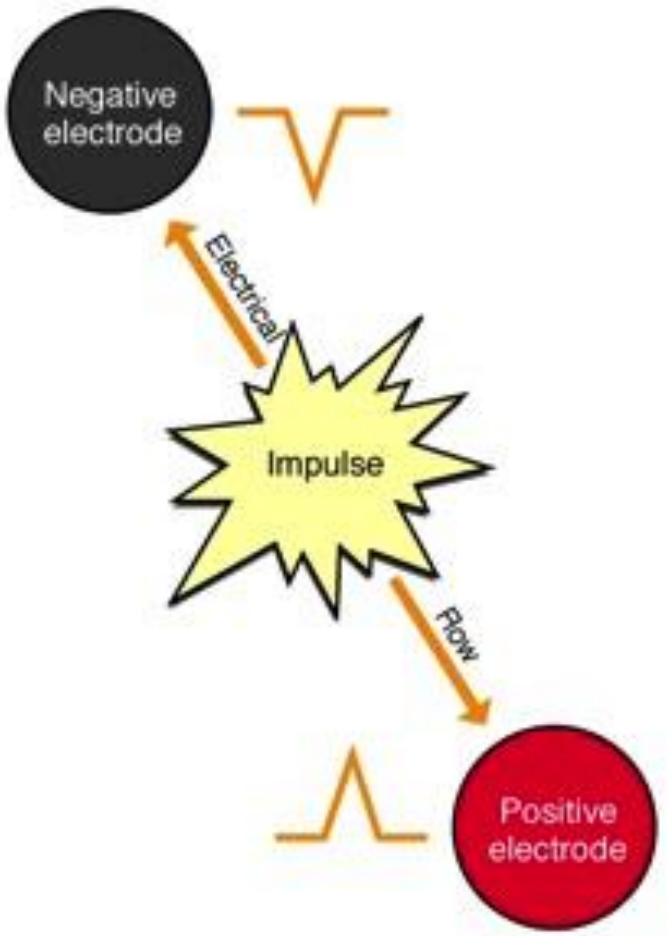
Electrical Current

- 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



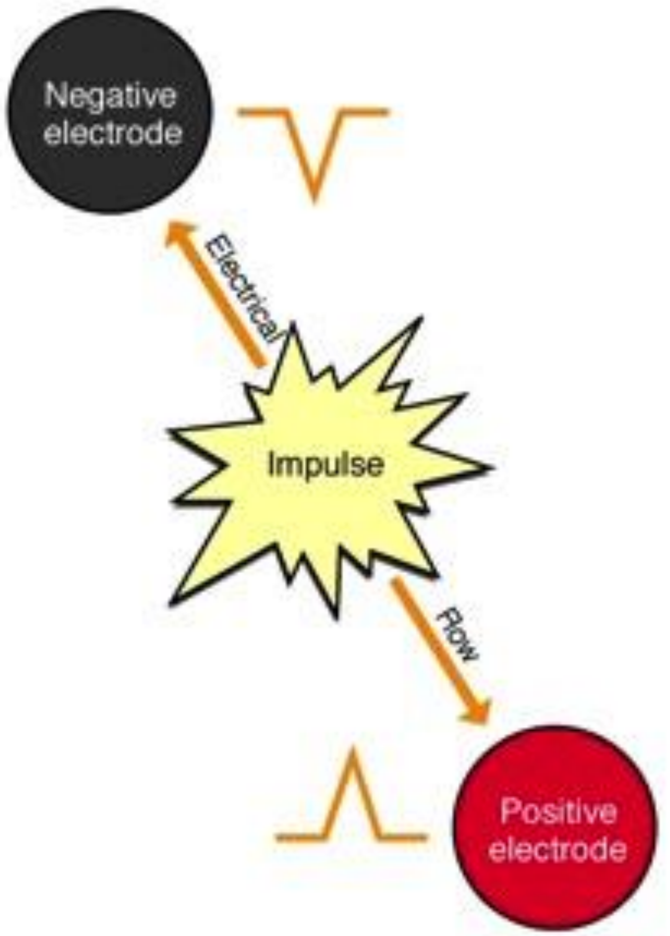
Electrical Current

- 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



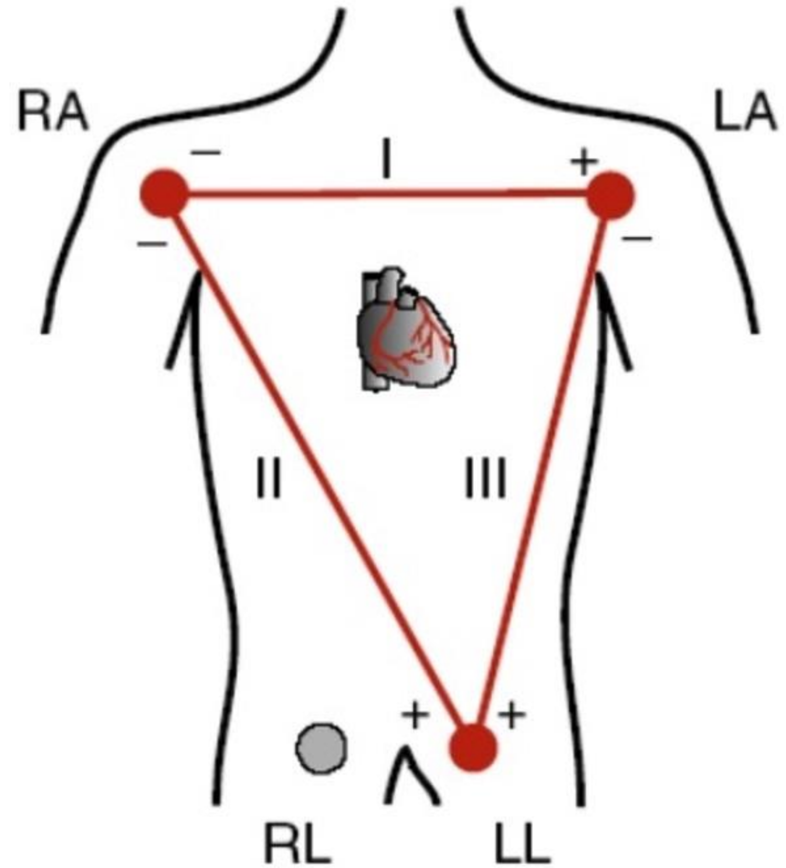
Electrical Current

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



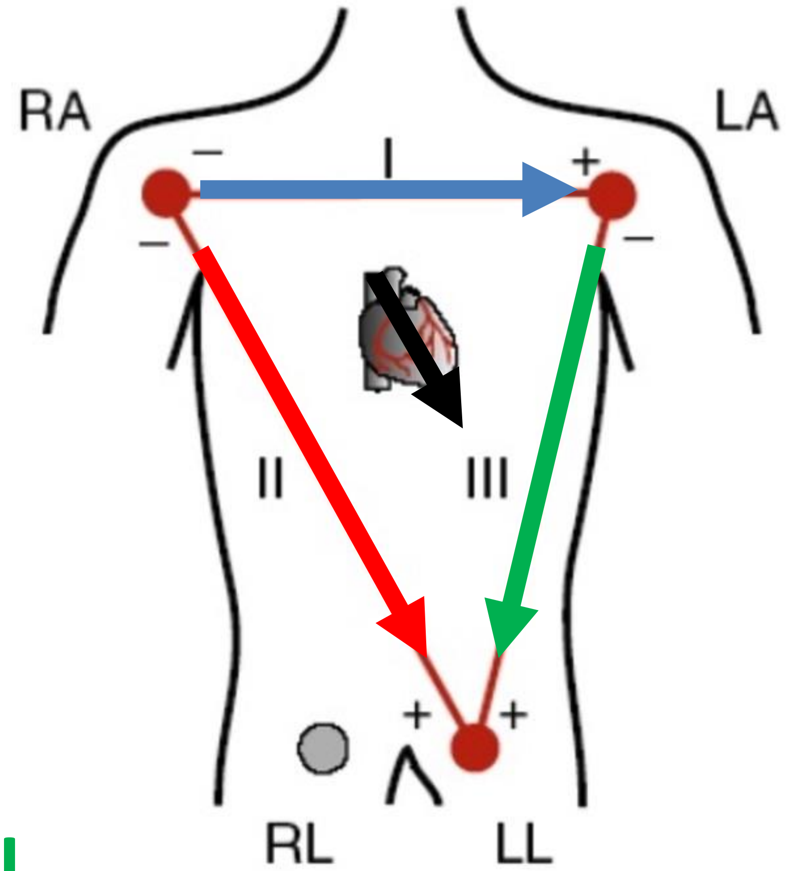
Einthoven’s Triangle

- 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



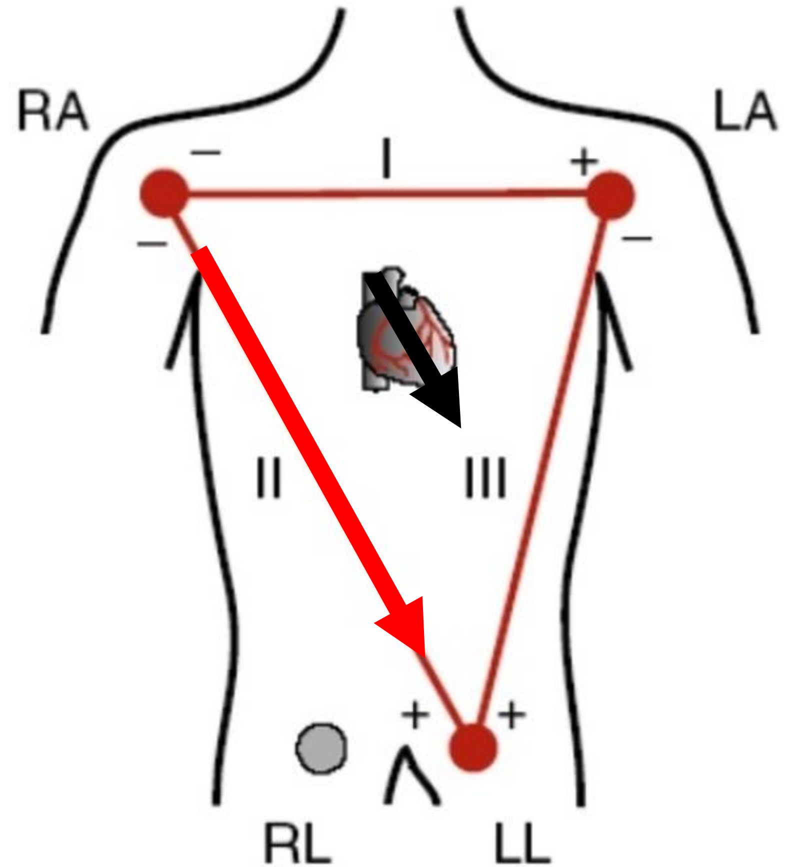
Einthoven's Triangle

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



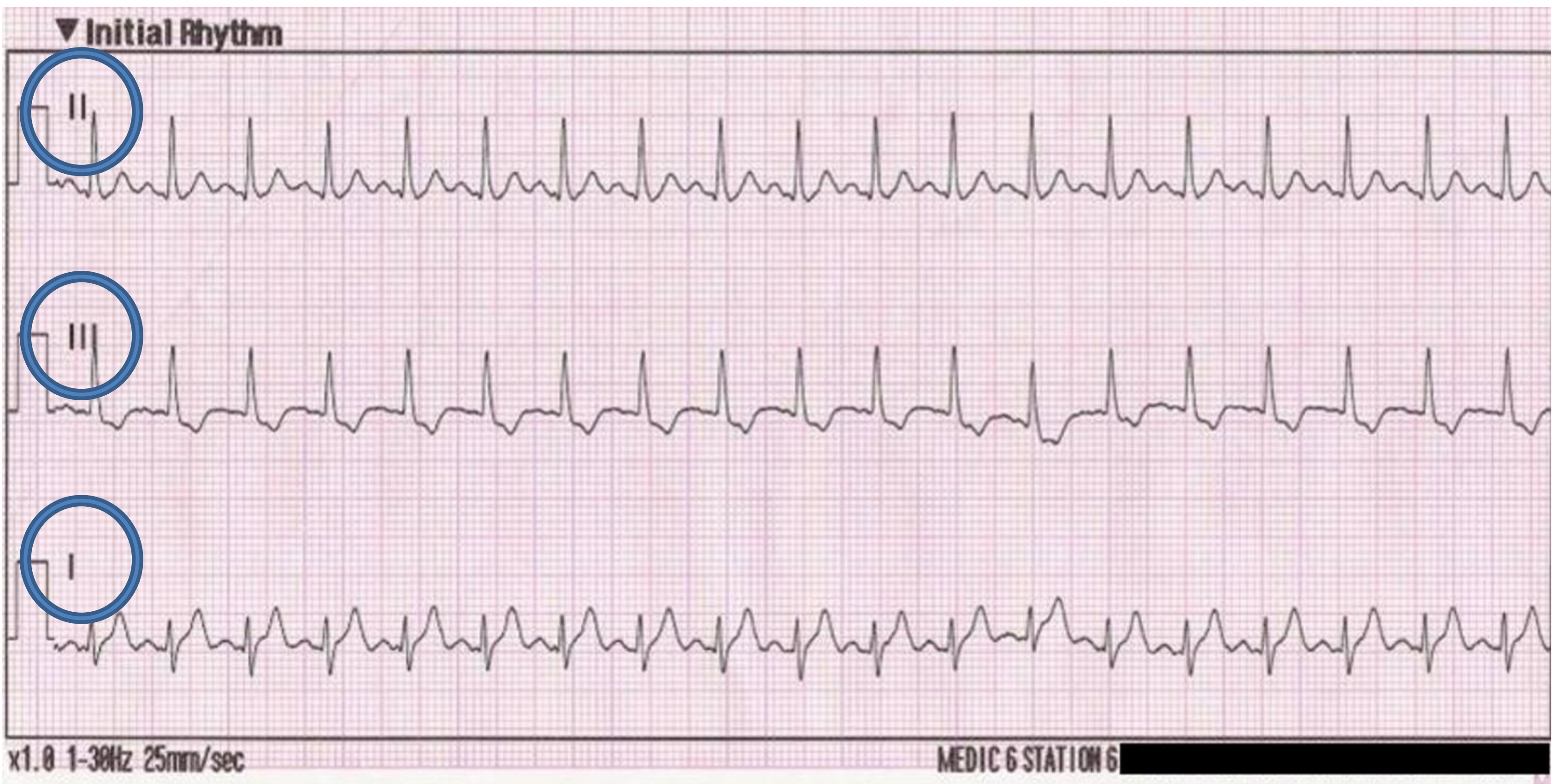
Einthoven's Triangle

- 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



3-lead ECG Tracing

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

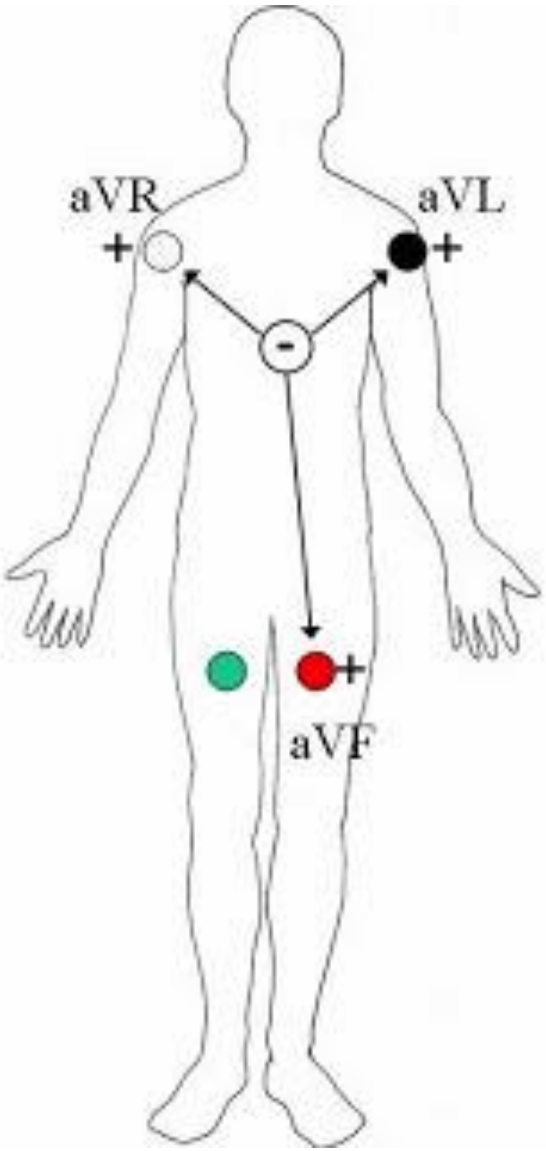


Extra Views

- 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**

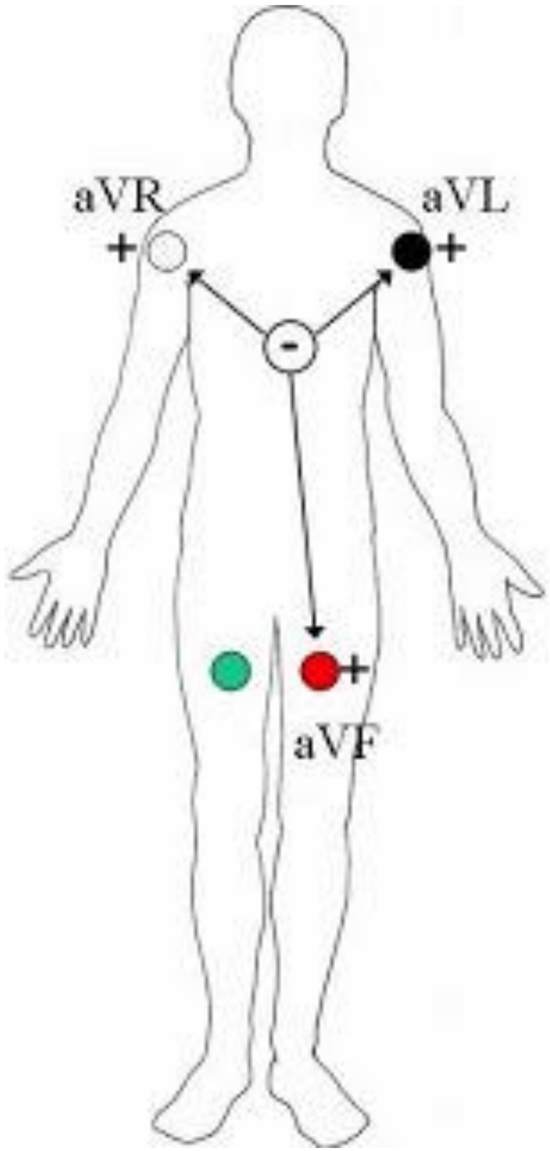
Extra Views

- 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



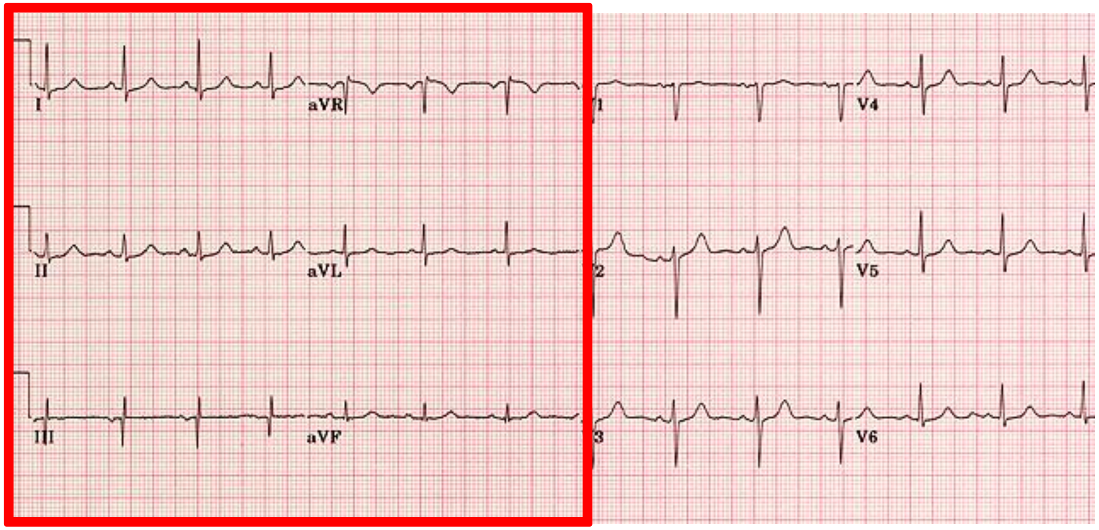
Extra Views

- 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

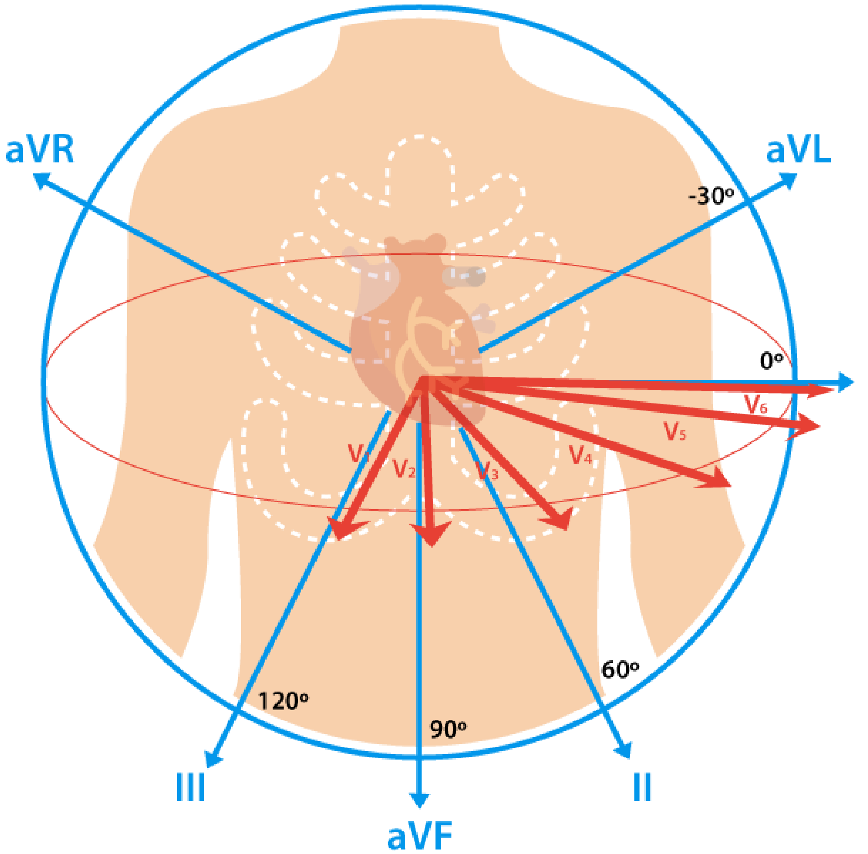
- In order to obtain the final 6 views of a 12-lead ECG we must place 6 more electrodes on the patient
- These 6 electrodes provide us with 6 more views known as the **precordial leads**

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

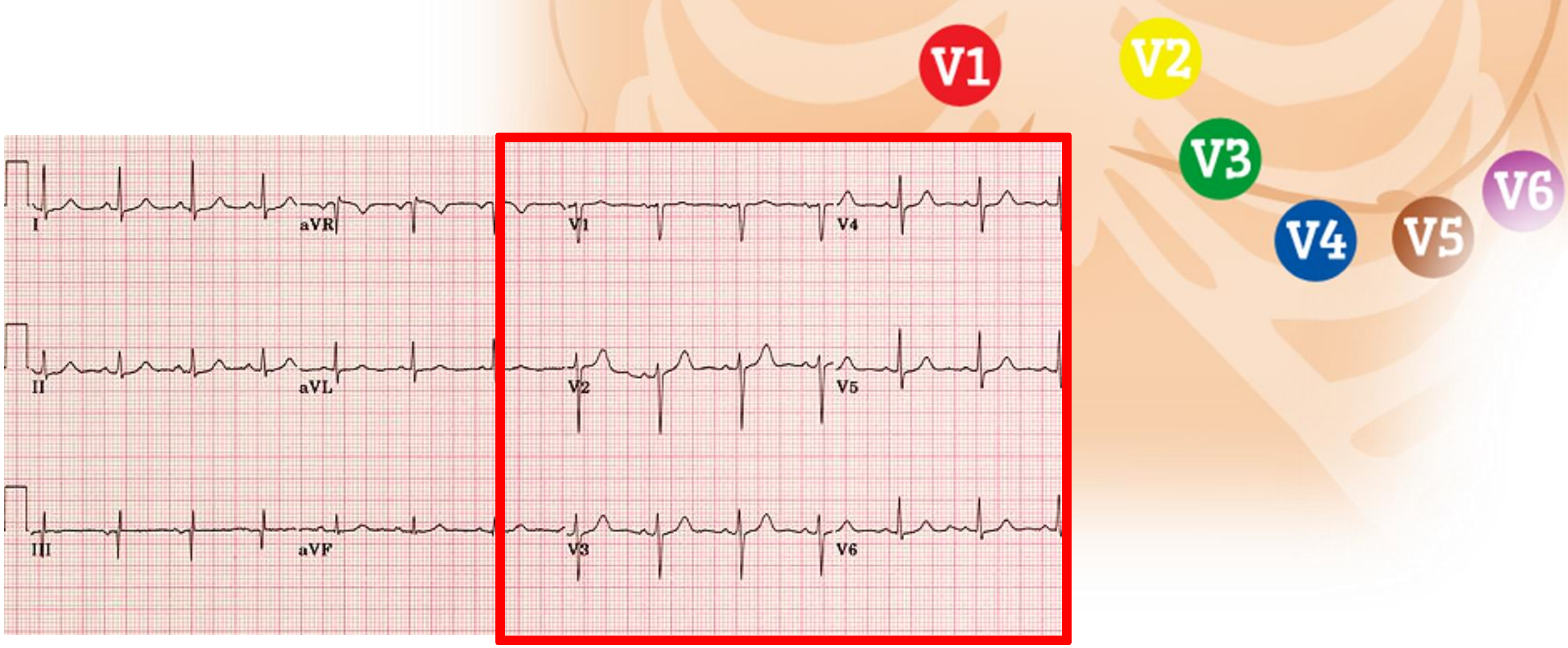
Precordial Leads

- 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.

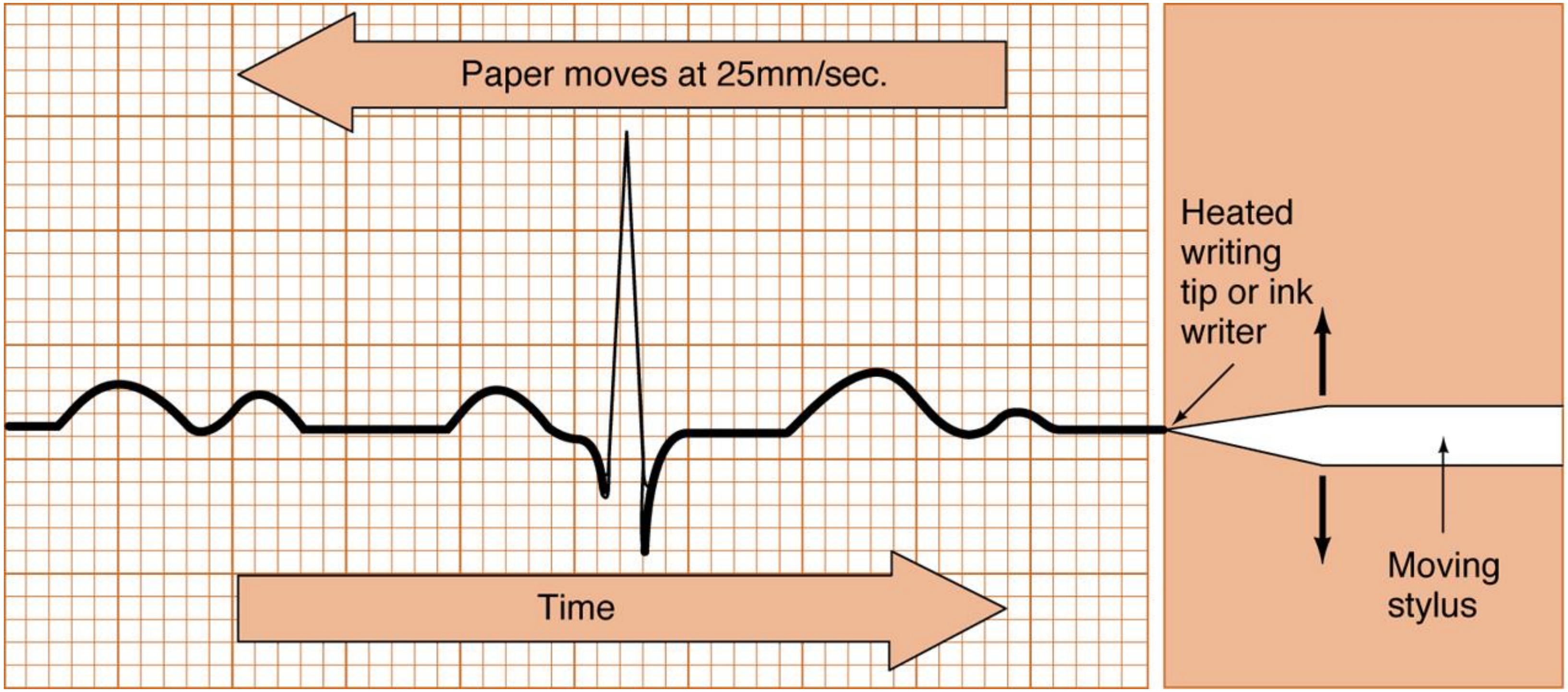


Cardiovascular Electrophysiology

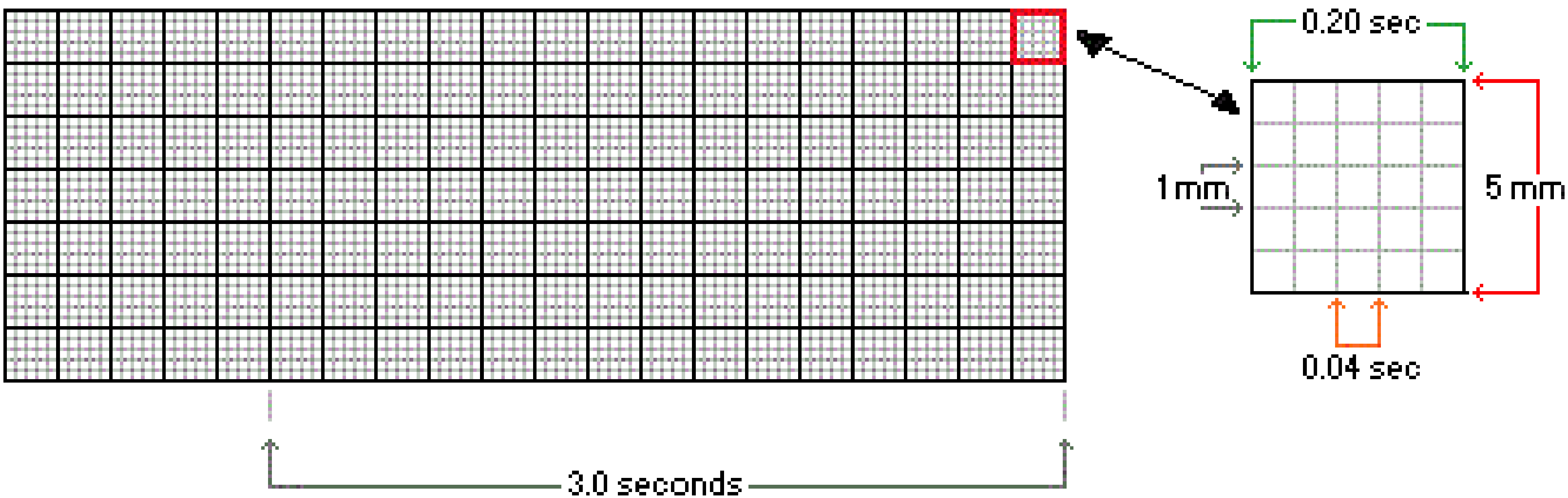
3-LEAD ECG INTERPRETATION

ECG Paper

- Speed and amplitude are standardized to allow for comparative analysis

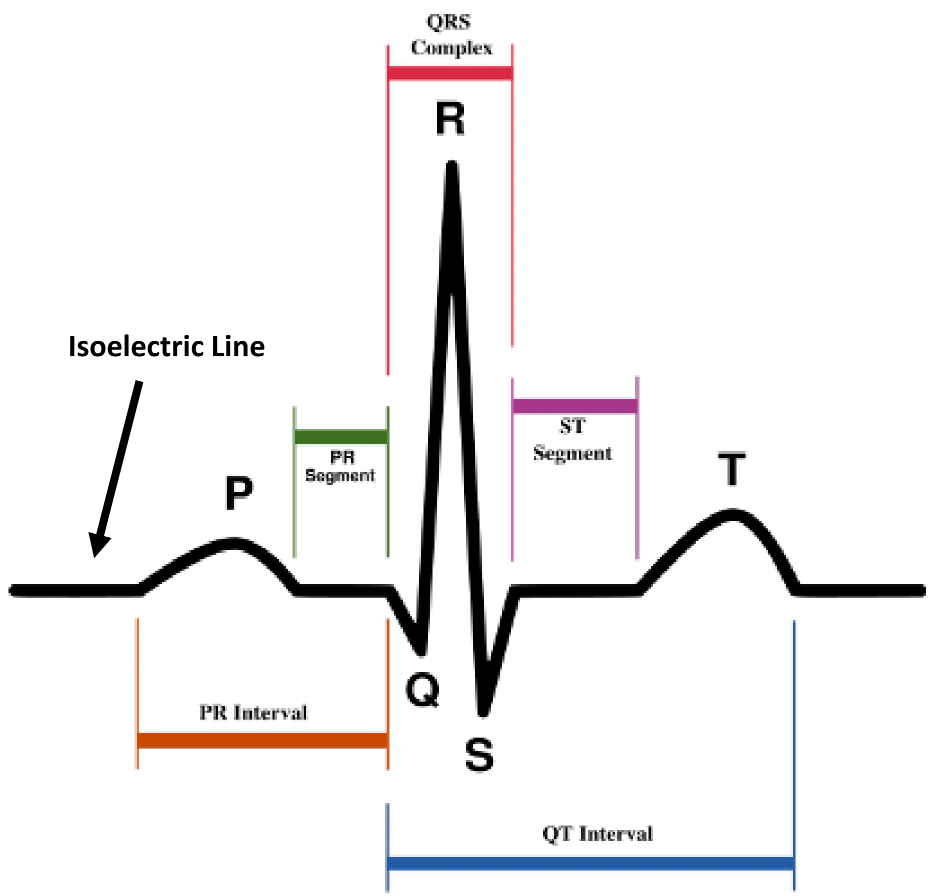


ECG Paper



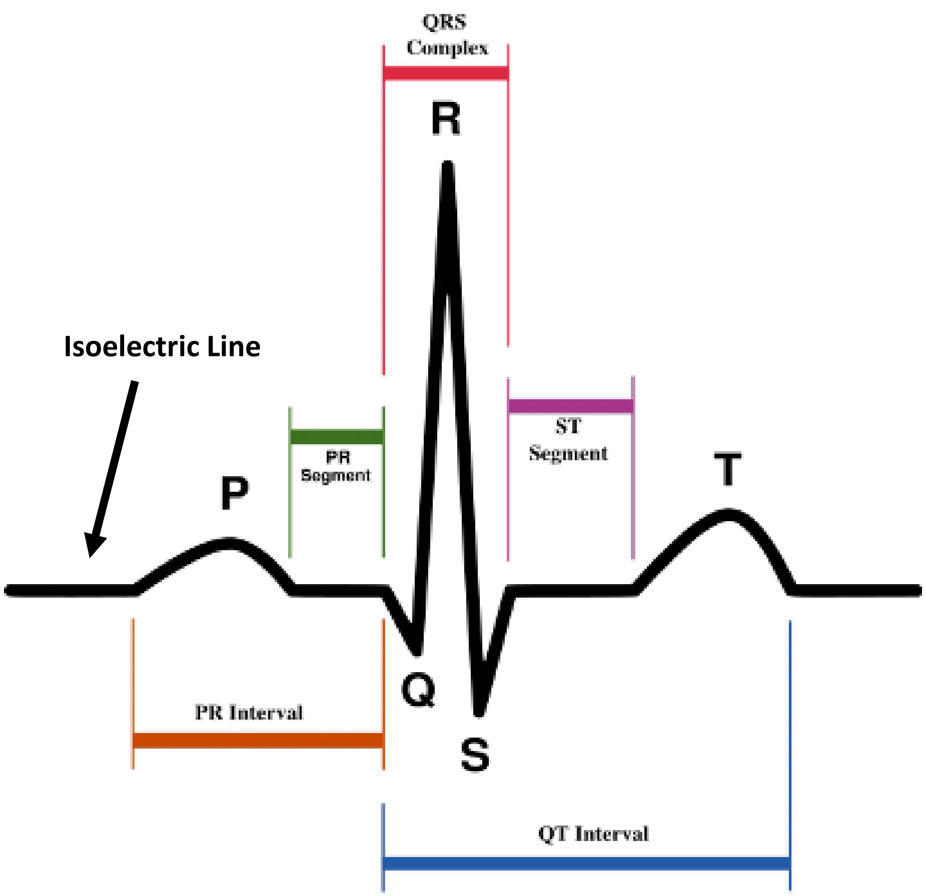
Components of an ECG Complex

- 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



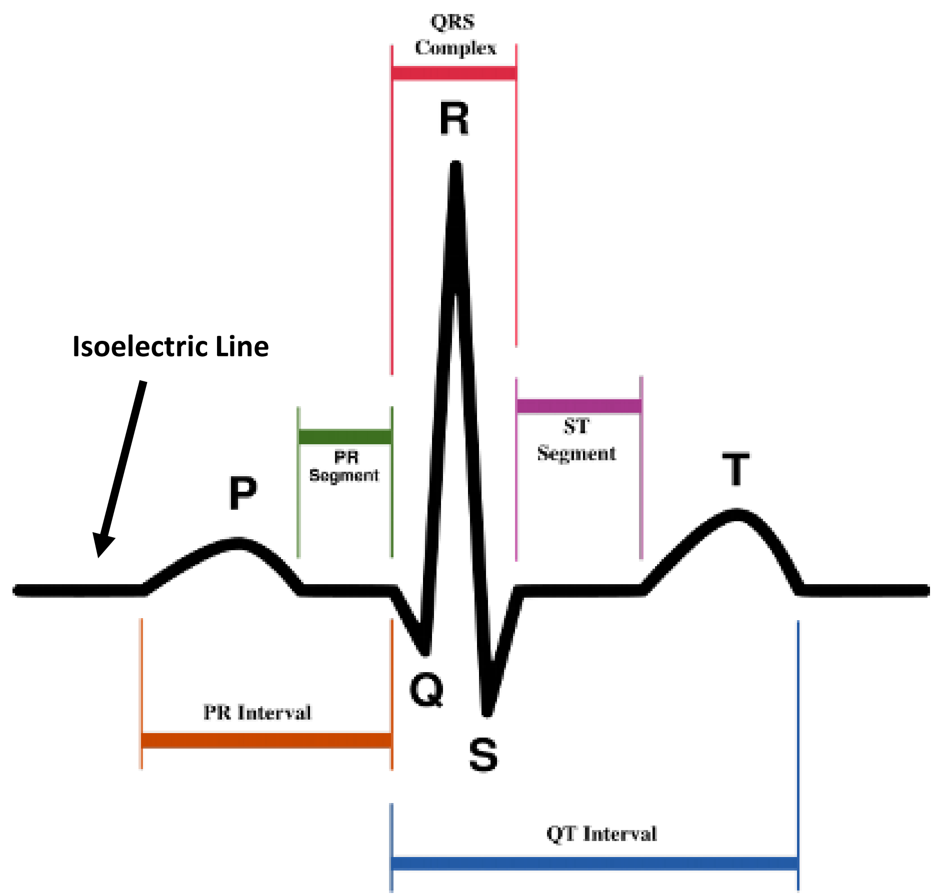
Components of an ECG Complex

- 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



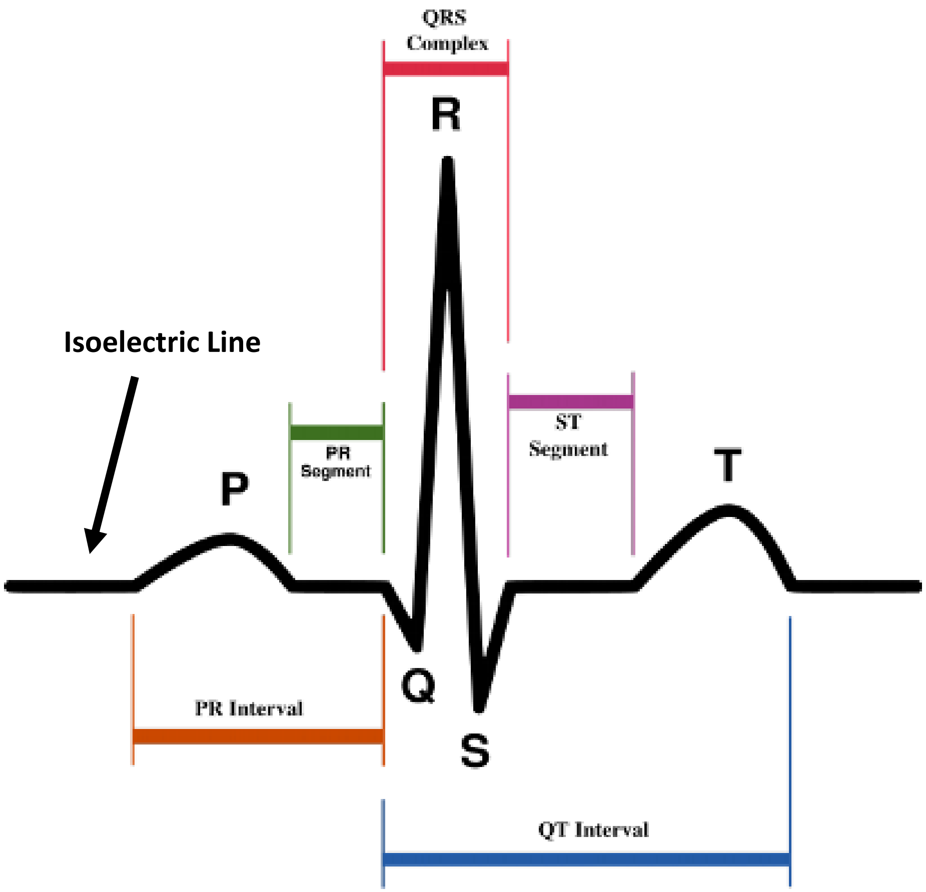
Components of an ECG Complex

- **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



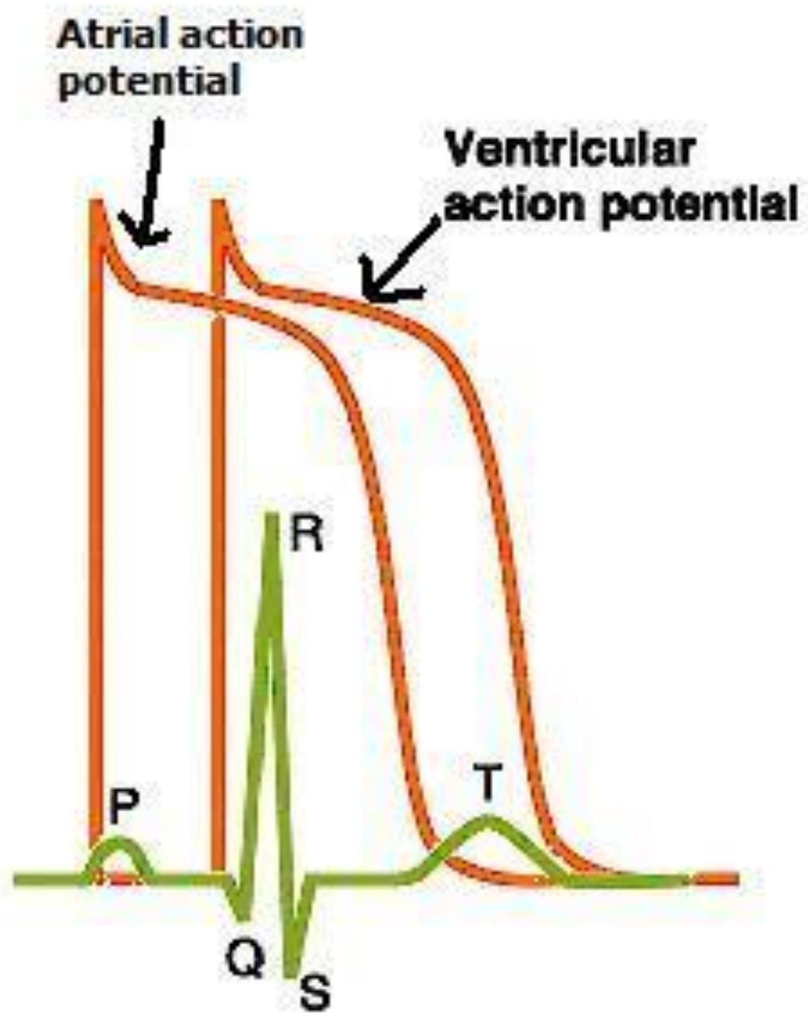
Components of an ECG Complex

- **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



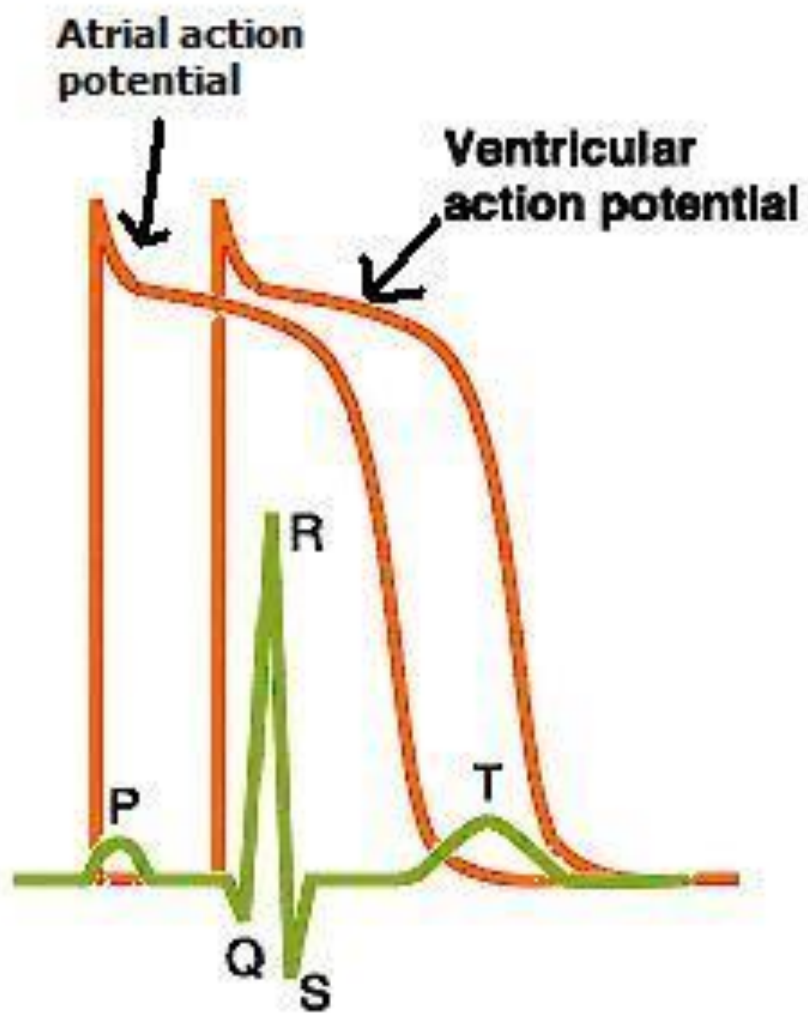
Action Potential

- 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



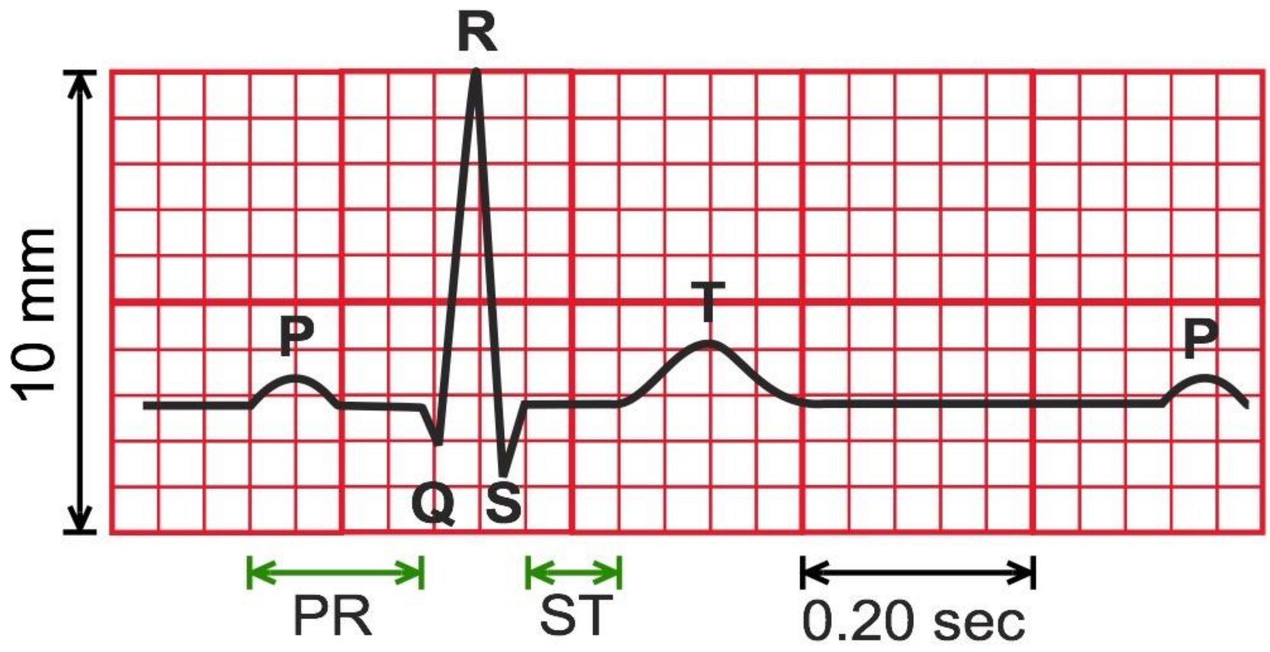
Action Potential

- 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

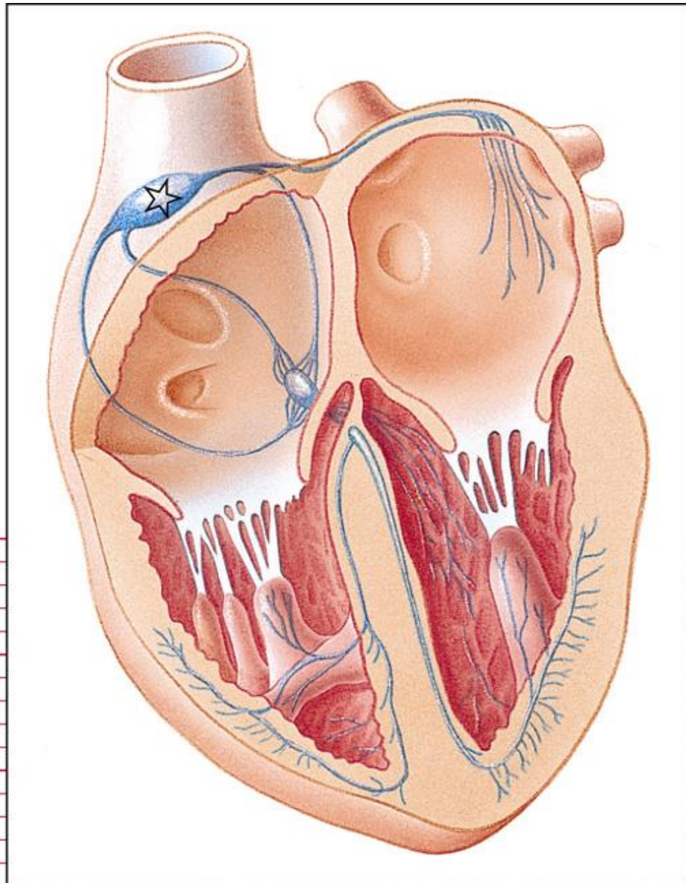


Normal Values

- 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)

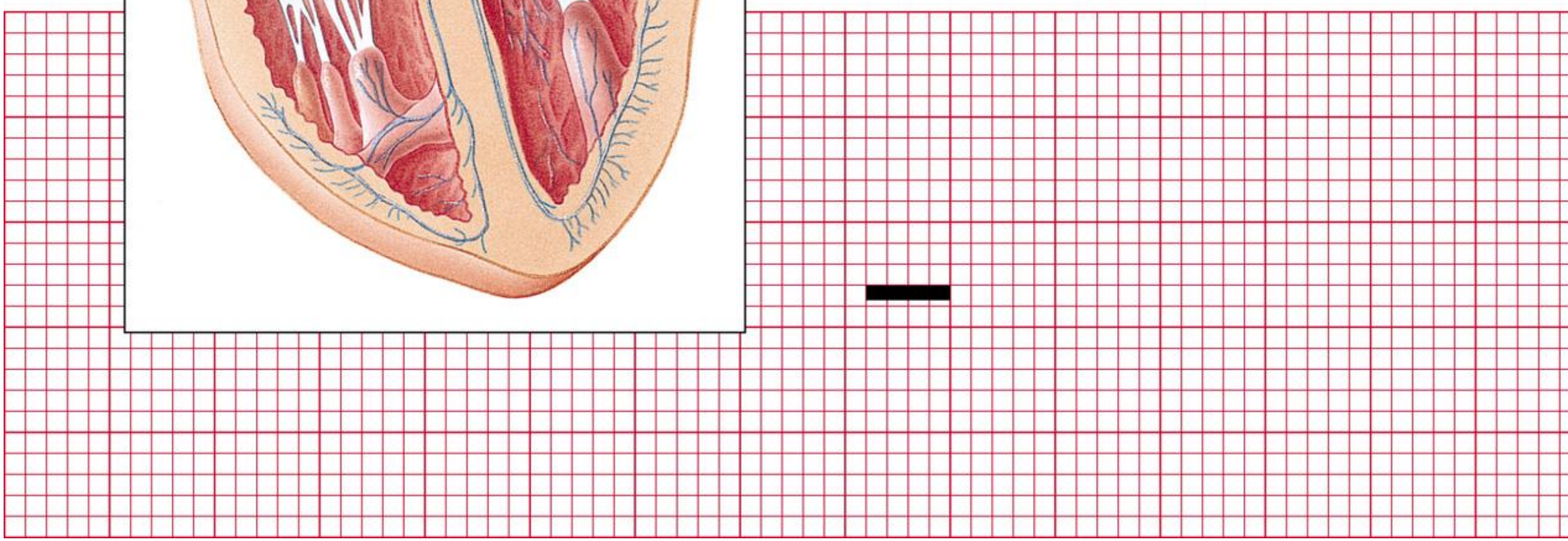


The Electrocardiogram

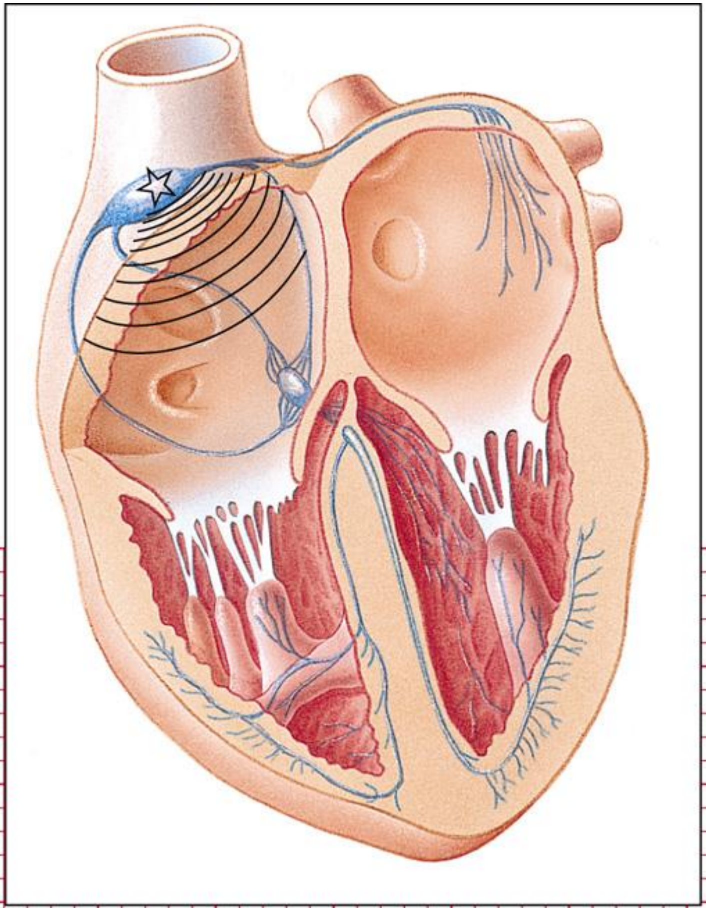


P Wave (upright in lead II)

Impulse initiated in the sinus node

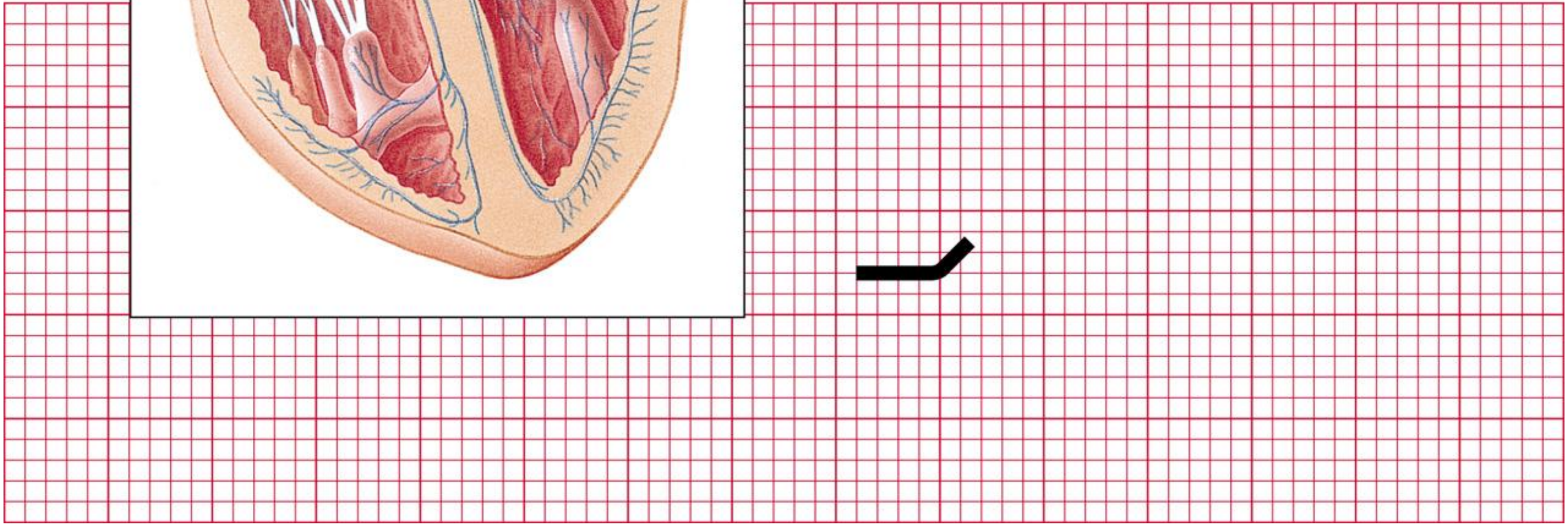


The Electrocardiogram

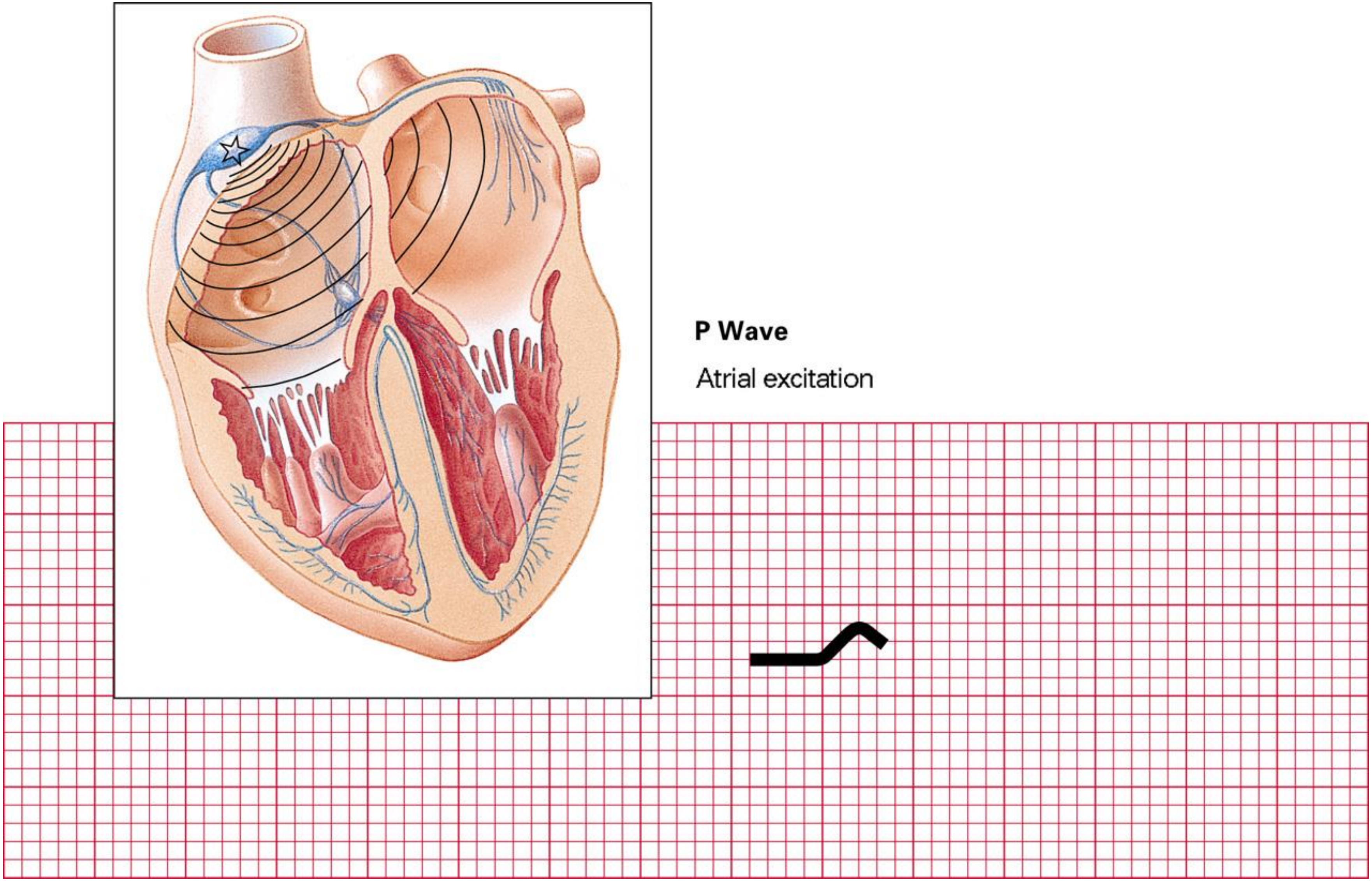


P Wave

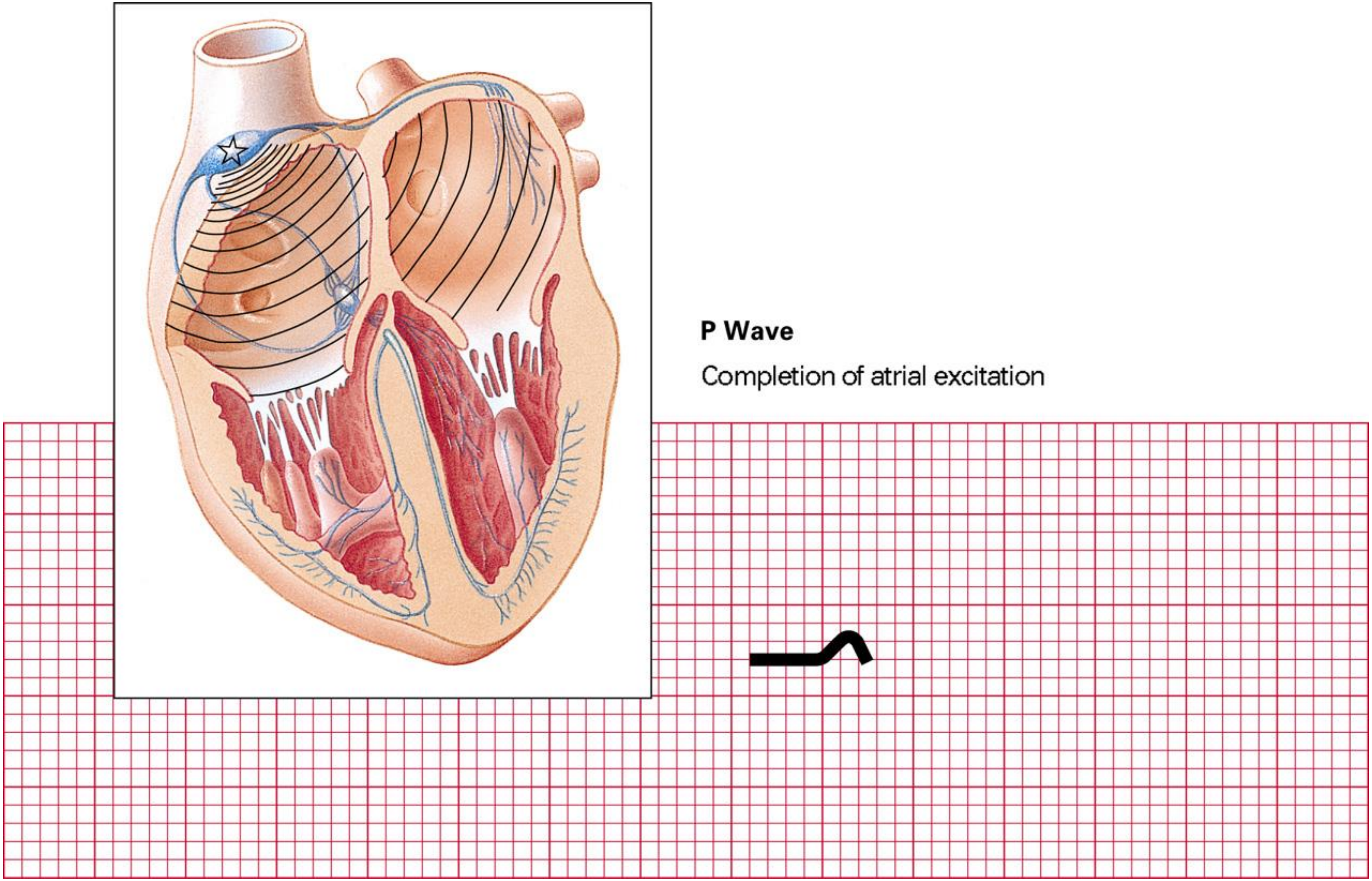
Beginning of artial excitation



The Electrocardiogram



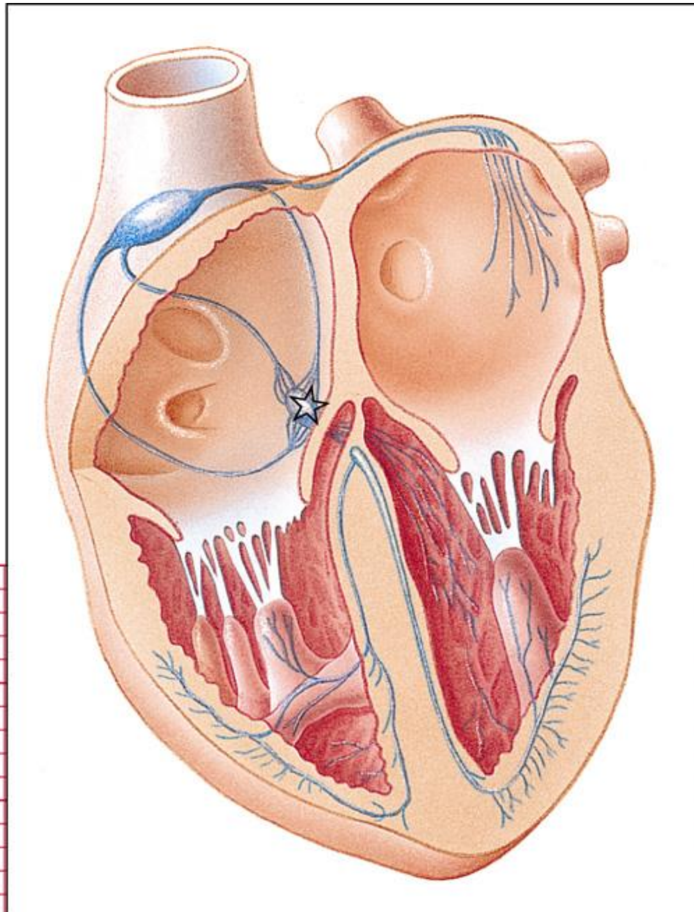
The Electrocardiogram



P Wave

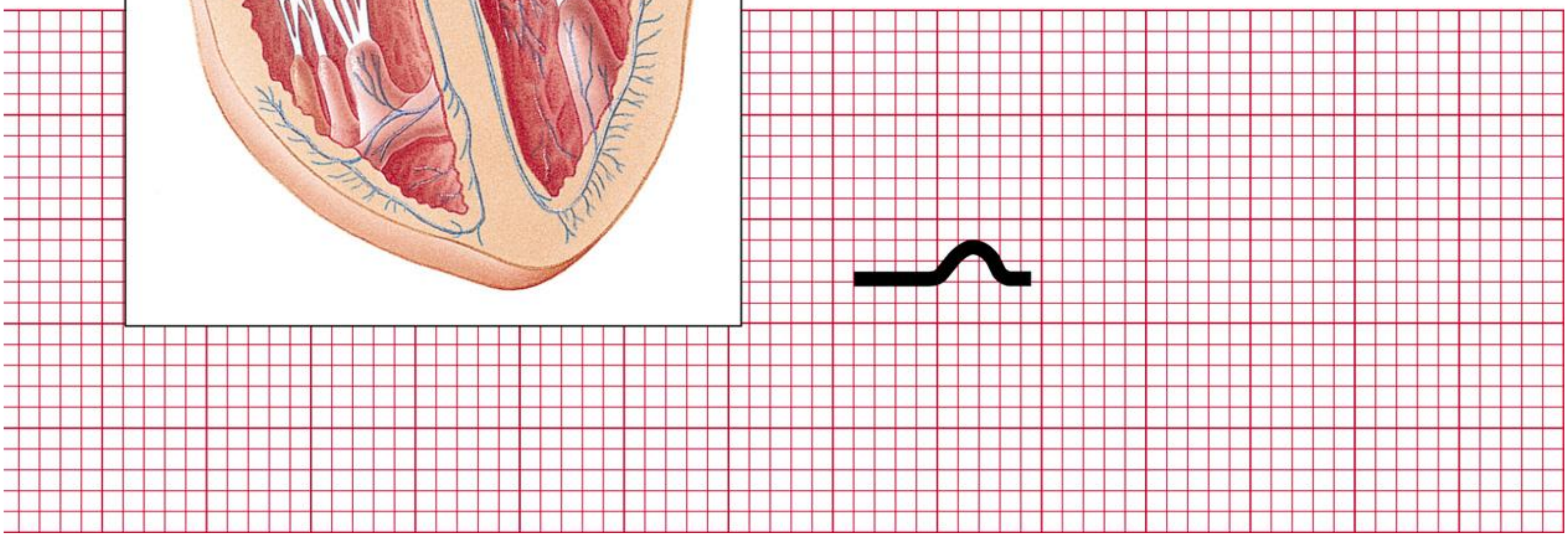
Completion of atrial excitation

The Electrocardiogram

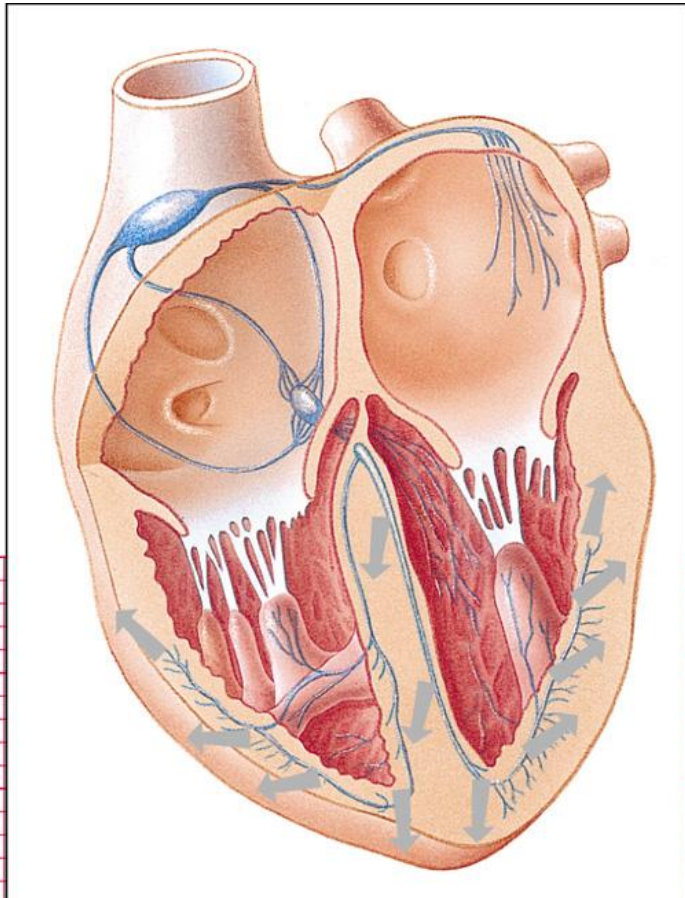


P-R Interval

Impulse delay at AV junction

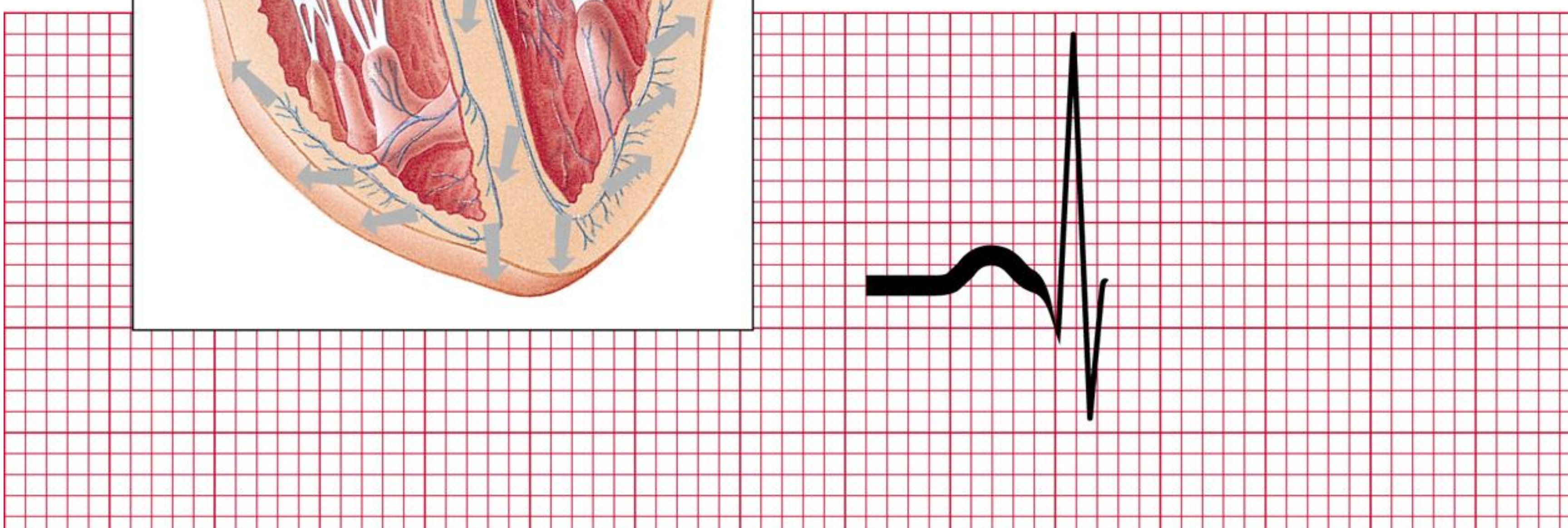


The Electrocardiogram

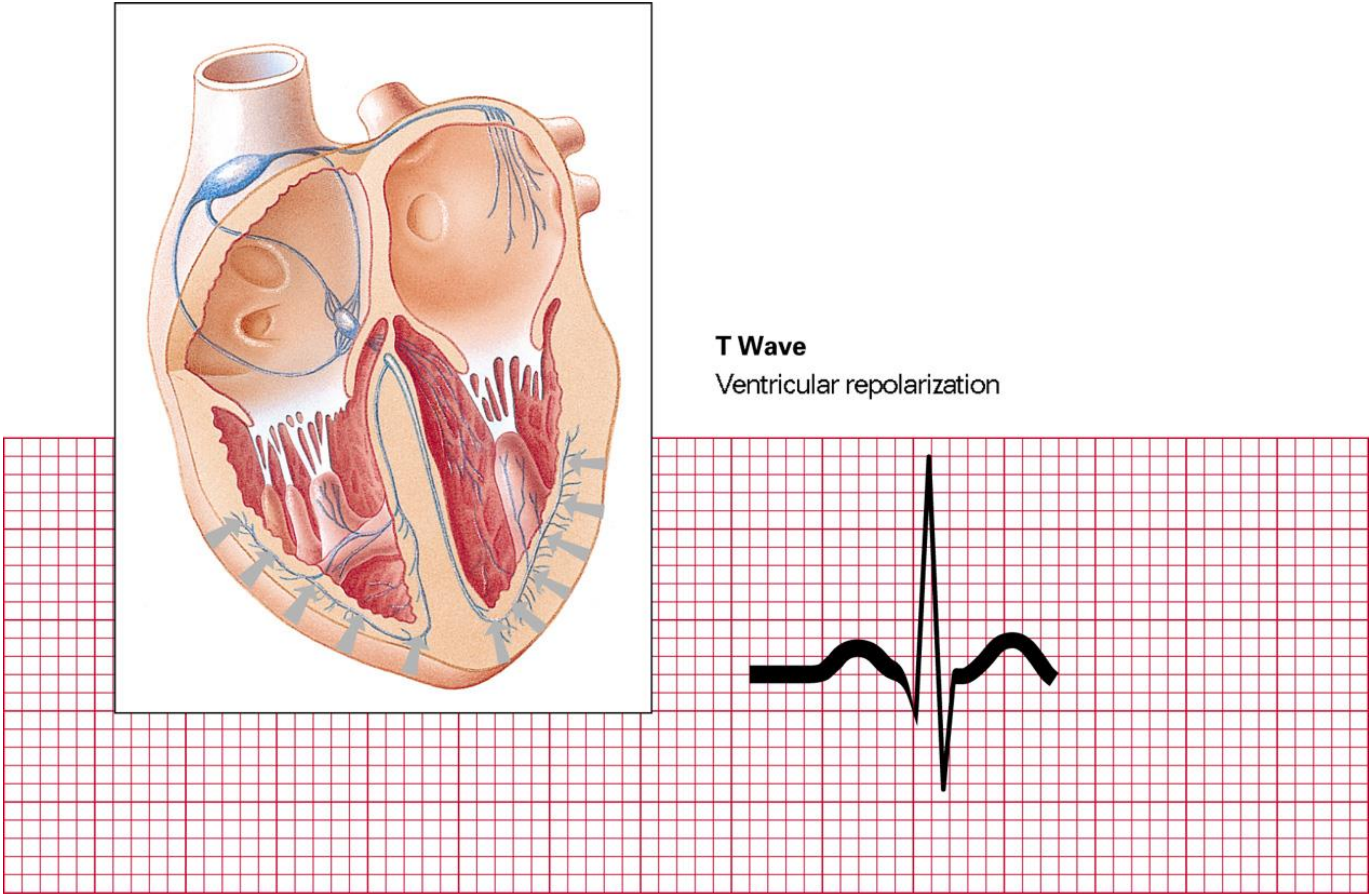


QRS complex

Electrical excitation of the ventricles



The Electrocardiogram



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:
  1. Rate
  2. Rhythm
  3. P wave
  4. PRI
  5. QRS

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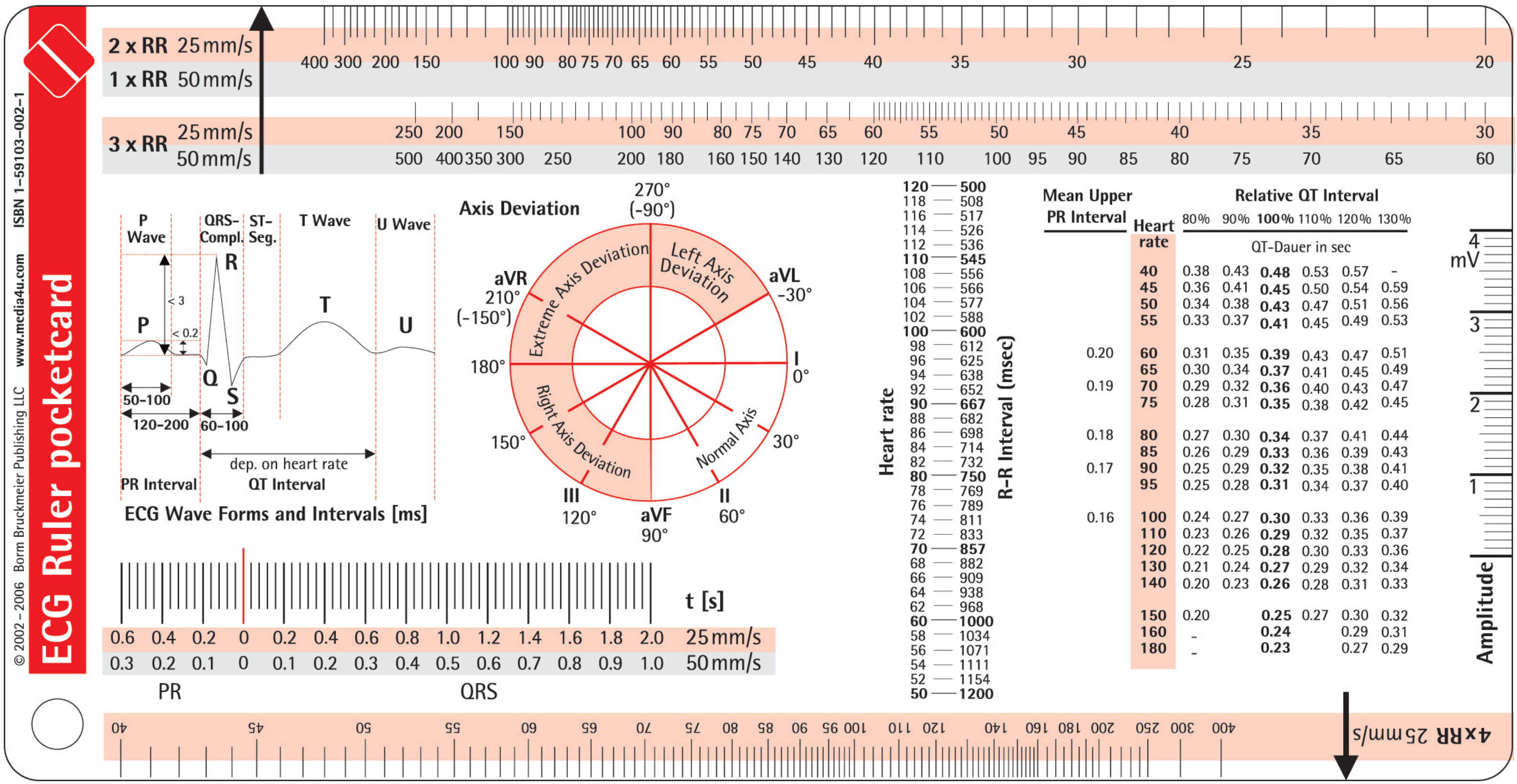
Rate Calculations

- 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

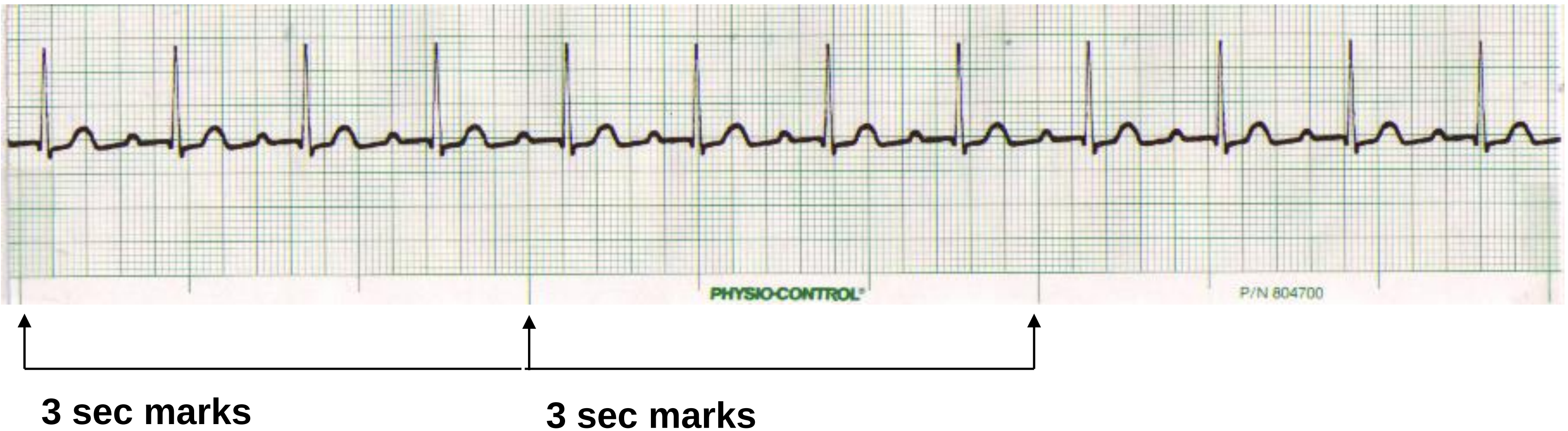
Rate Calculations

- Heart Rate Rulers



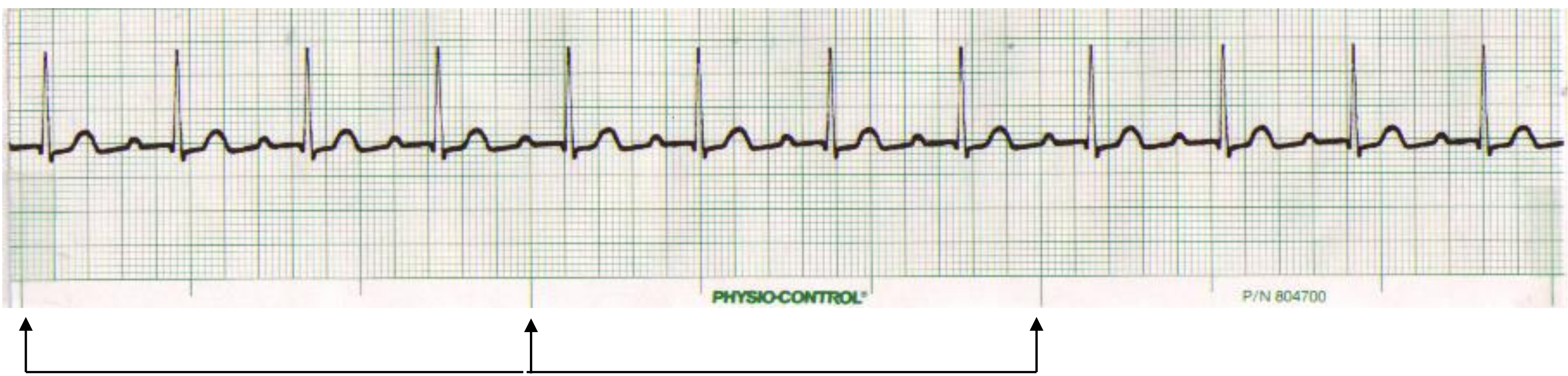
Rate Calculations

- Six Second Rule
  - Count the # of QRS complexes in 6 seconds and multiply by 10
    - Ex. 8 QRS complexes in 6 seconds = HR approx. 80bpm
    - Works well for normal to bradycardic rhythms



Rate Calculations

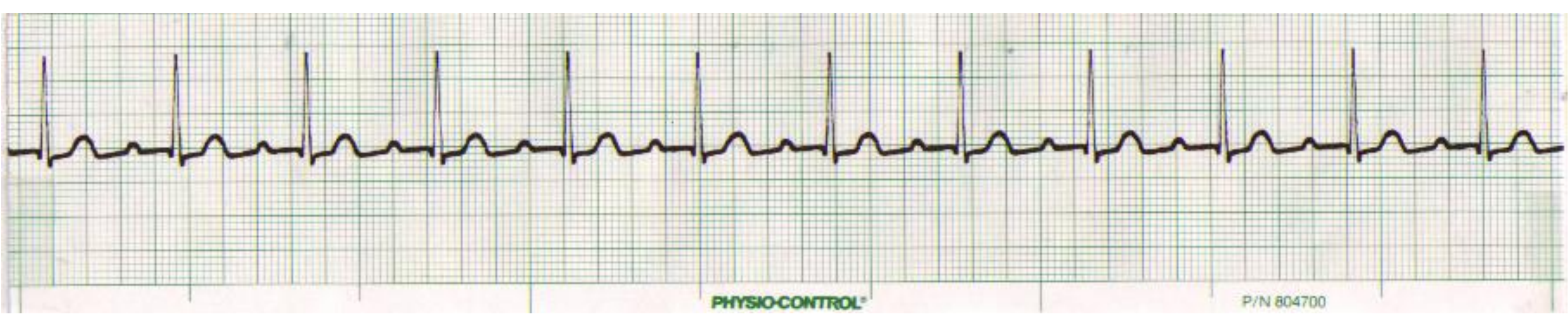
- Six Second Rule
  - If 3-second tick marks aren't visible, recall that:
    - 5 large boxes = 1 sec
    - 15 large boxes = 3 sec



3 sec marks **3 sec marks**

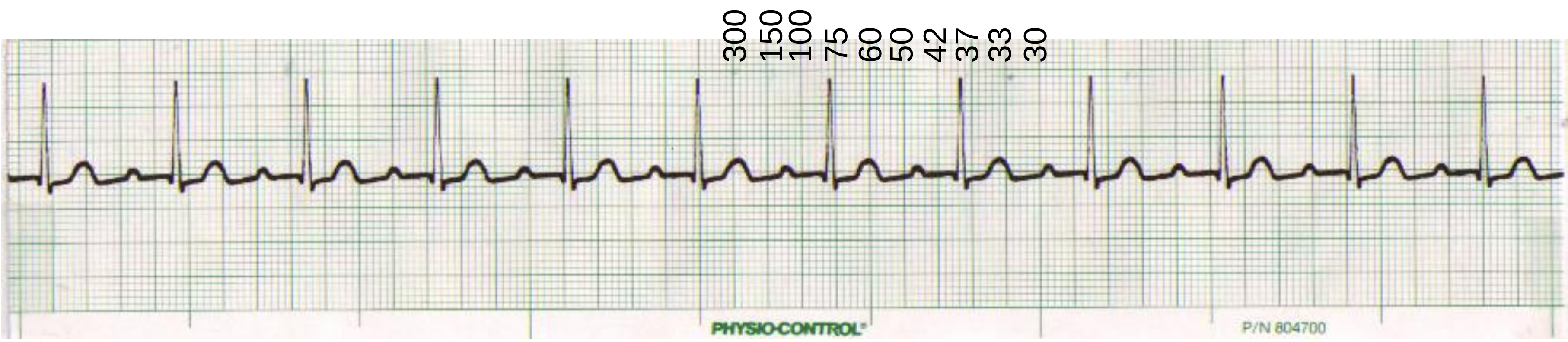
Rate Calculations

- 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



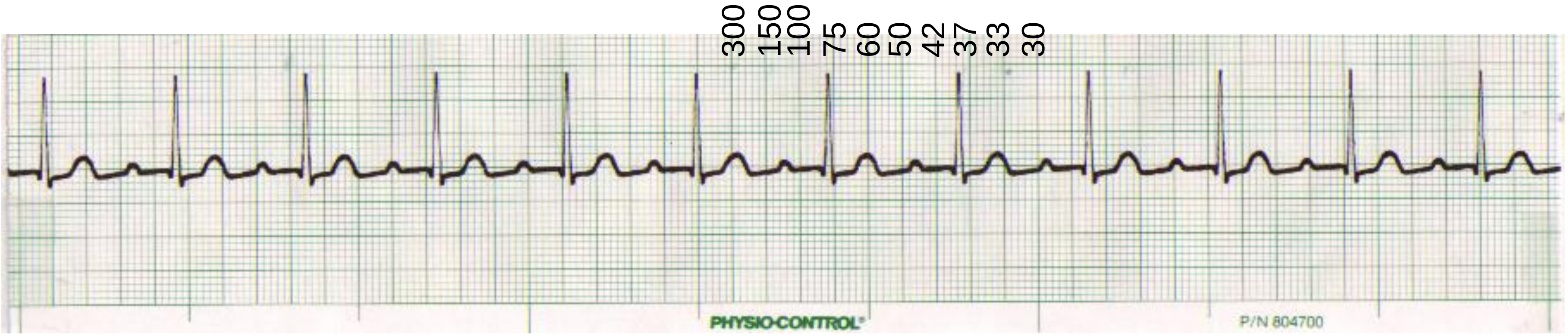
Rate Calculations

- 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



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Rhythm Interpretation

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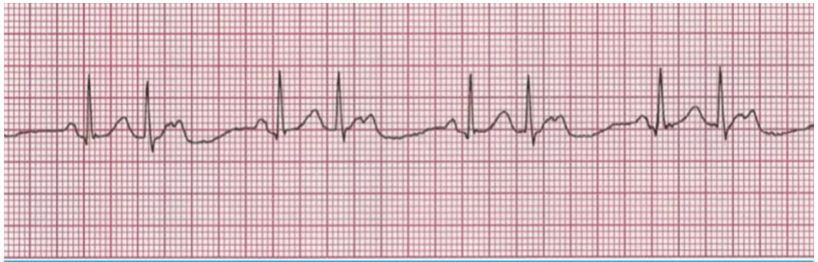
- Analyzing Rhythm
  - Determine the regularity of the rhythm

Regular



Regularly Irregular

Irregularly Irregular

Rhythm Interpretation

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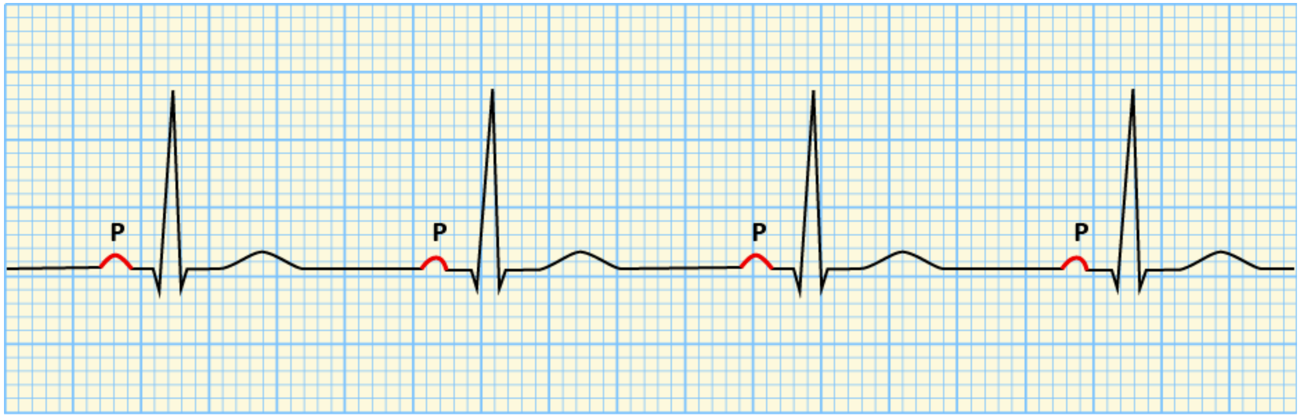
  3. P wave
  4. PRI
  5. QRS

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

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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

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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): 60 - 100 bpm
  - AV node (Junction): 40 - 60 bpm
  - Purkinje fibers (Ventricles): 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