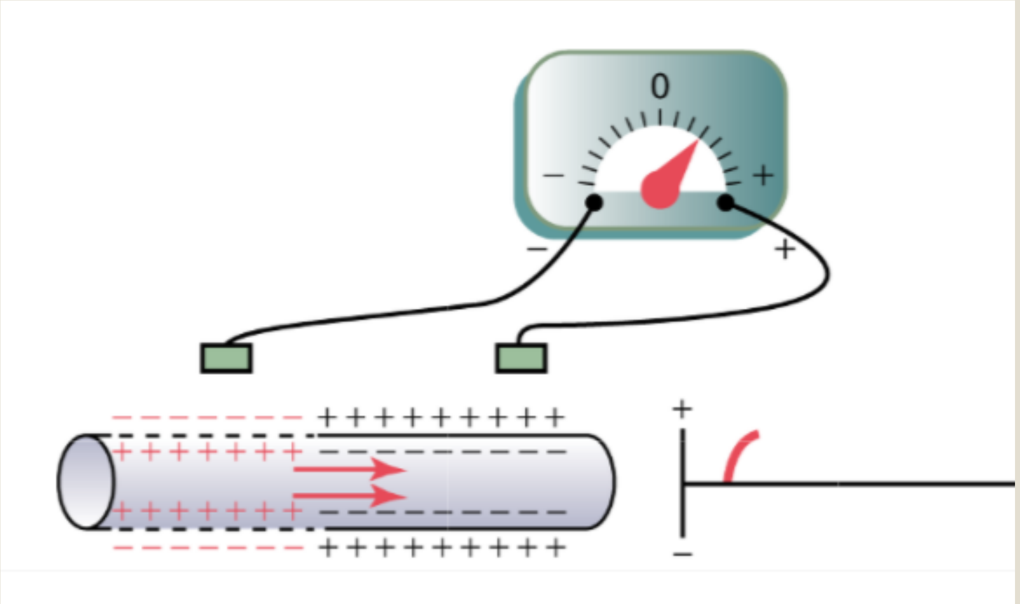
ECG

Prepared by: Dr.Fatima Daoud
Reference: Guyton and Hall Textbook of Medical Physiology, 12^{th} edition
Chapters: 11,12,13

The Concept

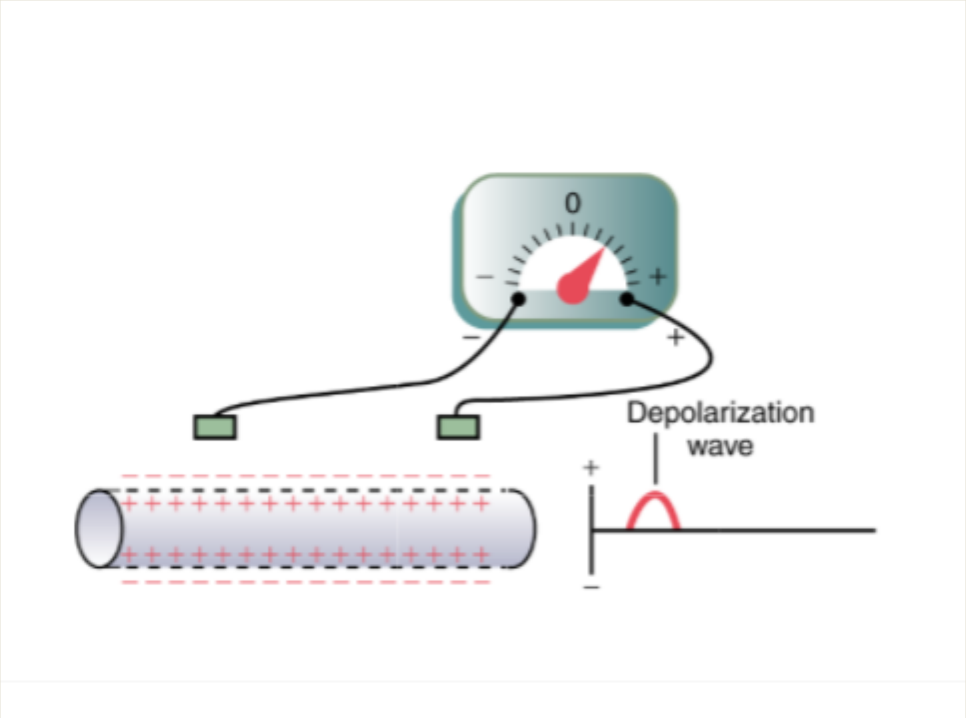
- When the cardiac impulse passes through the heart, electrical current also spreads from the heart into the adjacent tissues surrounding the heart. A small portion of the current spreads all the way to the surface of the body. If electrodes are placed on the skin, electrical potentials generated by the current can be recorded; the recording is known as an electrocardiogram.

Depolarization vs. Repolarization Waves



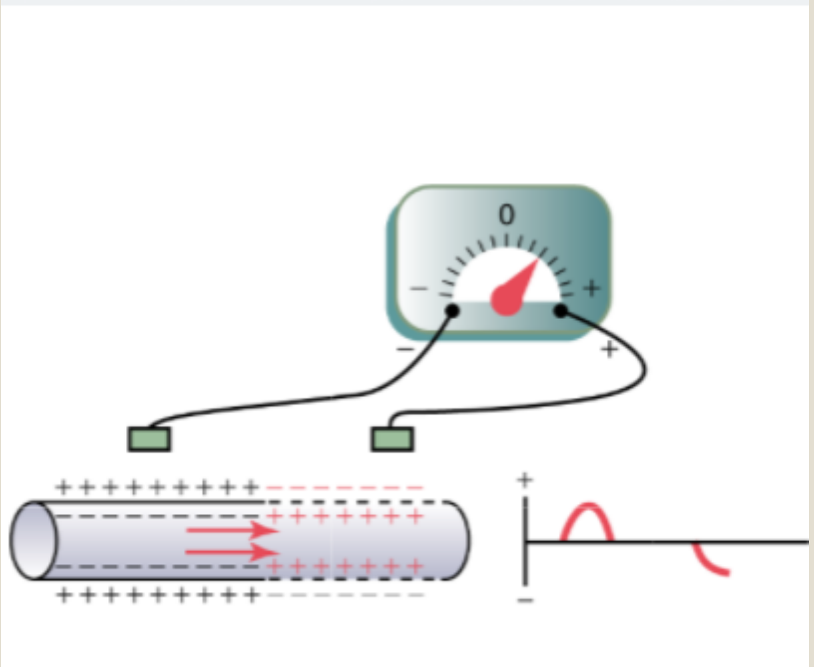
- The first half of the fiber has already depolarized, while the remaining half is still polarized. Therefore, the left electrode on the outside of the fiber is in an area of negativity, and the right electrode is in an area of positivity; this causes the meter to record positively

Depolarization vs. Repolarization Waves



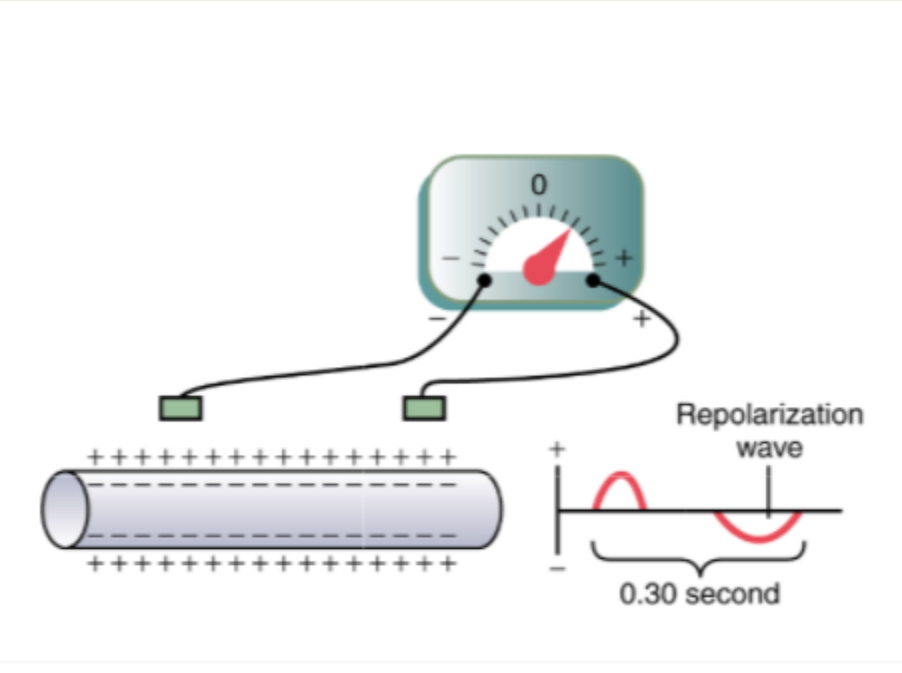
- Depolarization has extended over the entire muscle fiber, and the recording to the right has returned to the zero baseline because both electrodes are now in areas of equal negativity. The completed wave is a depolarization wave because it results from spread of depolarization along the muscle fiber membrane.

Depolarization vs. Repolarization Waves



- Halfway repolarization of the same muscle fiber, with positivity returning to the outside of the fiber. At this point, the left electrode is in an area of positivity, and the right electrode is in an area of negativity

Depolarization vs. Repolarization Waves



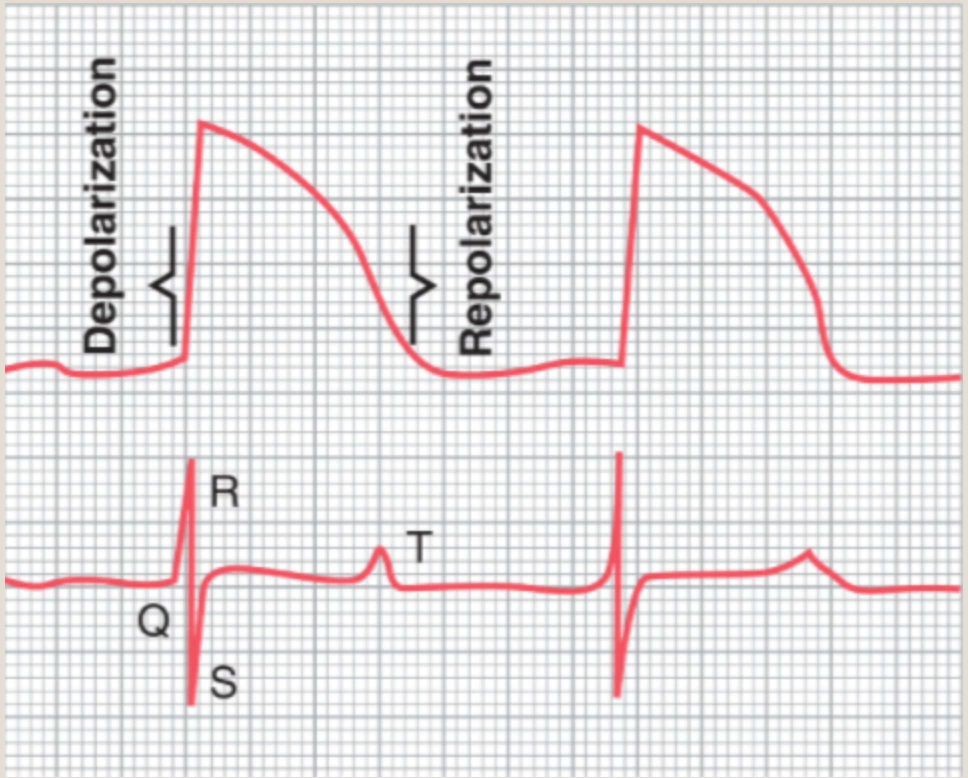
- The muscle fiber has completely repolarized, and both electrodes are now in areas of positivity so that no potential difference is recorded between them. Thus, in the recording to the right, the potential returns once more to zero. This completed negative wave is a repolarization wave because it results from spread of repolarization along the muscle fiber membrane.

Relation of the Monophasic Action Potential of Ventricular Muscle to the QRS and T Waves in the Standard Electrocardiogram.

- The monophasic action potential which is recorded from a microelectrode inserted to the inside of a single ventricular muscle fiber.

- Simultaneous recording of the electrocardiogram from this same ventricle.

Relation of the Monophasic Action Potential of Ventricular Muscle to the QRS and T Waves in the Standard Electrocardiogram.



The QRS waves appear at the beginning of the monophasic action potential and the T wave appear at the end.

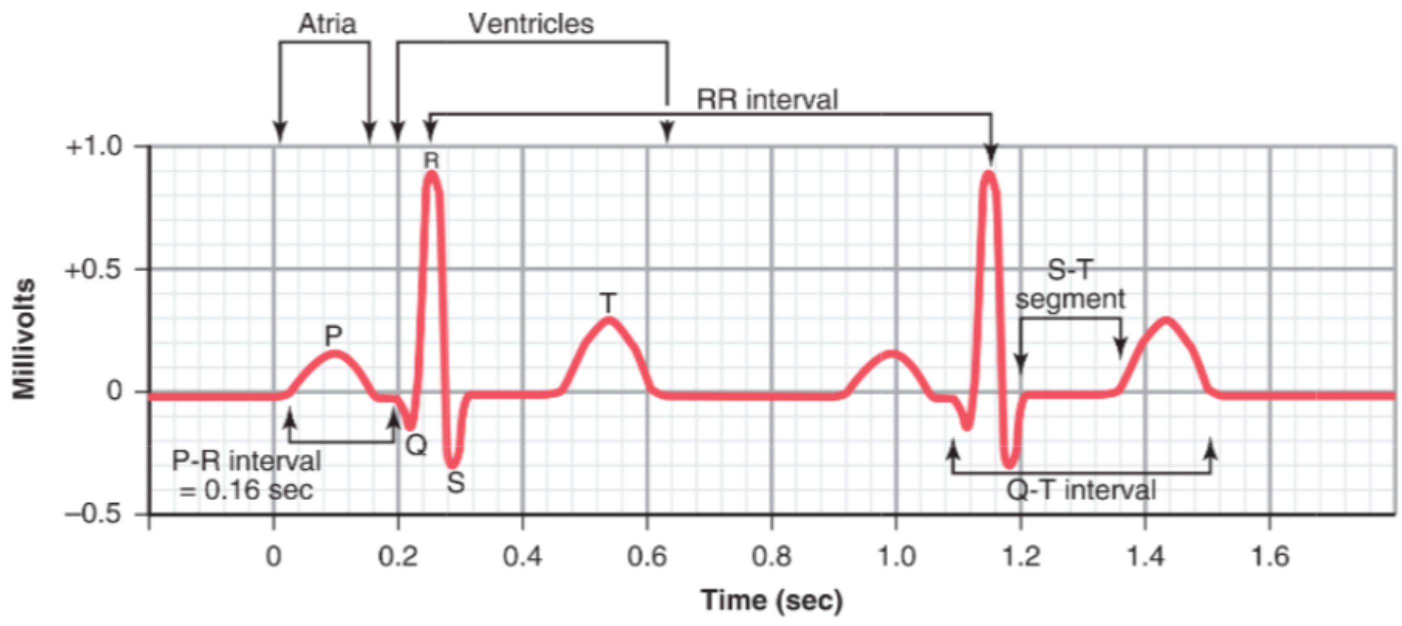
Note especially that *no potential is recorded in the electrocardiogram when the ventricular muscle is either completely polarized or completely depolarized.*

Relation of the Monophasic Action Potential of Ventricular Muscle to the QRS and T Waves in the Standard Electrocardiogram.

- The monophasic action potential is approximately 110 millivolts recorded directly at the heart muscle membrane.

- The recorded voltages of the waves in the normal electrocardiogram depend on the manner in which the electrodes are applied to the surface of the body and how close the electrodes are to the heart.
- When one electrode is placed directly over the ventricles and a second electrode is placed elsewhere on the body remote from the heart, the voltage of the QRS complex may be as great as 3 to 4 millivolts.
- When electrocardiograms are recorded from electrodes on the two arms or on one arm and one leg, the voltage of the QRS complex usually is 1.0 to 1.5 millivolts from the top of the R wave to the bottom of the S wave.
- the voltage of the P wave is between 0.1 and 0.3 millivolts; and that of the T wave is between 0.2 and 0.3 millivolts

Characteristics of the Normal Electrocardiogram



Characteristics of the Normal Electrocardiogram/waves

- ***DEPOLARIZATION WAVES***
  - The P wave : is caused by electrical potentials generated when the atria depolarize before atrial contraction begins.
  - The QRS complex: is caused by potentials generated when the ventricles depolarize before contraction.
- ***REPOLARIZATION WAVE***
  - The T wave is caused by potentials generated as the ventricles recover from the state of depolarization. This process normally occurs in ventricular muscle 0.25 to 0.35 second after depolarization.

Relationship of Atrial and Ventricular Contraction to the Waves of the Electrocardiogram

- Before contraction of muscle can occur, depolarization must spread through the muscle to initiate the chemical processes of contraction, the P wave occurs at the beginning of contraction of the atria, and the QRS complex of waves occurs at the beginning of contraction of the ventricles. The ventricles remain contracted until after repolarization has occurred, that is, until after the end of the T wave.
- The atria repolarize about 0.15 to 0.20 second after termination of the P wave. This is also approximately when the QRS complex is being recorded in the electrocardiogram. Therefore, the atrial repolarization wave, known as the *atrial T wave,* is usually obscured by the much larger QRS complex

Characteristics of the Normal Electrocardiogram/Intervals

- **P-Q or P-R Interval.**

The time between the beginning of the P wave and the beginning of the QRS complex is the interval between the beginning of electrical excitation of the atria and the beginning of excitation of the ventricles.

The normal P-R interval is about 0.16 second.

- **Q-T Interval.**

Contraction of the ventricle lasts almost from the beginning of the Q wave to the end of the T wave. This interval is called the *Q-T interval* and ordinarily is about 0.35 second.

Characteristics of the Normal Electrocardiogram/Intervals

- **R-R interval and determination of Heart rate**
- The rate of heartbeat can be determined easily from an electrocardiogram because the heart rate is the reciprocal of the time interval between two successive heartbeats.
- If the interval between two beats as determined from the time calibration lines is 1 second, the heart rate is 60 beats per minute.
- In one second the paper crosses 5 large squares, and 300 in one minute, So the heart rate can be calculated 300/number of large squares between RR.

Voltage and Time Calibration of the Electrocardiogram

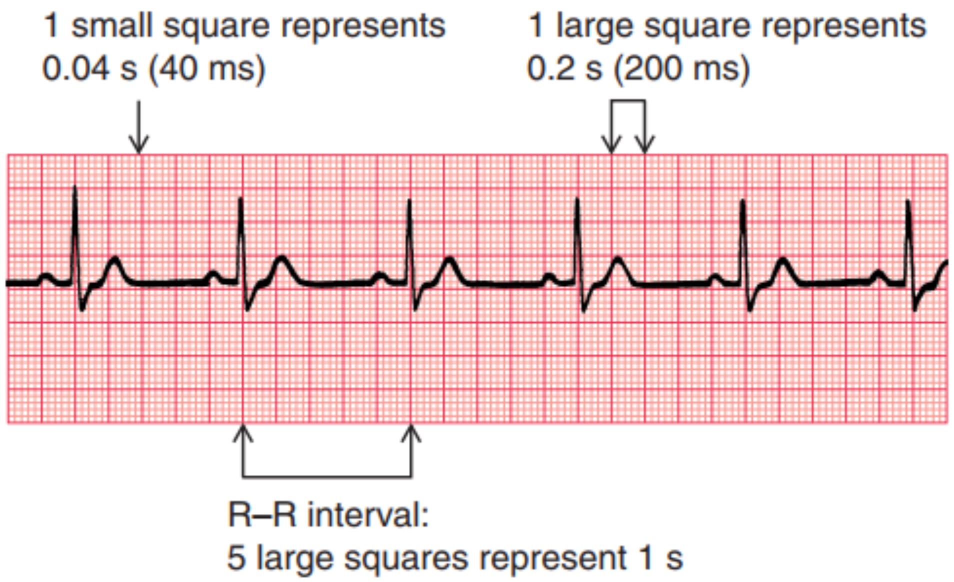
- The vertical axis is arranged so that 10mm upward or downward in the standard electrocardiogram represent 1 millivolt, with positivity in the upward direction and negativity in the downward direction.

- The horizontal axis is the time calibration.
- A typical electrocardiogram is run at a paper speed of 25 millimeters per second.
- Each 25 millimeters in the horizontal direction is 1 second.
- Each 5-millimeter segment, indicated by the dark vertical lines, represents 0.20 second.
- The 0.20-second intervals are then broken into five smaller intervals by thin lines, each of which represents 0.04 second.

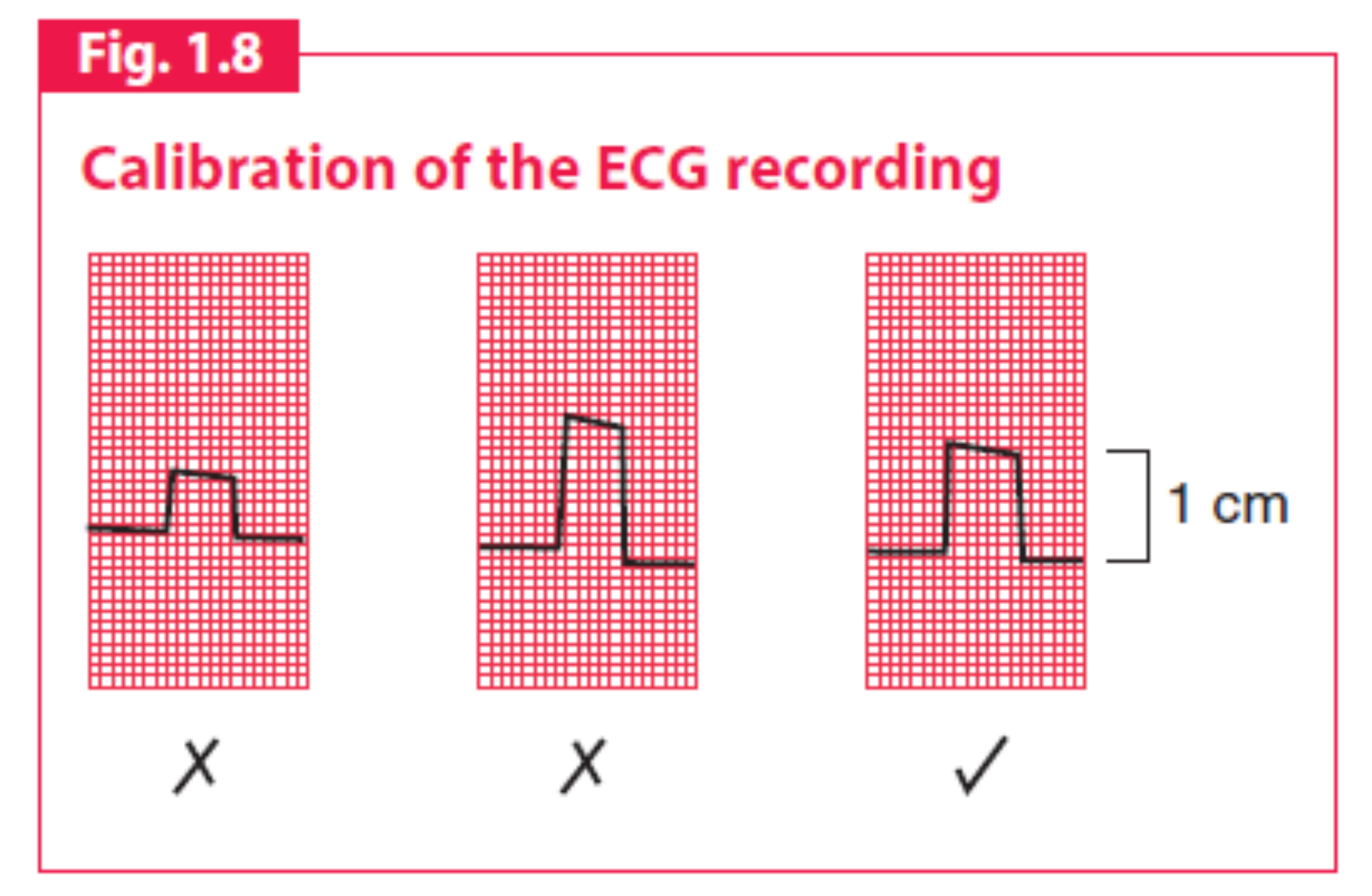
Voltage and Time Calibration of the Electrocardiogram

Fig. 1.4

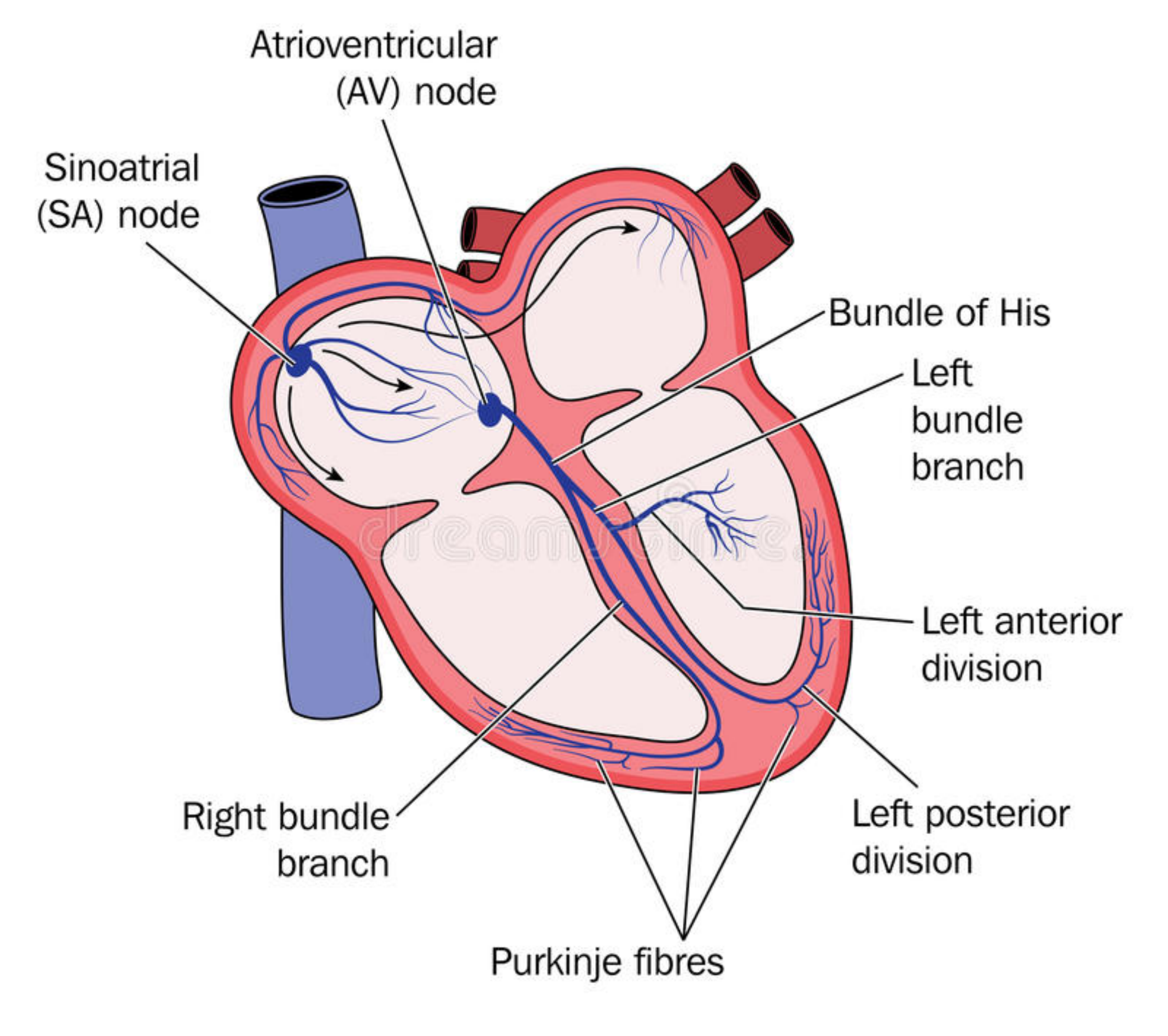
Relationship between the squares on ECG paper and time. Here, there is one QRS complex per second, so the heart rate is 60 beats/min



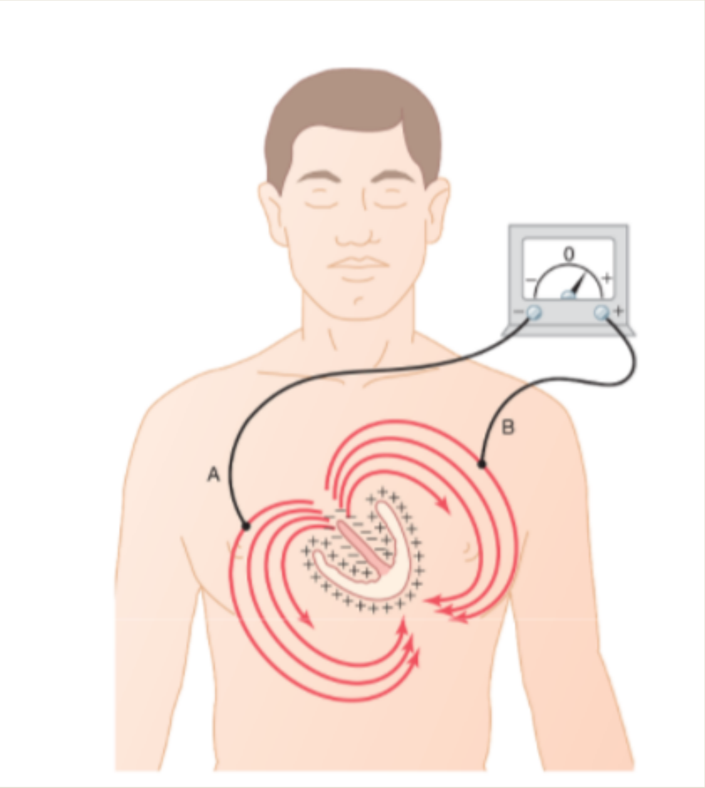
Voltage and Time Calibration of the Electrocardiogram



Conduction System of the Heart

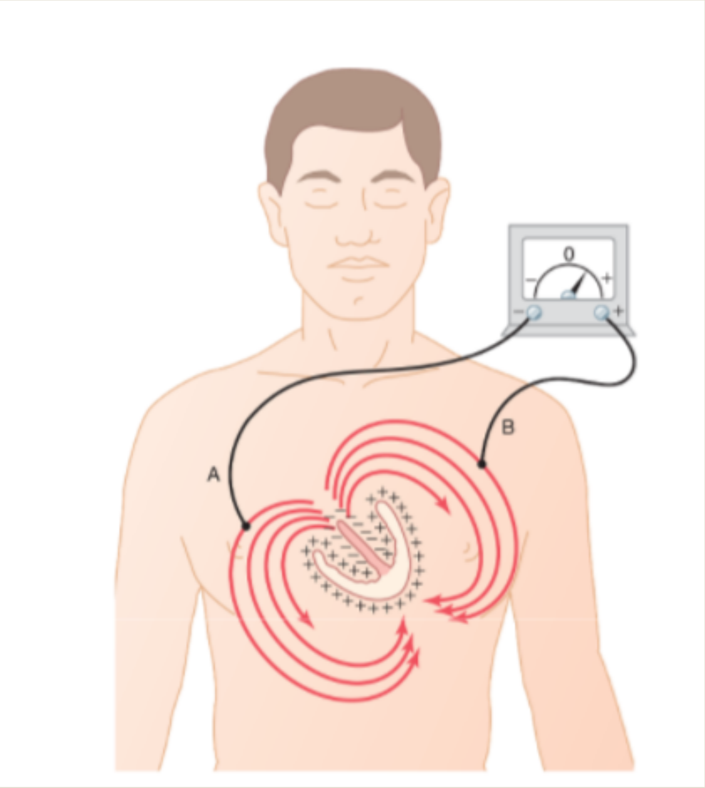


Flow of Electrical Currents



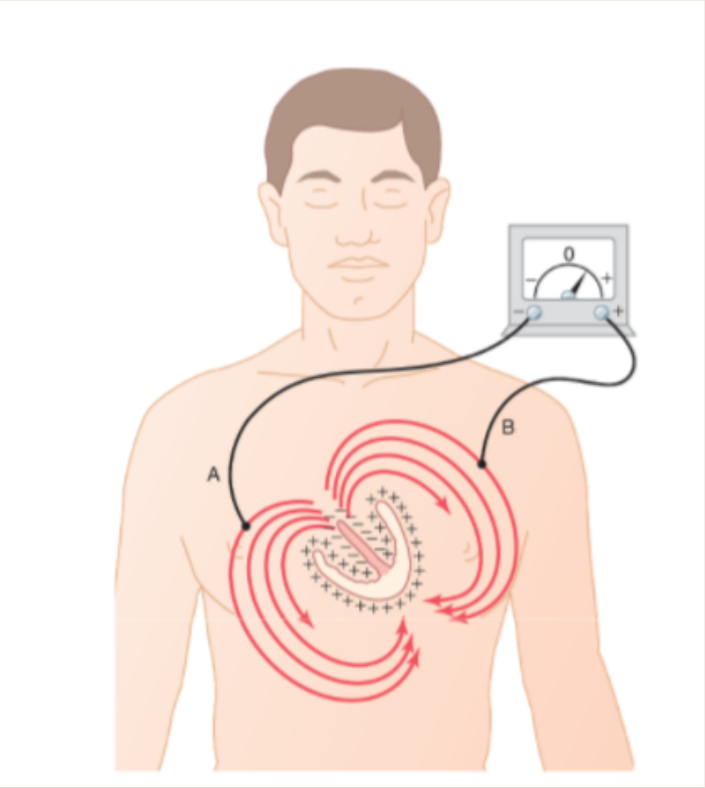
- The heart is actually suspended in a conductive medium. When one portion of the ventricles depolarizes and therefore becomes electronegative with respect to the remainder, electrical current flows from the depolarized area to the polarized area in large circuitous routes, as noted in the figure.

Flow of Electrical Currents



- The cardiac impulse first arrives in the ventricles in the septum and shortly thereafter spreads to the inside surfaces of the remainder of the ventricles.
- This provides electronegativity on the insides of the ventricles and electropositivity on the outer walls of the ventricles.
- The average current flow occurs with negativity toward the base of the heart and with positivity toward the apex.

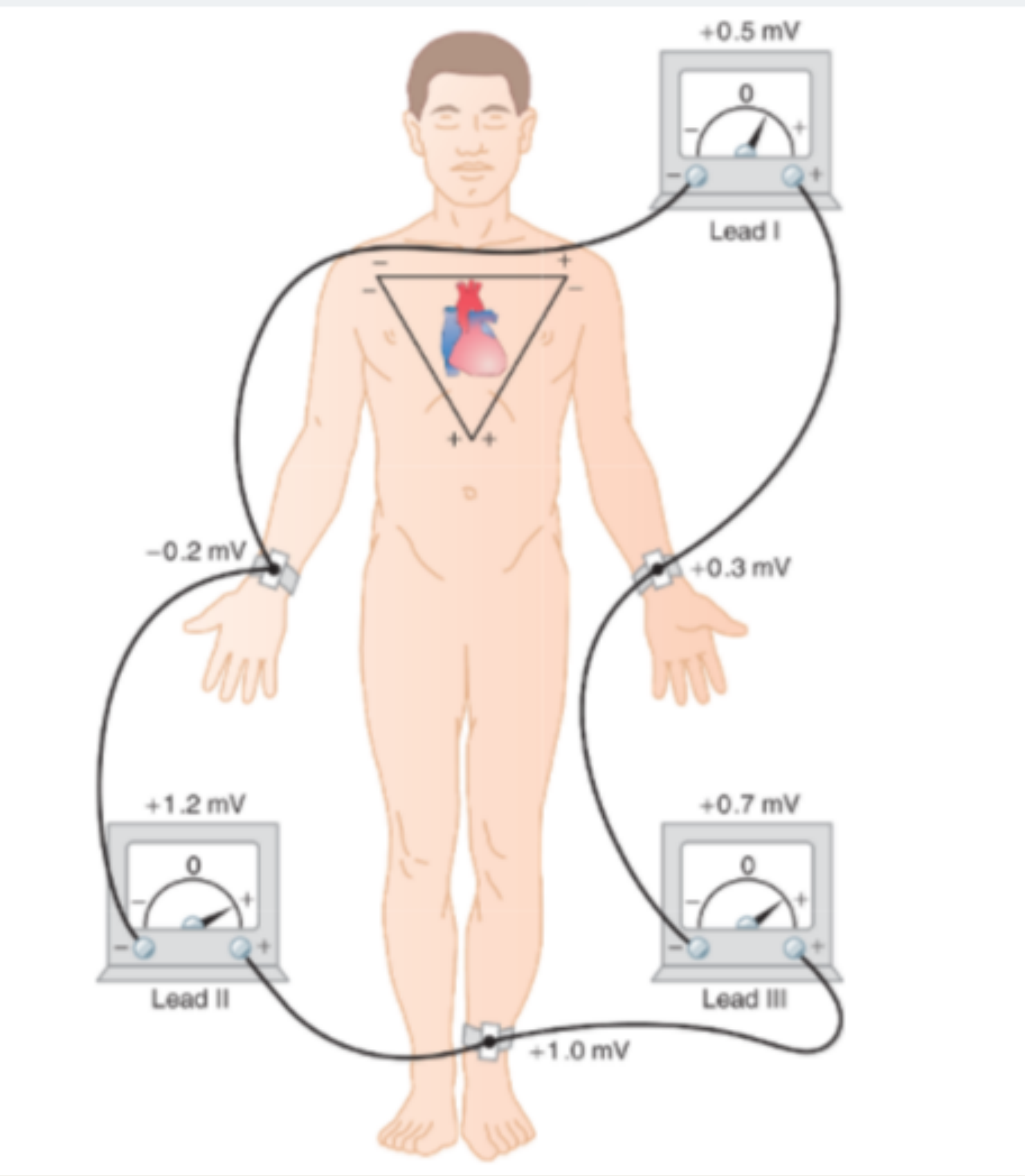
Flow of Electrical Currents



- Immediately before depolarization has completed its course through the ventricles, the average direction of current flow reverses for about 0.01 second, flowing from the ventricular apex toward the base,
- The last part of the heart to become depolarized is the outer walls of the ventricles near the base of the heart.

THREE BIPOLAR LIMB LEADS

The term “bipolar” means that the electrocardiogram is recorded from two electrodes located on different sides of the heart—in this case, on the limbs.


+0.5 mV
0
Lead I
−0.2 mV
+0.3 mV
+1.2 mV
0
Lead II
+0.7 mV
0
Lead III
+1.0 mV

Lead I

- The negative terminal of the electrocardiograph is connected to the right arm and the positive terminal to the left arm.
- Therefore, when the point where the right arm connects to the chest is electronegative with respect to the point where the left arm connects, the electrocardiograph records positively, that is, above the zero voltage line in the electrocardiogram. When the opposite is true, the electrocardiograph records below the line.

Lead II

- The negative terminal of the electrocardiograph is connected to the right arm and the positive terminal to the left leg.
- Therefore, when the right arm is negative with respect to the left leg, the electrocardiograph records positively.

Lead III

- The negative terminal of the electrocardiograph is connected to the left arm and the positive terminal to the left leg.
- This means that the electrocardiograph records positively when the left arm is negative with respect to the left leg.

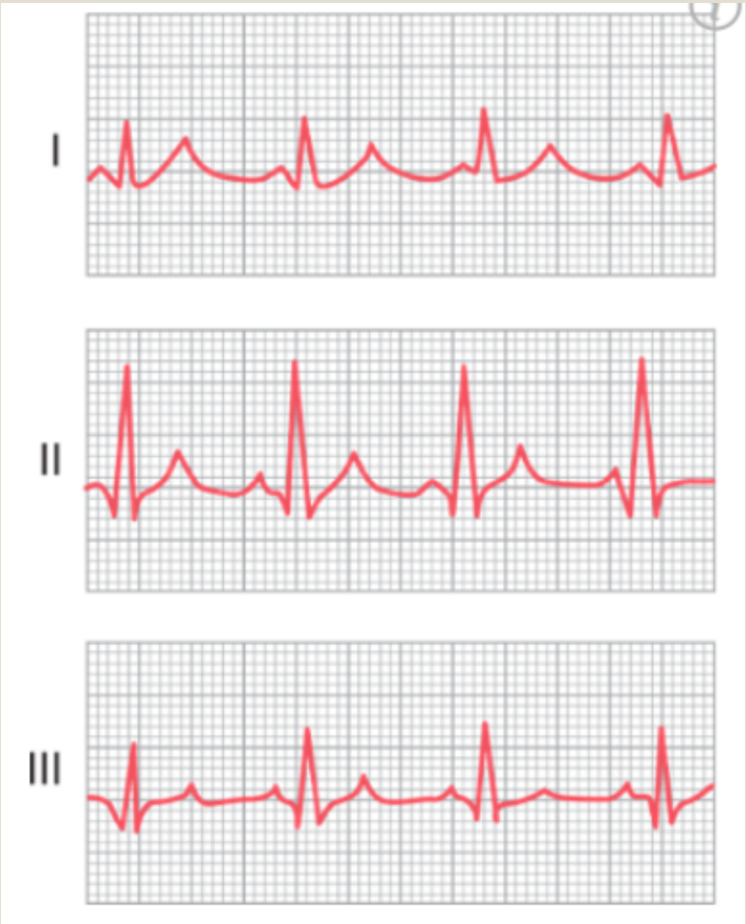
Einthoven’s Law

- if the electrical potentials of any two of the three bipolar limb electrocardiographic leads are known at any given instant, the third one can be determined mathematically by simply summing the first two.

- At any given instant the sum of the potentials in leads I and III equals the potential in lead II, thus illustrating the validity of Einthoven’s law.

Normal Electrocardiograms Recorded from the Three Standard Bipolar Limb Leads.

- They all record positive P waves and positive T waves, and the major portion of the QRS complex is also positive in each electrocardiogram.



AUGMENTED UNIPOLAR LIMB LEADS

Augmented Unipolar Limb Leads

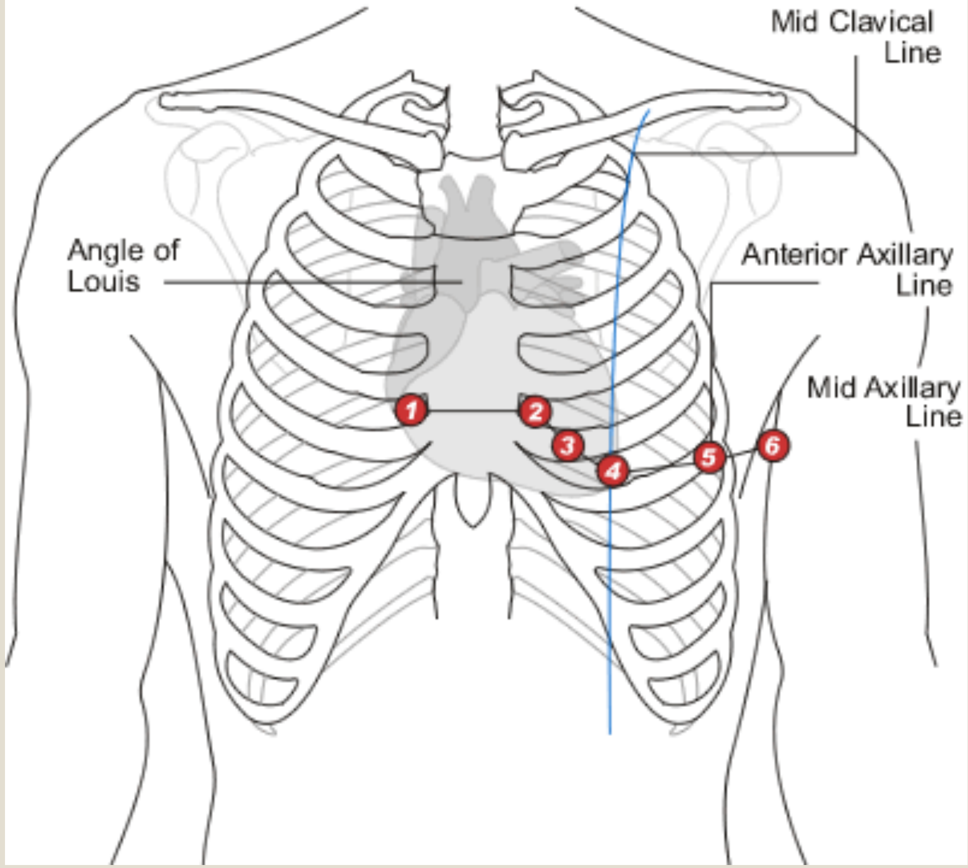
- In this type of recording, two of the limbs are connected through electrical resistances to the negative terminal of the electrocardiograph, and the third limb is connected to the positive terminal.
- When the positive terminal is on the right arm, the lead is known as the aVR lead; when on the left arm, the aVL lead; and when on the left leg, the aVF lead.

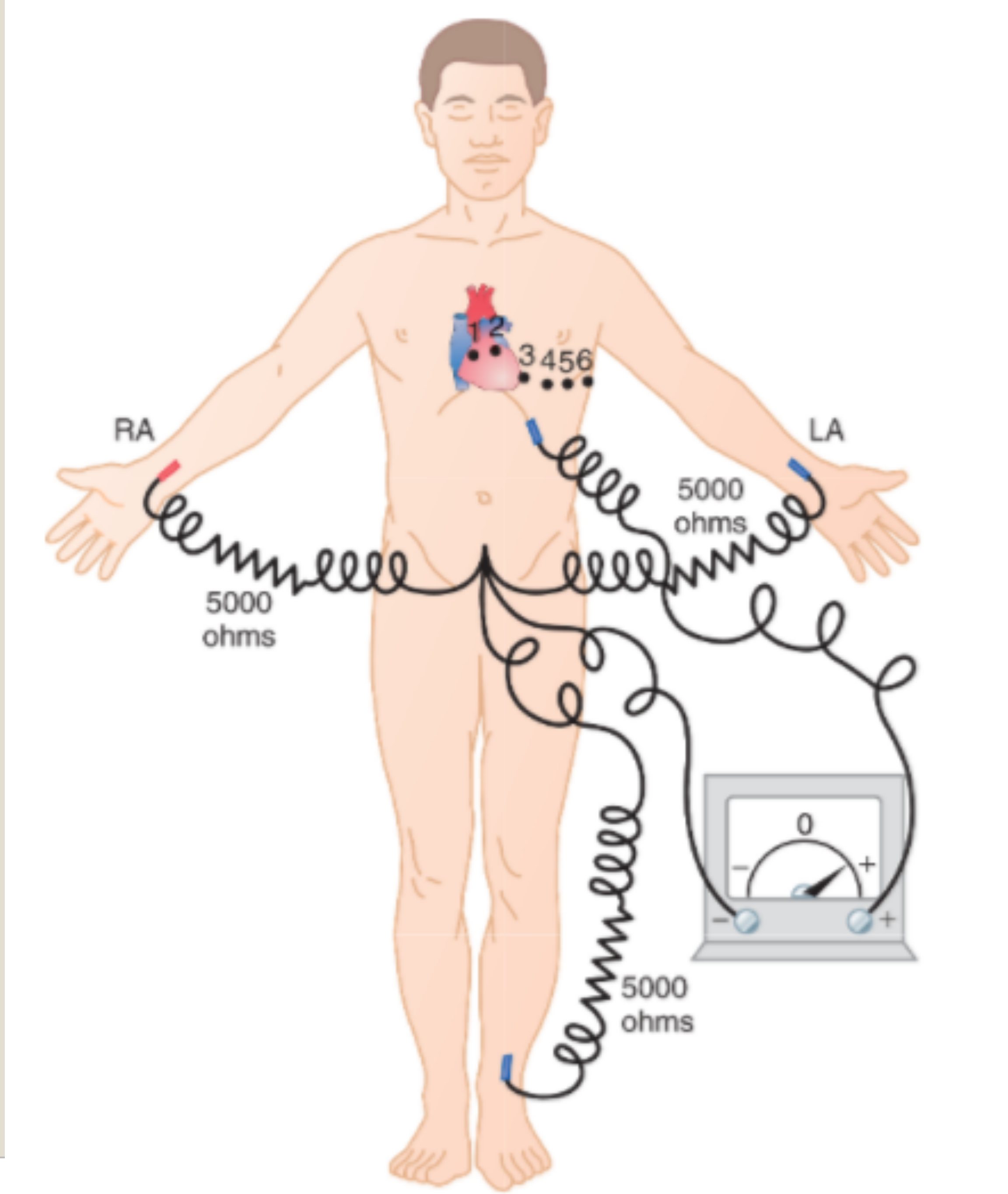
Normal recordings of the augmented unipolar limb leads

CHEST LEADS (PRECORDIAL LEADS)

Positions of Chest Leads

- V1 - Fourth intercostal space at the right sternal border.
- V2 - Fourth intercostal space at the left sternal border.
- V3 - Midway between placement of V2 and V4.
- V4 - Fifth intercostal space at the midclavicular line.
- V5 - Anterior axillary line on the same horizontal level as V4.
- V6 - Mid-axillary line on the same horizontal level as V4 and V5.





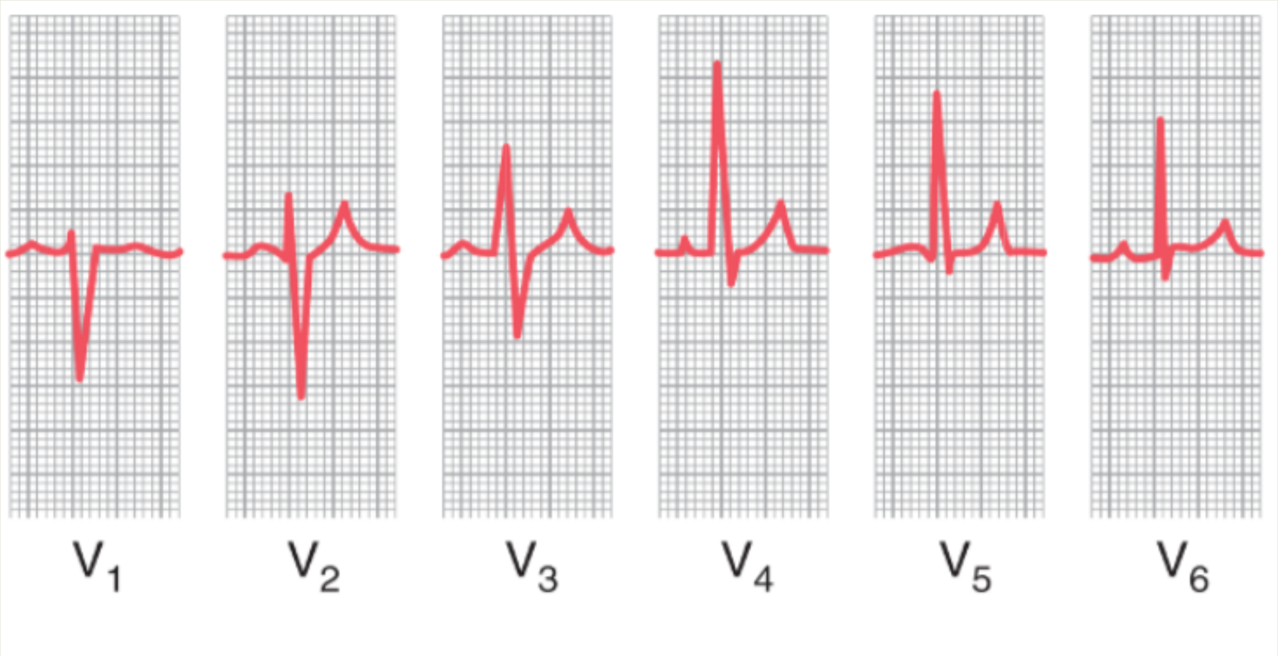
1
2
3
4
5
6
RA
LA
5000 ohms
5000 ohms
5000 ohms
0
–
+
–
+

Chest Leads

- One electrode is placed on the anterior surface of the chest directly over the heart and this electrode is connected to the positive terminal of the electrocardiograph.
- The negative electrode, called the *indifferent electrode,* is connected through equal electrical resistances to the right arm, left arm, and left leg all at the same time.
- The different recordings are known as leads V1, V2, V3, V4, V5, and V6.

Chest Leads

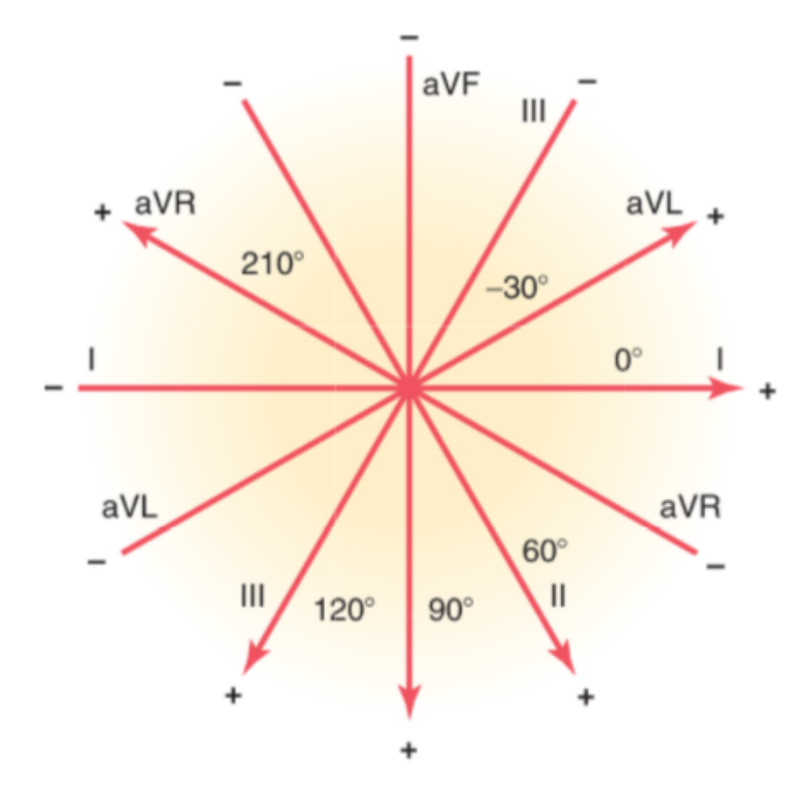
- In leads V1 and V2, the QRS recordings of the normal heart are mainly negative because, the chest electrode in these leads is nearer to the base of the heart than to the apex, and the base of the heart is the direction of electronegativity during most of the ventricular depolarization process
- Conversely, the QRS complexes in leads V4, V5, and V6 are mainly positive because the chest electrode in these leads is nearer the heart apex, which is the direction of electropositivity during most of depolarization.



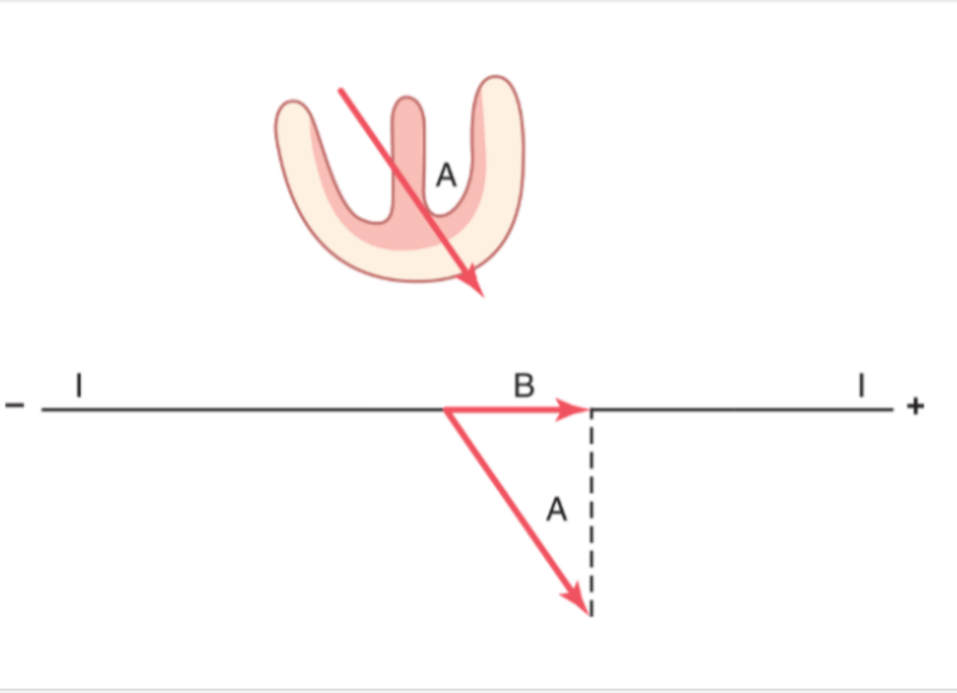
VECTORIAL ANALYSIS

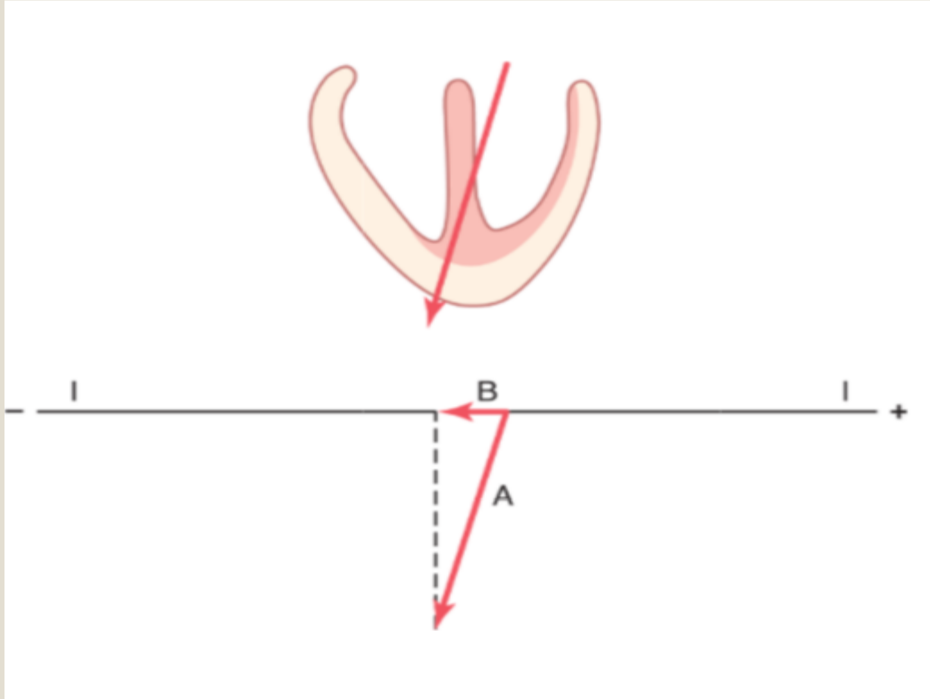
Hexagonal reference system

- Axes of the three bipolar and three unipolar leads

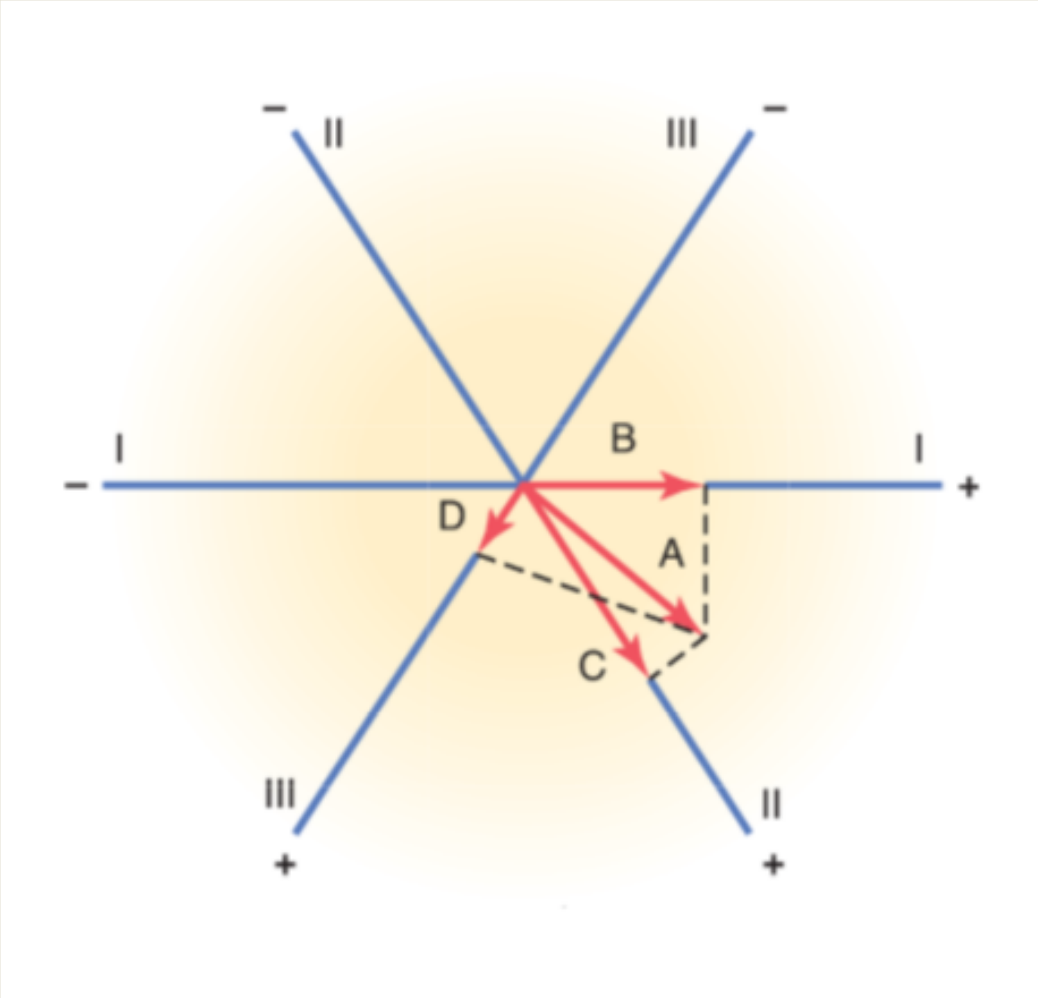


Vectorial analysis



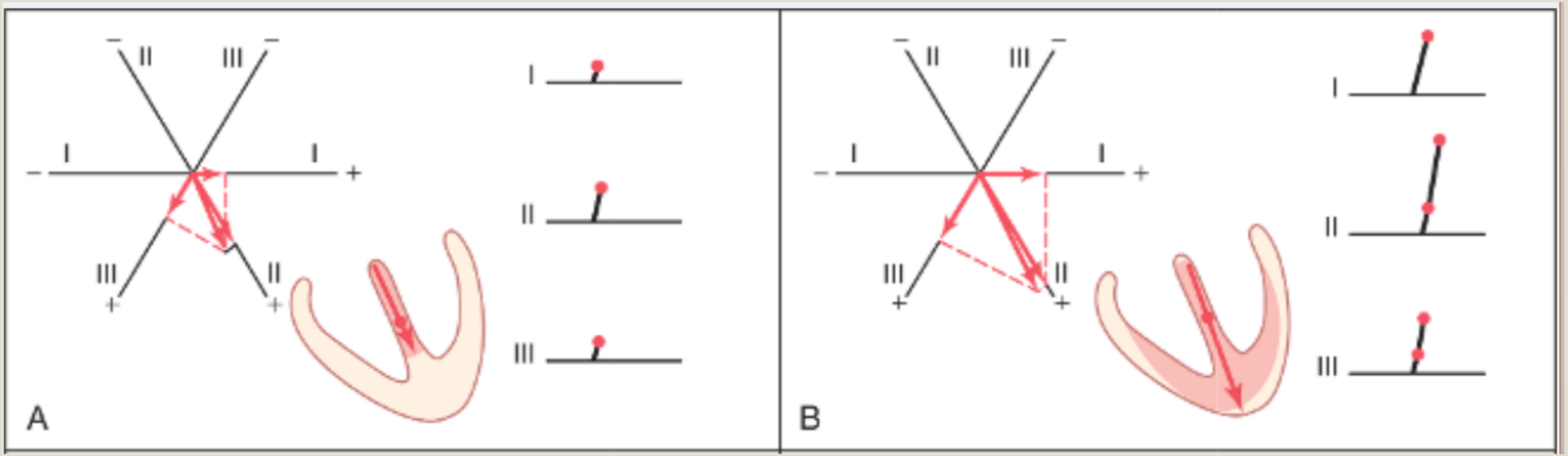


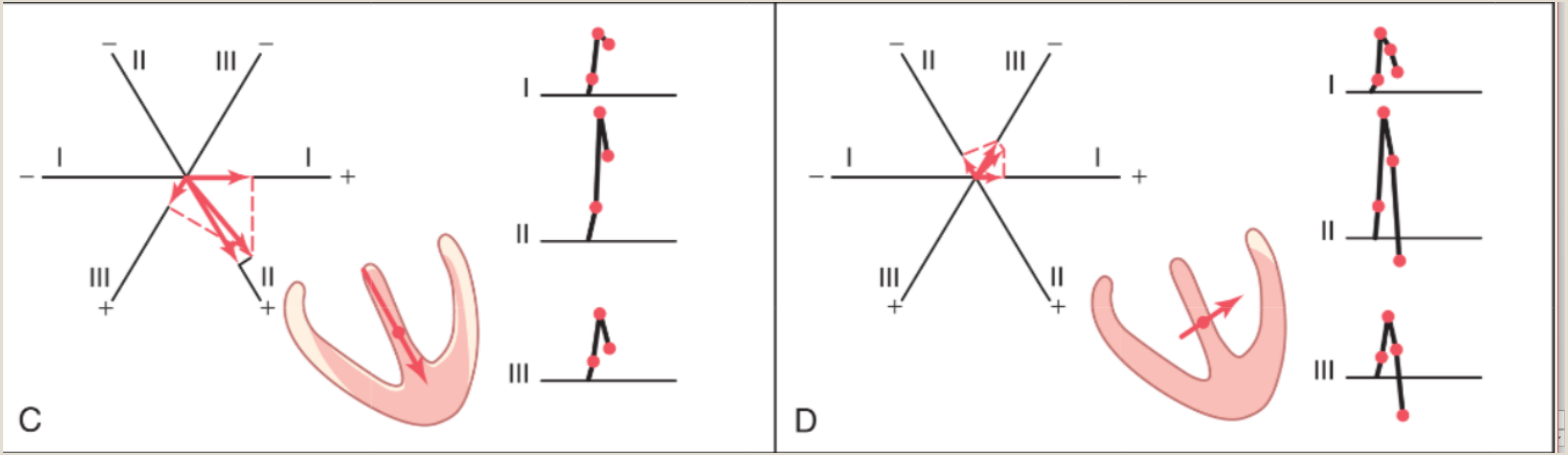
Determination of projected vectors in leads I, II, and III when vector A represents the instantaneous potential in the ventricles.



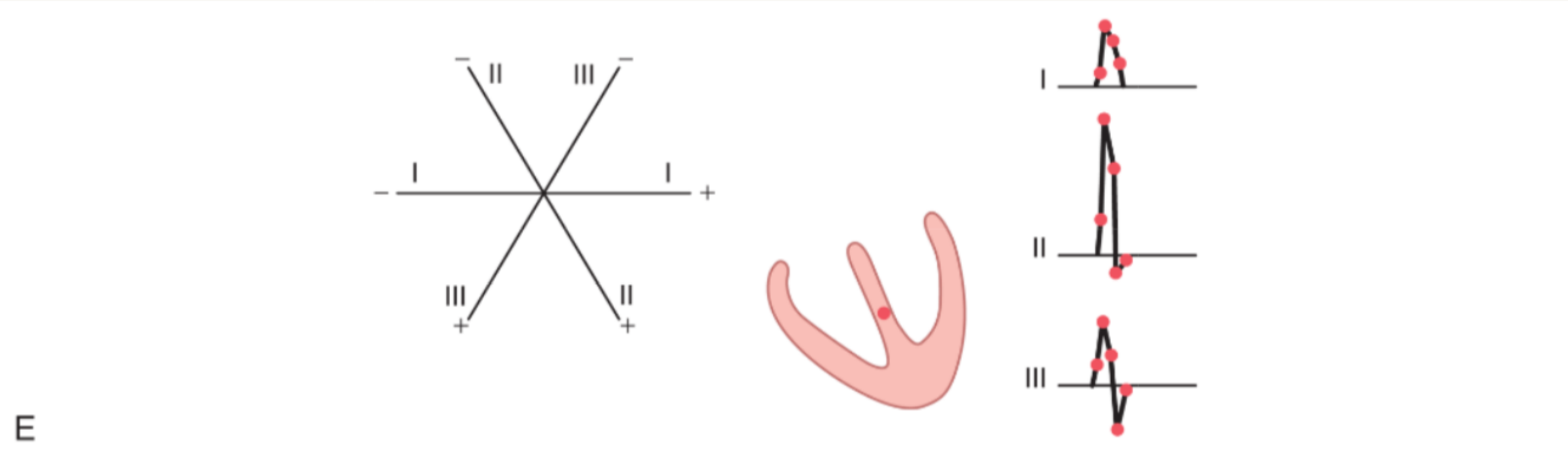
VECTORS THAT OCCUR AT SUCCESSIVE INTERVALS DURING DEPOLARIZATION OF THE VENTRICLES—THE QRS COMPLEX

- When the cardiac impulse enters the ventricles through the atrioventricular bundle, the first part of the ventricles to become depolarized is the left endocardial surface of the septum. Then depolarization spreads rapidly to involve both endocardial surfaces of the septum, as demonstrated by the darker shaded portion of the ventricle in A. Next, depolarization spreads along the endocardial surfaces of the remainder of the two ventricles, as shown in B and C. Finally, it spreads through the ventricular muscle to the outside of the heart, as shown progressively in D, and E.


A
B
I
II
III
–
+



C
D
I
II
III
+
–



II
III
I
I
III
II
I
II
III
E

Q wave

It is caused by initial depolarization of the left side of the septum before the right side, which creates a weak vector from left to right for a fraction of a second before the usual base-to-apex vector occurs.

ELECTROCARDIOGRAM DURING REPOLARIZATION—THE T WAVE

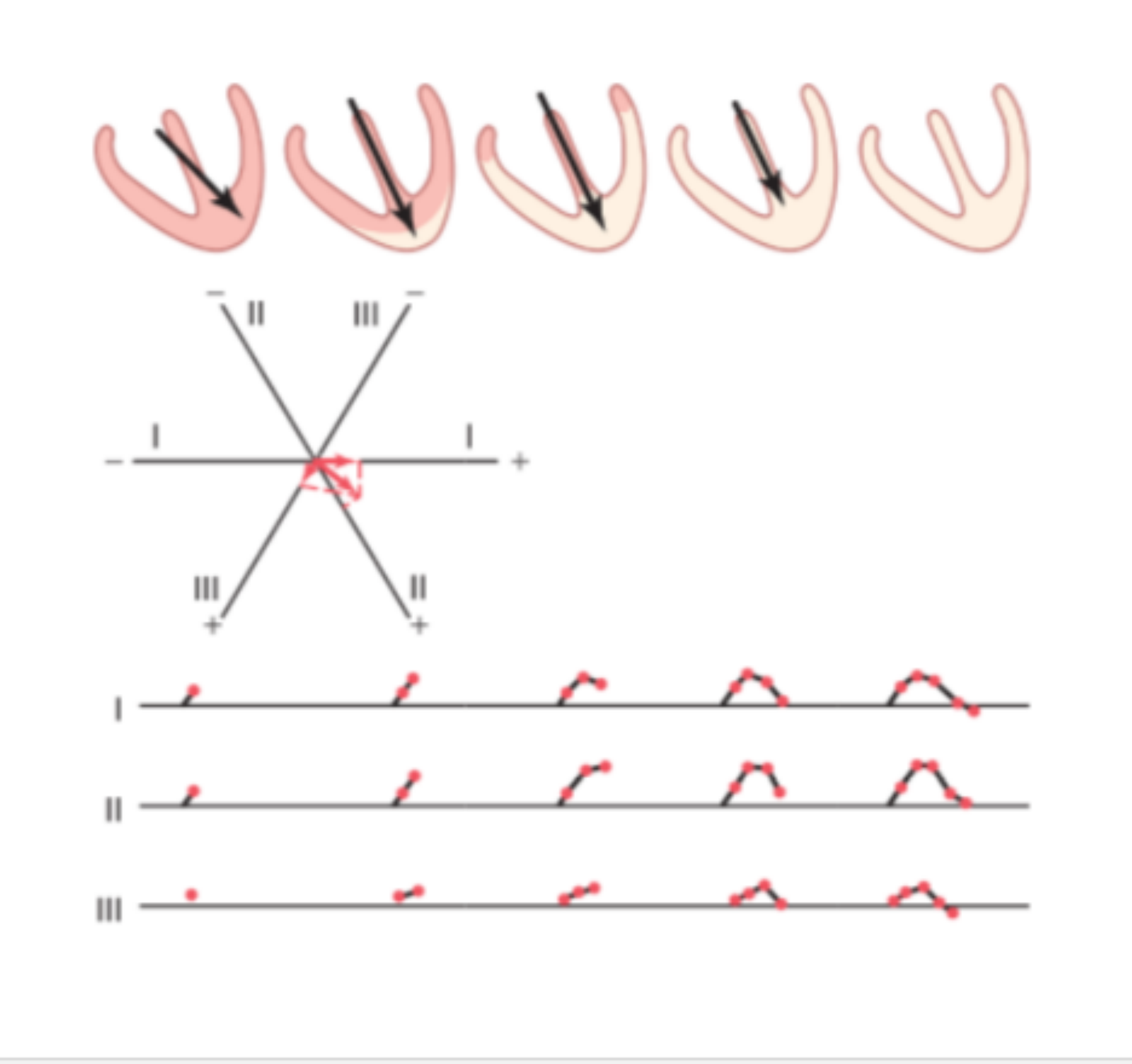
T wave

- Because the septum and endocardial areas of the ventricular muscle depolarize first, it seems logical that these areas should repolarize first as well. However, this is not the usual case because the septum and other endocardial areas have a longer period of contraction than most of the external surfaces of the heart. Therefore, the greatest portion of ventricular muscle mass to repolarize first is the entire outer surface of the ventricles, especially near the apex of the heart.

T wave

- Because the outer apical surfaces of the ventricles repolarize before the inner surfaces, the positive end of the overall ventricular vector during repolarization is toward the apex of the heart. *As a result, the normal T wave in all three bipolar limb leads is positive, which is also the polarity of most of the normal QRS complex.*

T wave



DEPOLARIZATION AND REPOLARIZATION OF ATRIUM

Depolarization of the atria

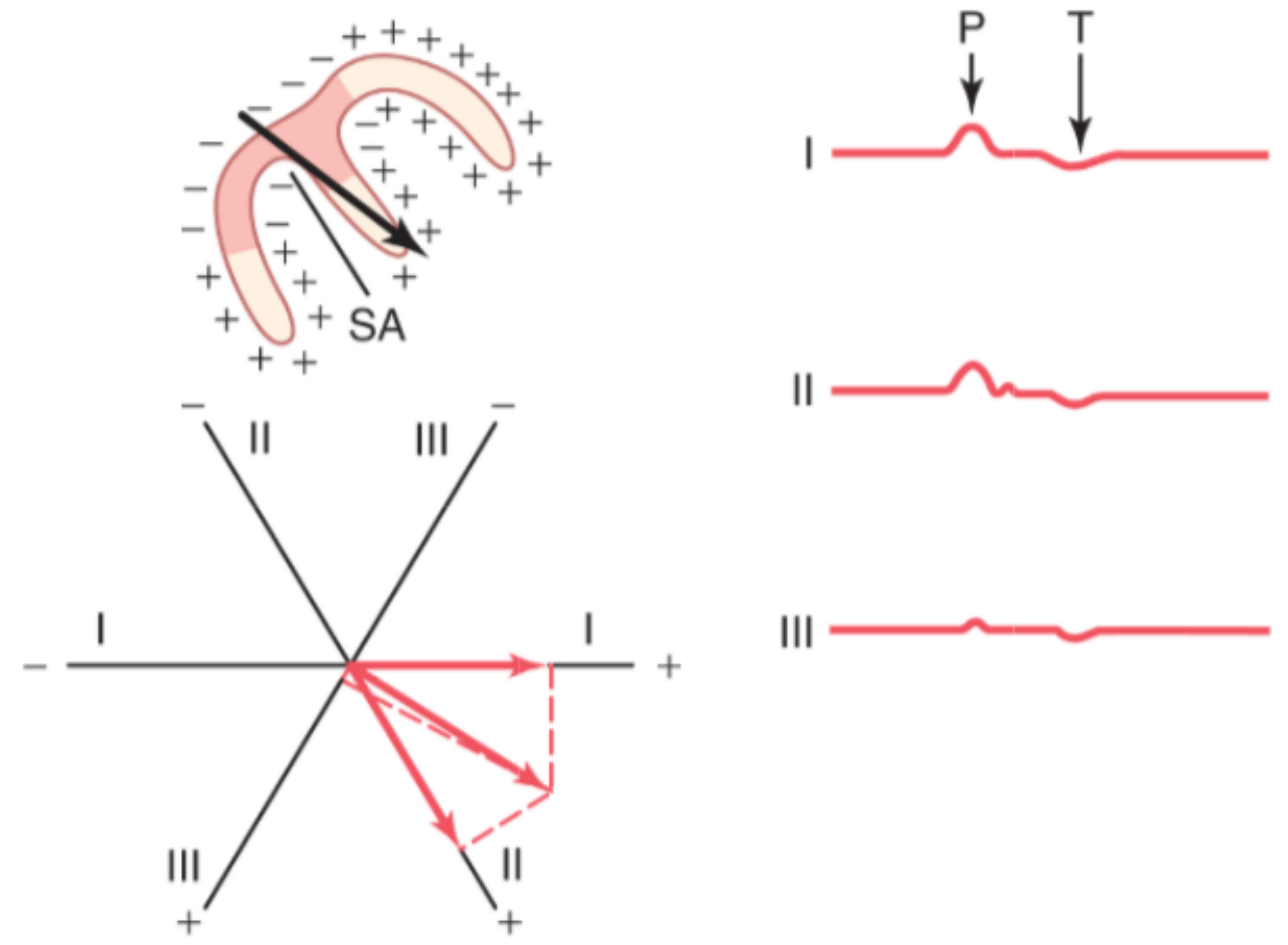
- Begins in the sinus node and spreads in all directions over the atria. Therefore, the point of original electronegativity in the atria is about at the point of entry of the superior vena cava where the sinus node lies, and the direction of initial depolarization is denoted by the black vector. Furthermore, the vector remains generally in this direction throughout the process of normal atrial depolarization. Because this direction is generally in the positive directions of the axes of the three standard bipolar limb leads I, II, and III, the electrocardiograms recorded from the atria during depolarization are also usually positive in all three of these leads. This record of atrial depolarization is known as the atrial P wave.

Repolarization of the Atria—the Atrial T Wave

- Spread of depolarization through the atrial muscle is *much slower than in the ventricles* because the atria have no Purkinje system for fast conduction of the depolarization signal. Therefore, the musculature around the sinus node becomes depolarized a long time before the musculature in distal parts of the atria. Because of this, *the area in the atria that also becomes repolarized first is the sinus nodal region, the area that had originally become depolarized first*. Thus, when repolarization begins, the region around the sinus node becomes positive with respect to the rest of the atria. Therefore, the atrial repolarization vector is *backward to the vector of depolarization*. (Note that this is opposite to the effect that occurs in the ventricles.) Therefore, the atrial T wave follows about 0.15 second after the atrial P wave, but this T wave is on the opposite side of the zero reference line from the P wave; that is, it is normally negative rather than positive in the three standard bipolar limb leads.

Repolarization of the Atria—the Atrial T Wave

- In the normal electrocardiogram, the *atrial* T wave appears at about the same time that the QRS complex of the ventricles appears. Therefore, it is almost always totally obscured by the large *ventricular* QRS complex, although in some very abnormal states, it does appear in the recorded electrocardiogram.



SA
P
T
I
II
III

NORMAL AXIS OF THE HEART

Although the mean electrical axis of the ventricles averages about 59 degrees, this axis can swing even in the normal heart from about -30 degrees to about 90 degrees

The normal cardiac axis is in the range –30° to +90°

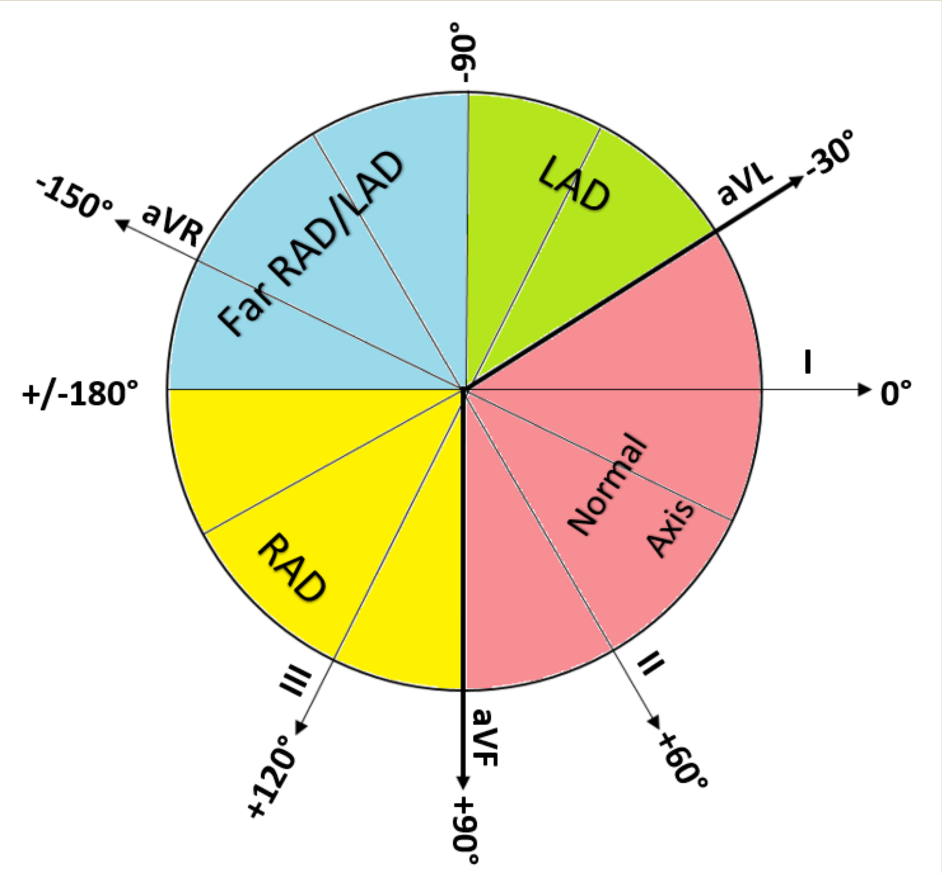
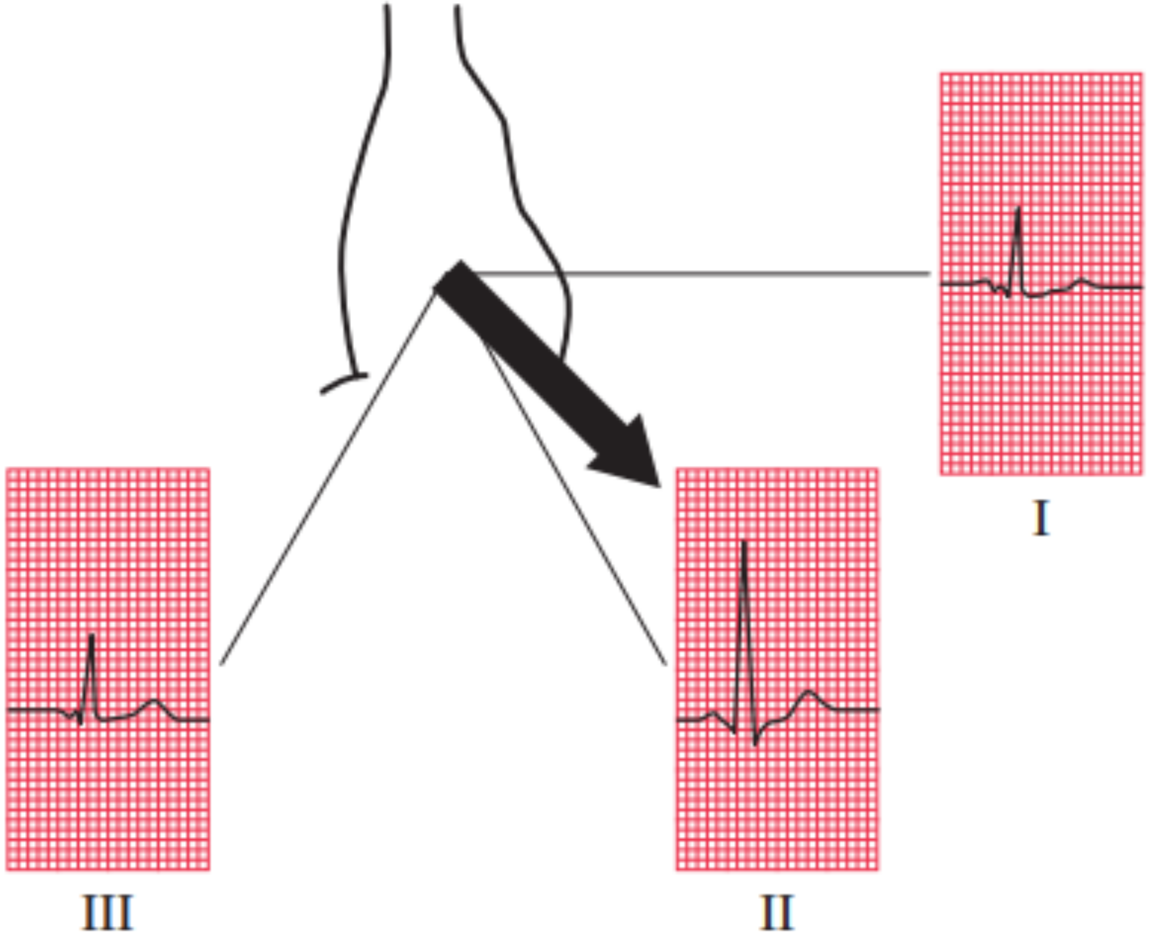


Fig. 1.14

The normal axis

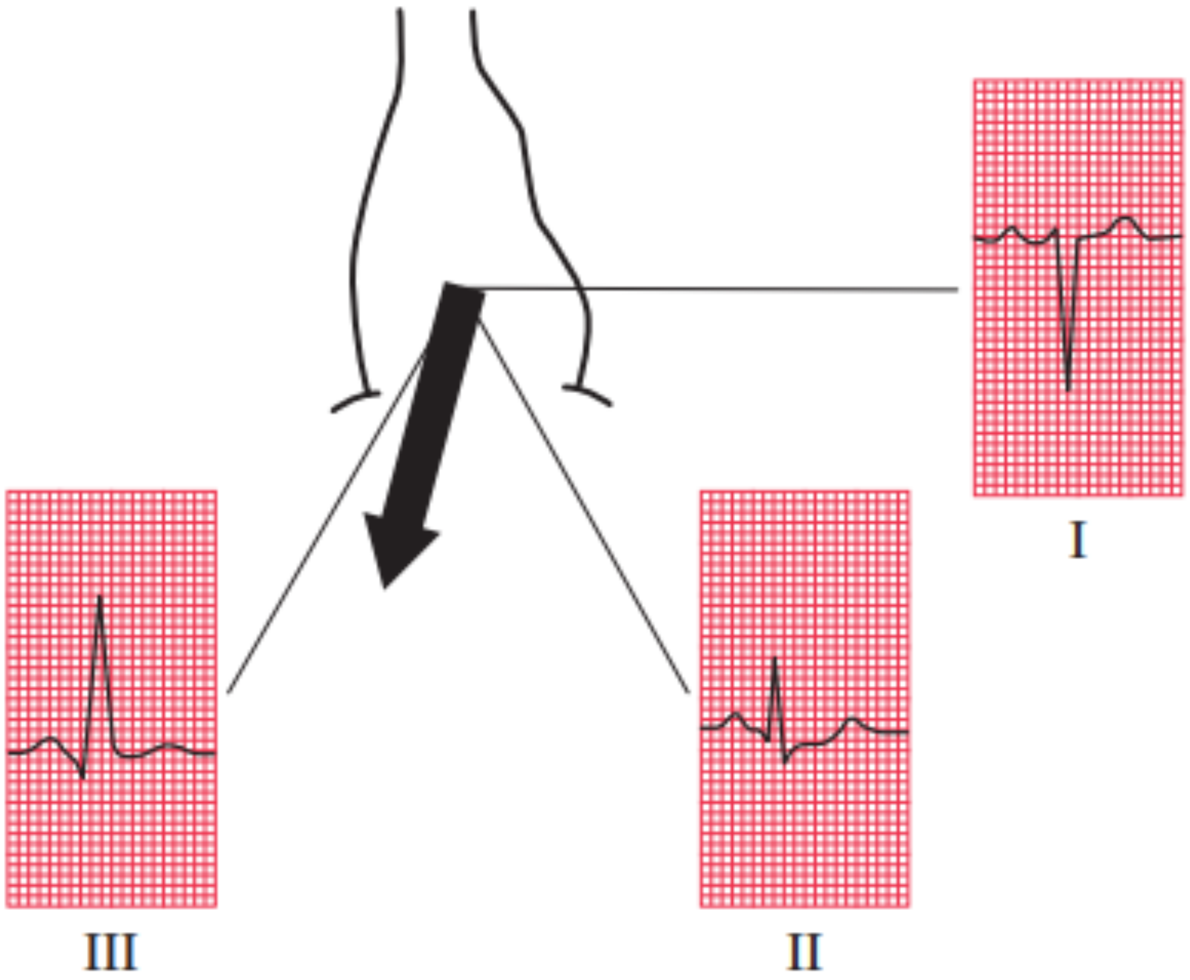


Right Axis Deviation

- If the right ventricle becomes hypertrophied, it has more effect on the QRS complex than the left ventricle, and the average depolarization wave – the axis – will swing towards the right. The deflection in lead I becomes negative (predominantly downward) because depolarization is spreading away from it, and the deflection in lead III becomes more positive (predominantly upward) because depolarization is spreading towards it .
- It is associated mainly with pulmonary conditions.

Fig. 1.15

Right axis deviation

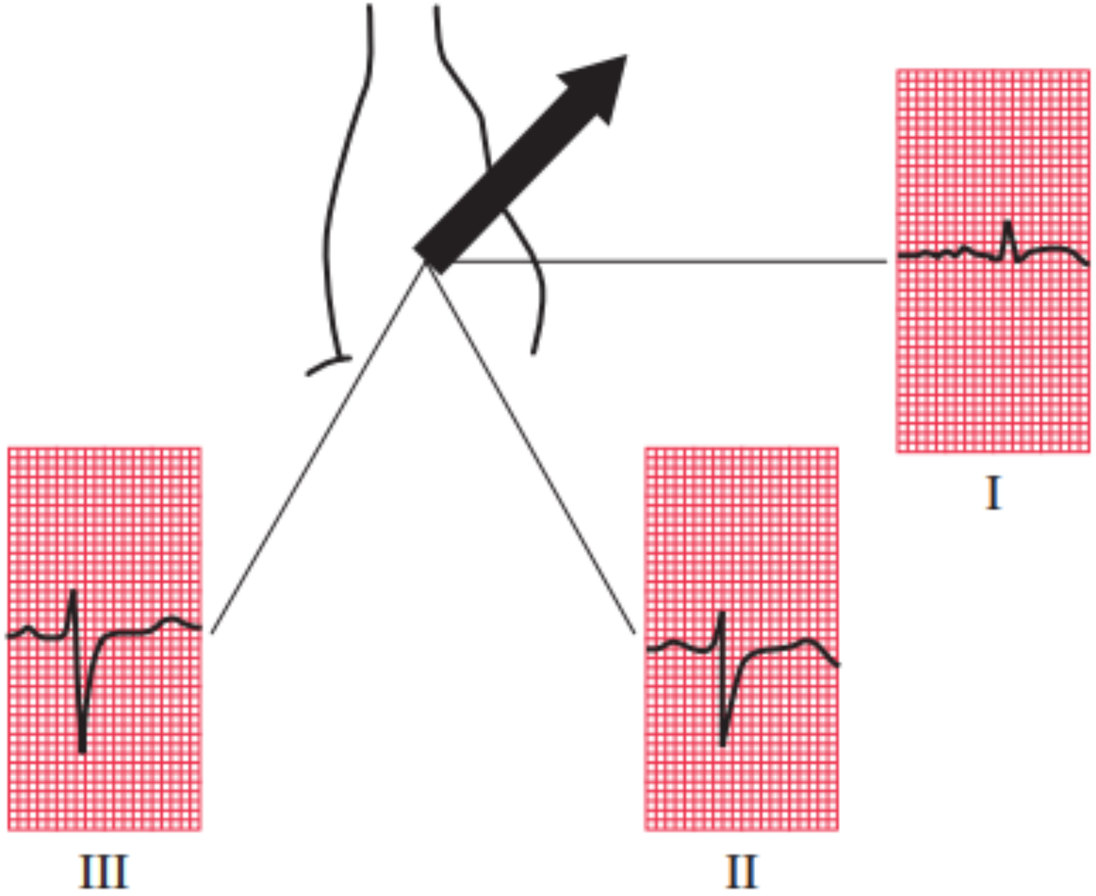


Left axis deviation

- When the left ventricle becomes hypertrophied, it exerts more influence on the QRS complex than the right ventricle. Hence, the axis may swing to the left, and the QRS complex becomes predominantly negative in lead III.

Fig. 1.16

Left axis deviation

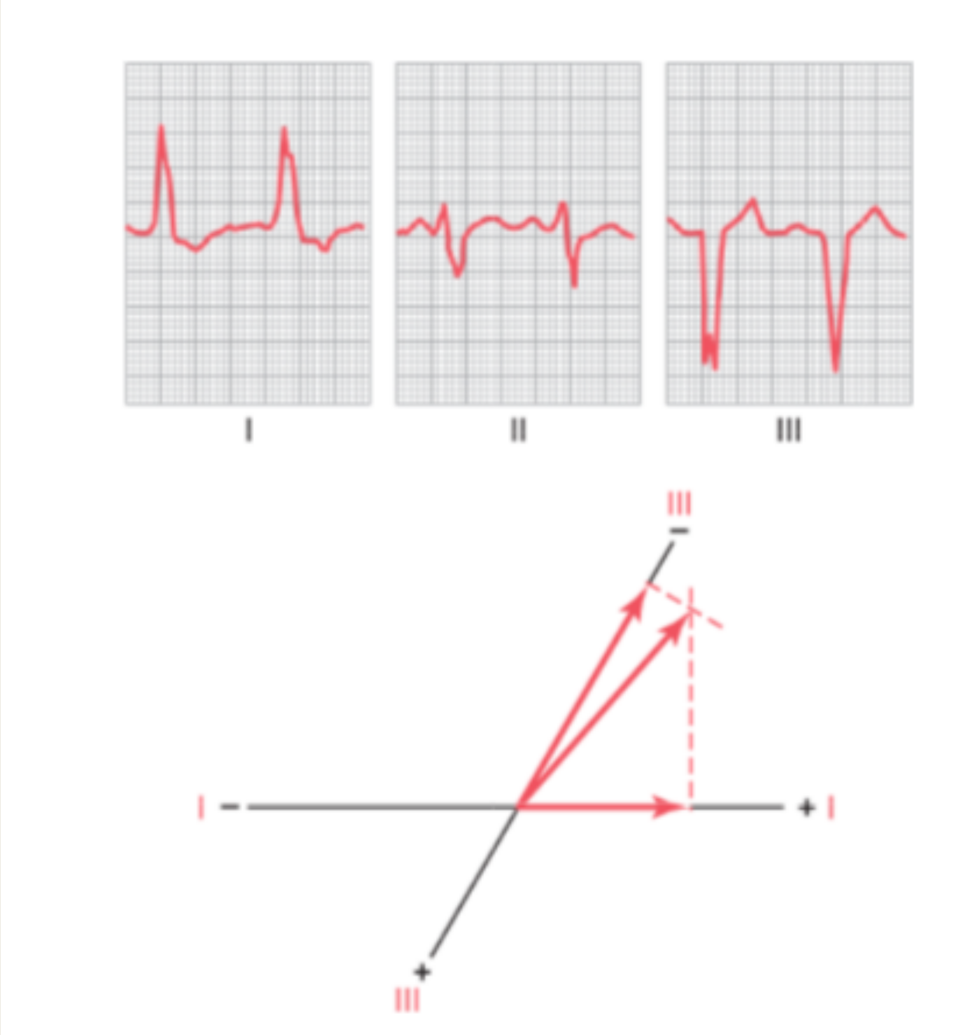


BUNDLE BRANCH BLOCK

Left Bundle Branch Block

- When the left bundle branch is blocked, cardiac depolarization spreads through the right ventricle two to three times as rapidly as through the left ventricle.
- The right ventricle becomes electronegative, whereas the left ventricle remains electropositive during most of the depolarization process.
- There is intense left axis deviation of about -50 degrees because the positive end of the vector points toward the left ventricle
- Duration of the QRS complex is greatly prolonged because of extreme slowness of depolarization in the affected side of the heart.

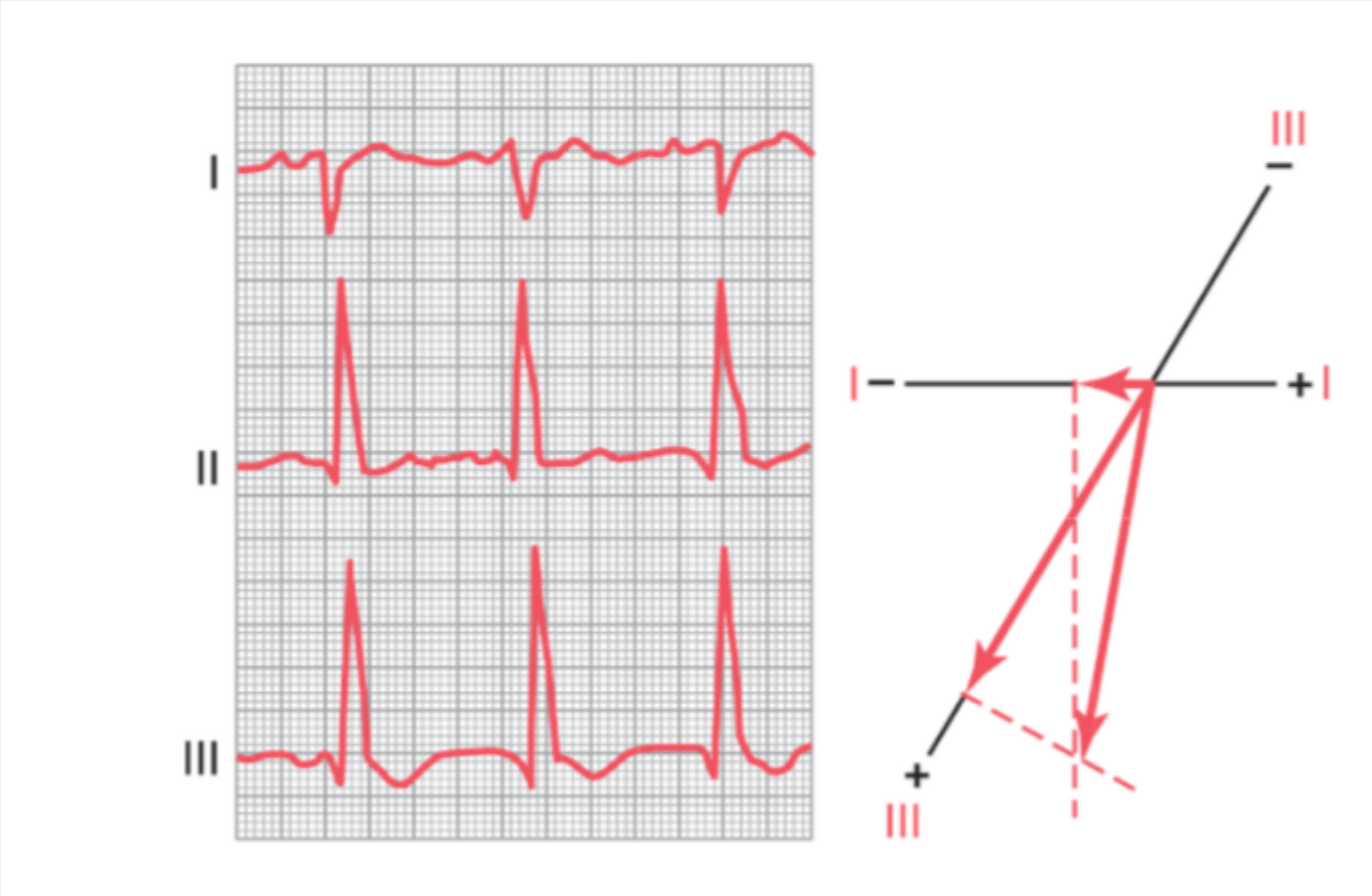
Left Bundle Branch Block



Right Bundle Branch Block

- The left ventricle depolarizes far more rapidly than the right ventricle.
- So vector develops, with its negative end toward the left ventricle and its positive end toward the right ventricle. In other words, intense right axis deviation occurs.
- Prolonged QRS complex because of slow conduction.

Right Bundle Branch Block



ECG INTERPRETATION

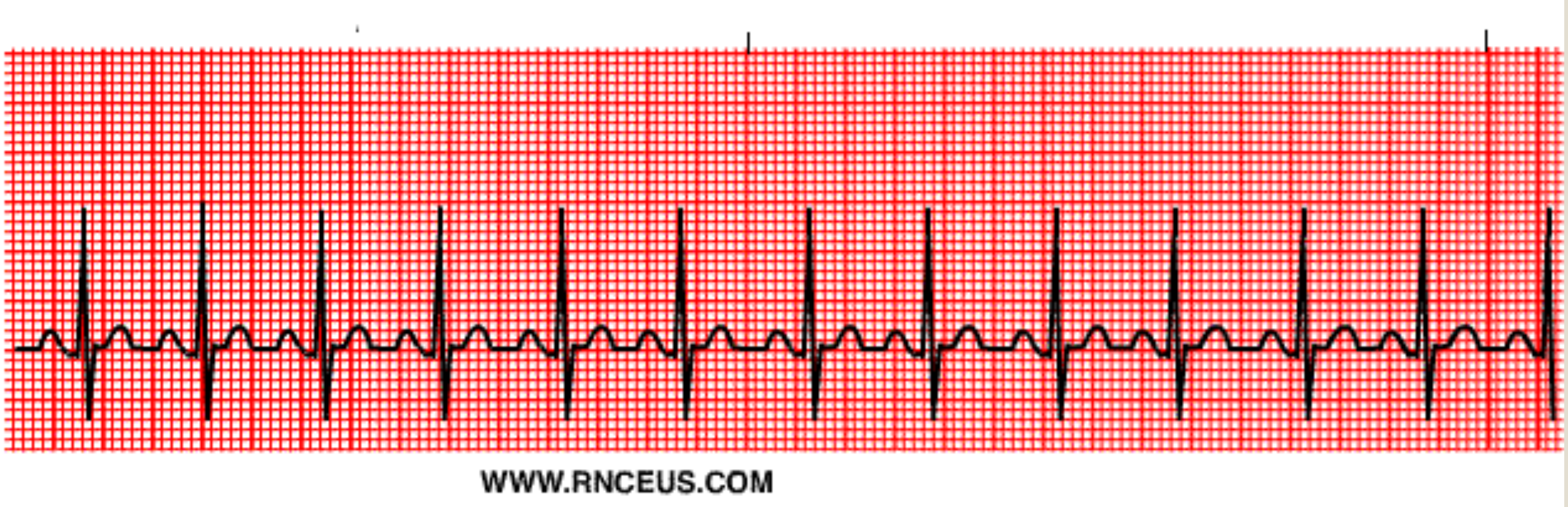
General look

- Name
- Date
- Calibration (Review slides: 15,16,17)
- Step 1: Rate
- Step 2: Rhythm
- Step 3: Axis (Review slides: 56 to 67)
- Step 4: Intervals.
- Step 5: P wave
- Step 6: QRS complex
- Step 7: ST segment-T wave
- Step 8: Overall interpretation

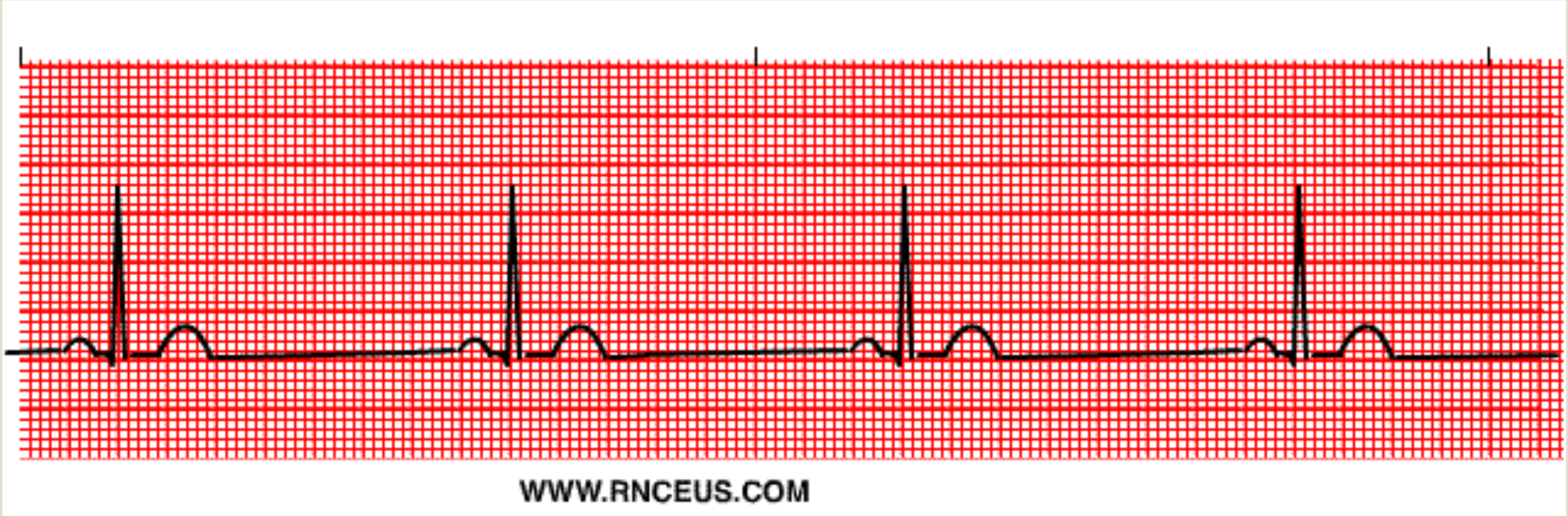
Step1: Rate

- Is the rate between 60 and 100?
- Rates less than 60 are bradycardic and greater than 100 are tachycardic.
- The division of 300 by the number of large boxes calculates the heart rate. If the interval between two successive complexes is one large box, then the rate is 300 beats/min (300 ÷ 1 = 300 beats/min). If the interval is two large boxes, the rate is 150 (300 ÷ 2 = 150 beats/min).

Sinus Tachycardia



Sinus Bradycardia



Step 2: Rhythm

- Regular Vs. irregular
- Is it normal sinus or other?
- Are P waves present? Is there a P wave before every QRS complex

IS it Sinus Rhythm?

- There must always be a p wave.
- The P wave should be a rounded shape
- Each P wave should be the same shape
- Each P wave should be followed by a QRS
- The P-R interval should be 3-5 small squares and constant
- The rhythm should be regular.

Step 3: Axis

- Is there left or right axis deviation?
- **Review slides: 56 to 67**

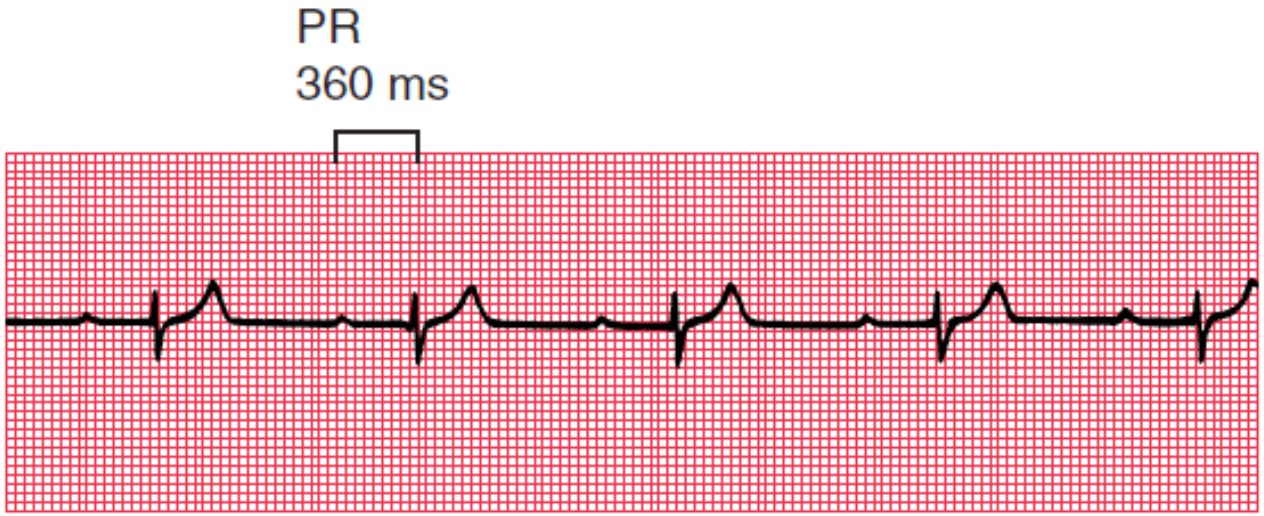
Step 4: Intervals

- **What is the PR interval?**
- Normally 0.12 to 0.20 sec (three to five small boxes)
- The PR interval is shorter at faster heart rates due to sympathetically mediated enhancement of atrioventricular (AV) nodal conduction; it is longer when the rate is slowed as a consequence of slower AV nodal conduction resulting from withdrawal of sympathetic tone or an increase in vagal inputs.
- **What is the QT interval?**

Prolonged PR Interval In First Degree Heart Block

Fig. 2.2

First degree heart block



Note

- One P wave per QRS complex
- PR interval 360 ms

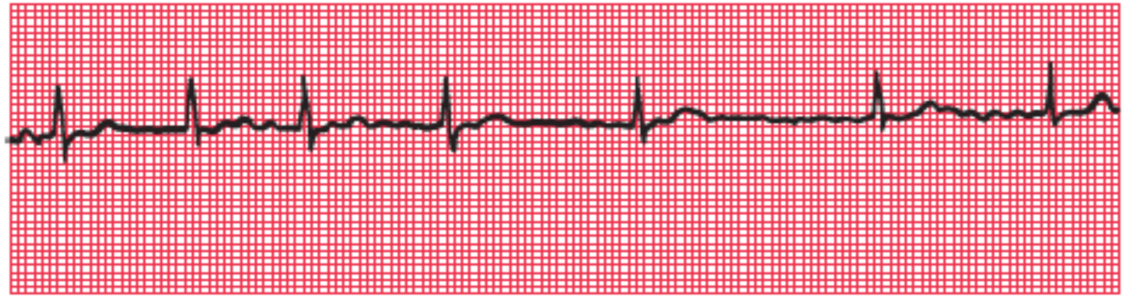
Step 5: P wave

- What is the shape and axis of the P wave?

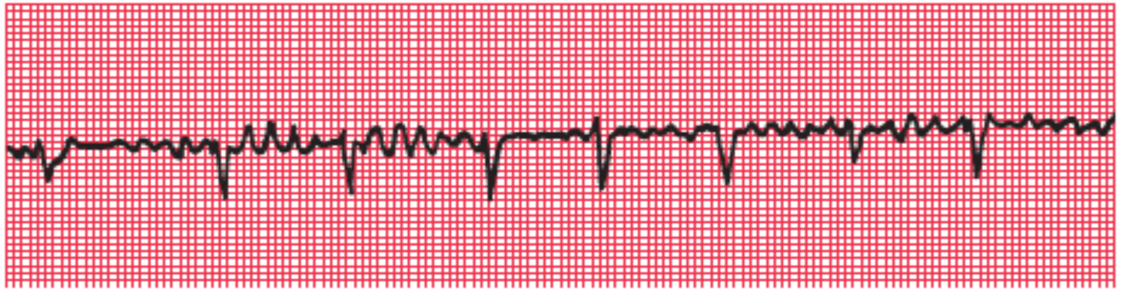
Fig. 3.25

Atrial fibrillation

Lead II:



Lead V_1:



Note

- No P waves, and an irregular baseline
- Irregular QRS complexes
- Normally shaped QRS complexes
- In lead V_1, waves can be seen with some resemblance to those seen in atrial flutter – this is common in atrial fibrillation

Step 6: QRS complex

- Is the QRS wide?
- What is voltage ?

Prolonged QRS Complex

- The normal QRS complex lasts 0.06 to 0.08 second.
- whereas in hypertrophy or dilatation of the left or right ventricle, the QRS complex may be prolonged to 0.09 to 0.12 second.
- If complete block of one of the bundle branches occurs, the duration of the QRS complex is usually increased to 0.14 second or greater.

Step 7: ST segment-T wave

- Is there ST elevation or depression ?
- Are the T waves inverted?

Acute ST Elevation MI

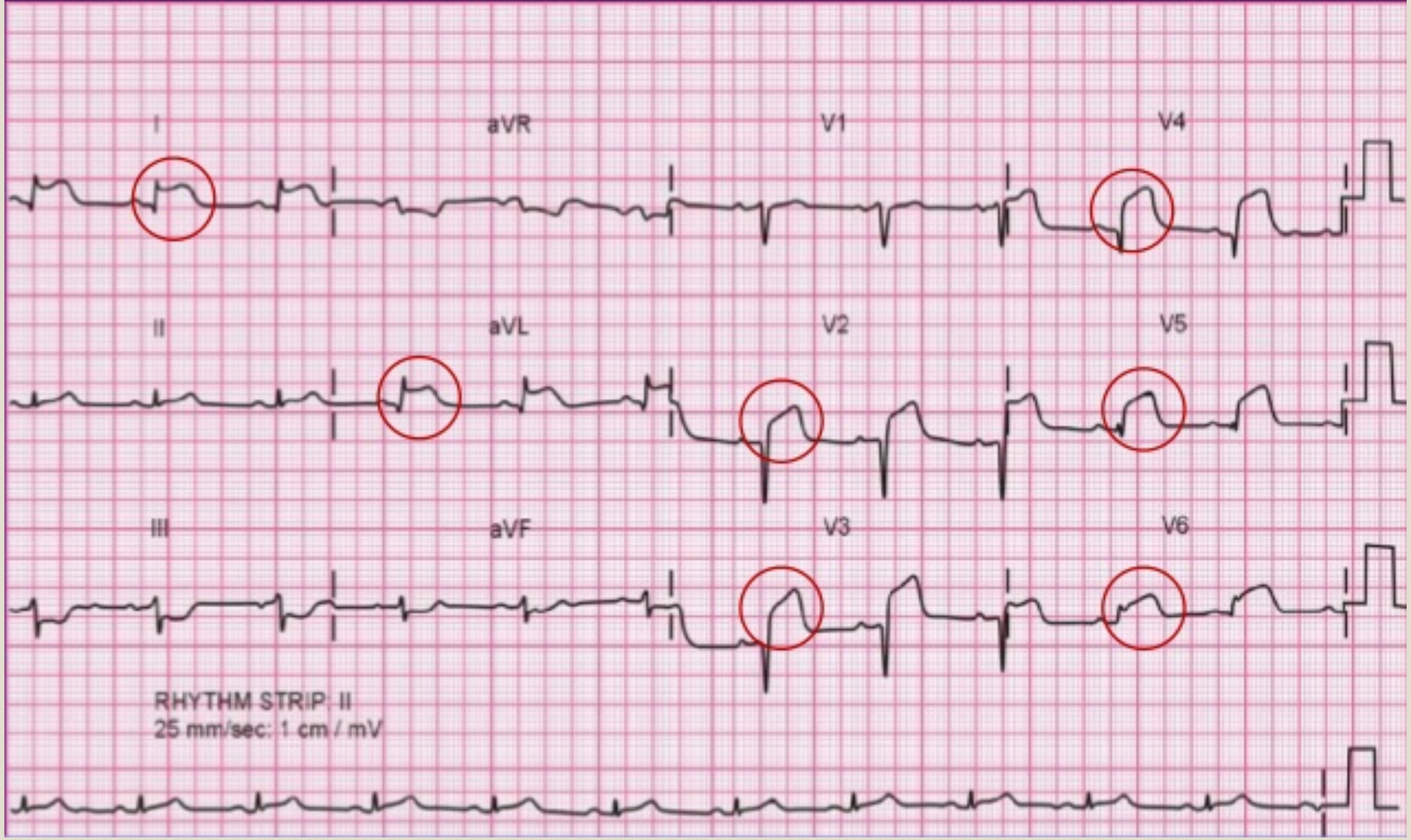
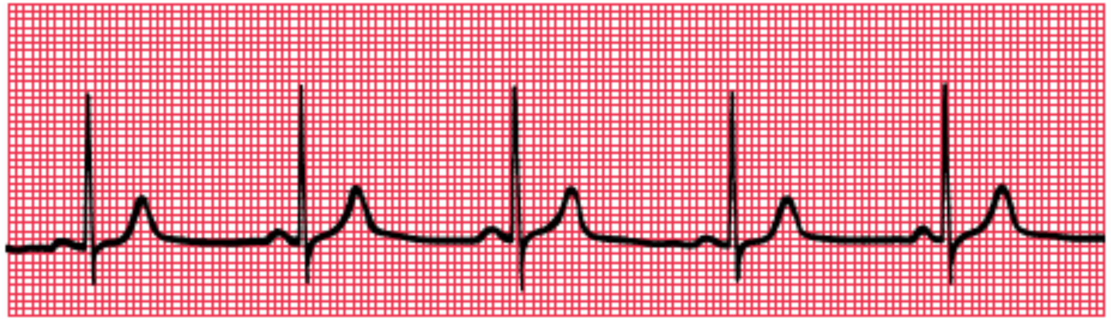


Fig. 4.14

Exercise-induced ischaemic changes

Rest:

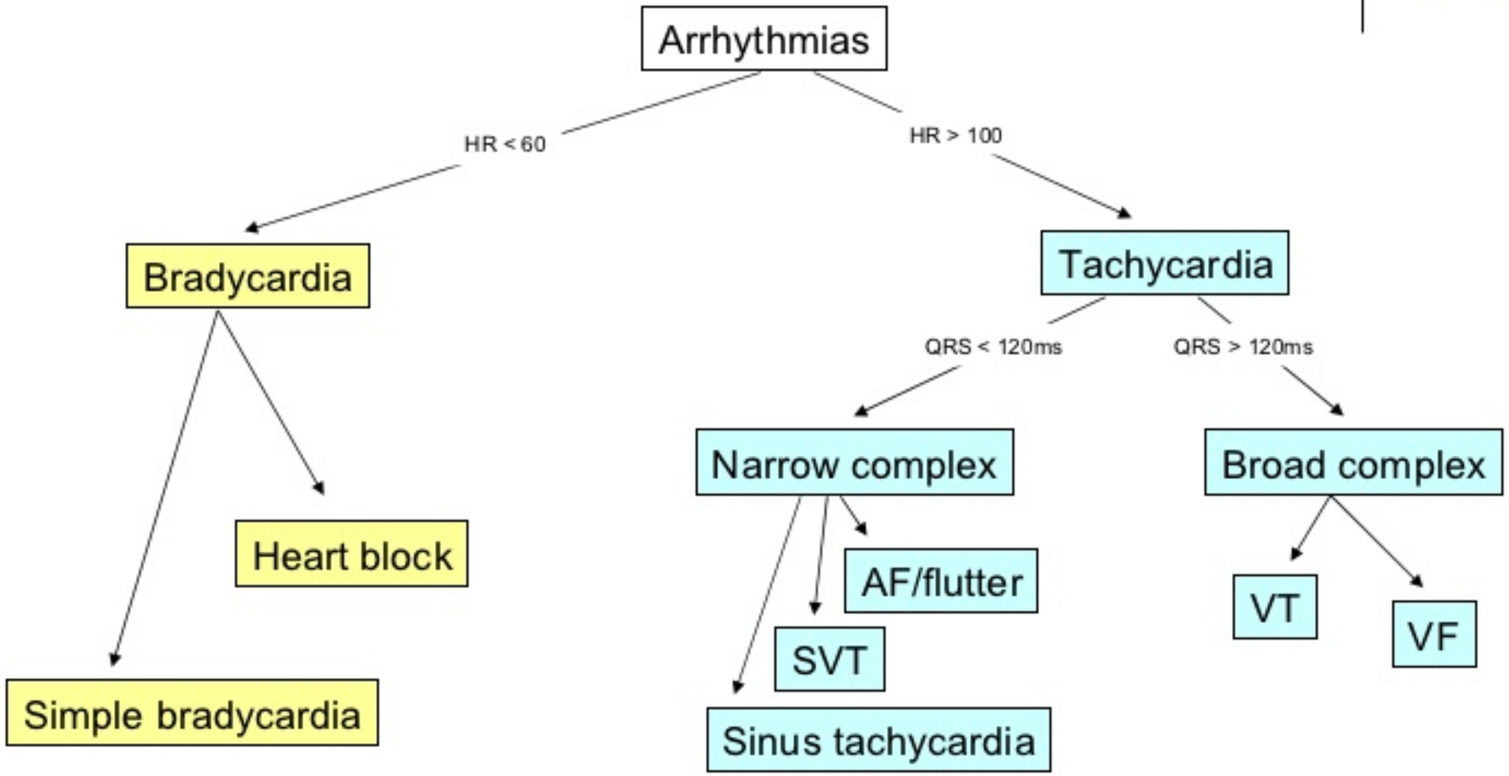


Exercise:

Note

- In the upper (normal) trace, the heart rate is 55/min and the ST segments are isoelectric
- In the lower trace, the heart rate is 125/min and the ST segments are horizontally depressed

Classification of arrhythmias



Sinus Bradycardia

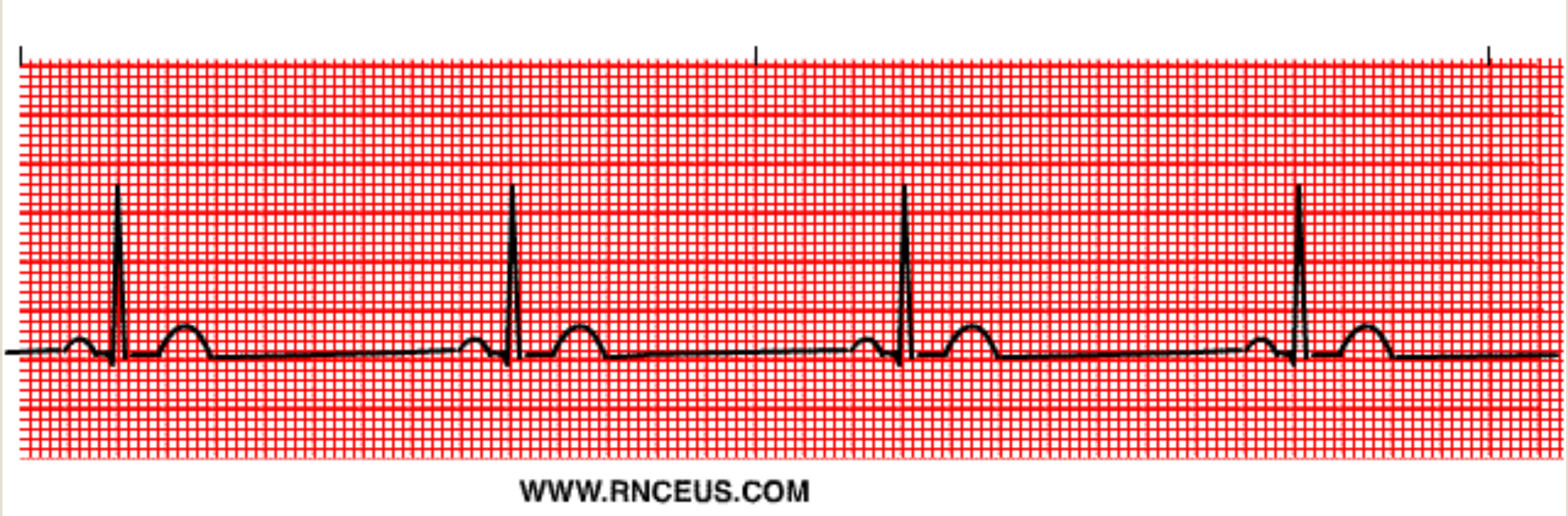
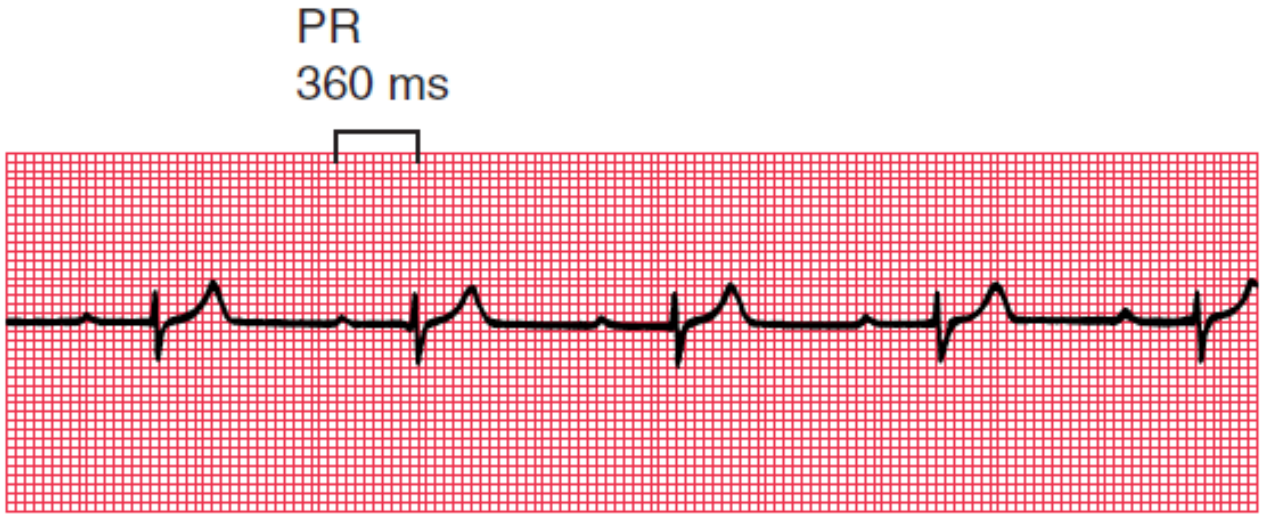


Fig. 2.2

First degree heart block

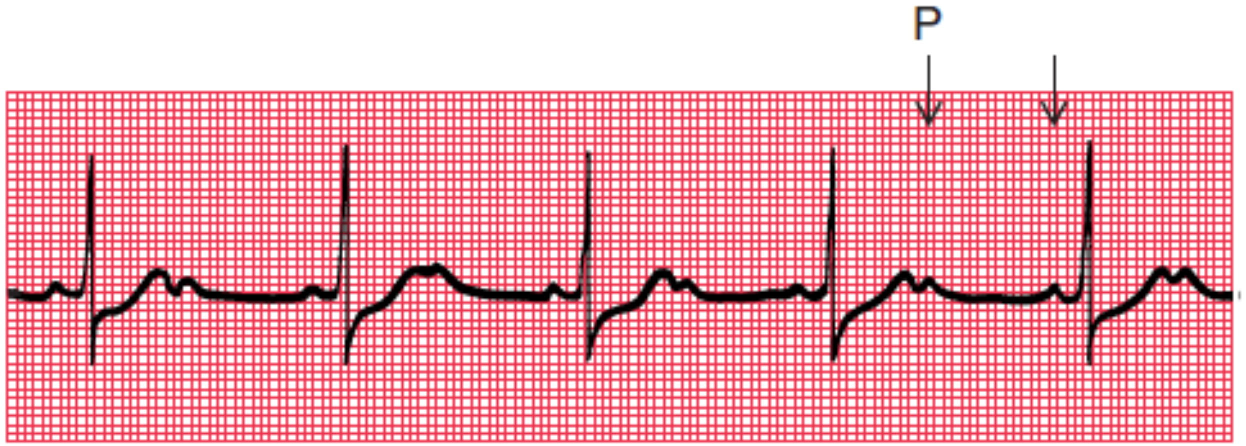


Note

- One P wave per QRS complex
- PR interval 360 ms

Fig. 2.5

Second degree heart block (2:1 type)

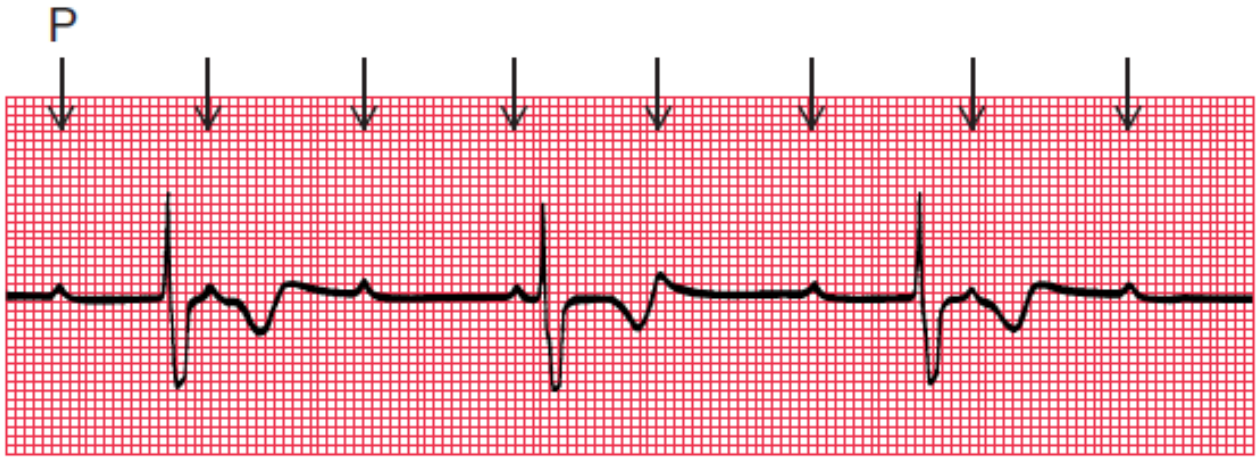


Note

- Two P waves per QRS complex
- Normal, and constant, PR interval in the conducted beats

Fig. 2.7

Third degree heart block



Note

- P wave rate 90/min
- No relationship between P waves and QRS complexes
- QRS complex rate 36/min
- Abnormally shaped QRS complexes, because of abnormal spread of depolarization from a ventricular focus

Sinus Tachycardia

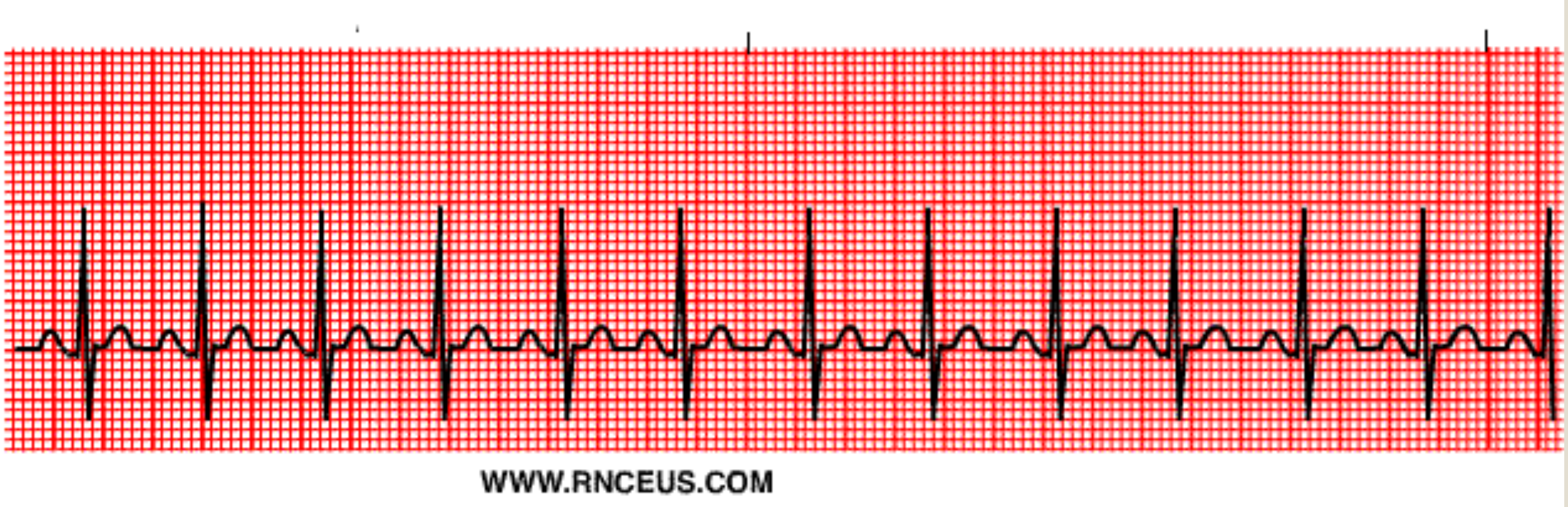
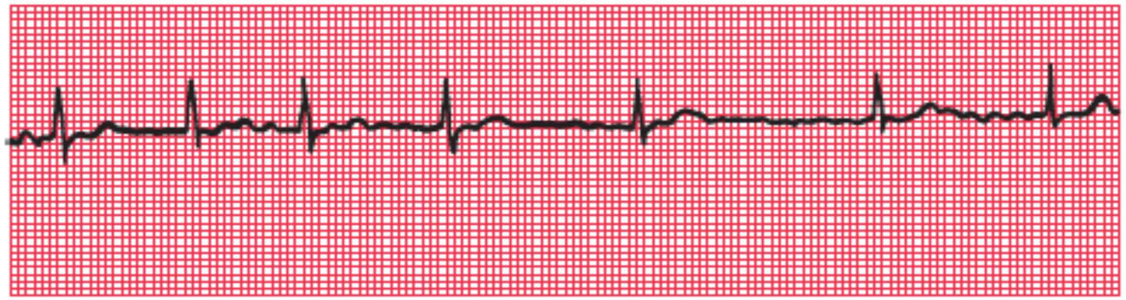


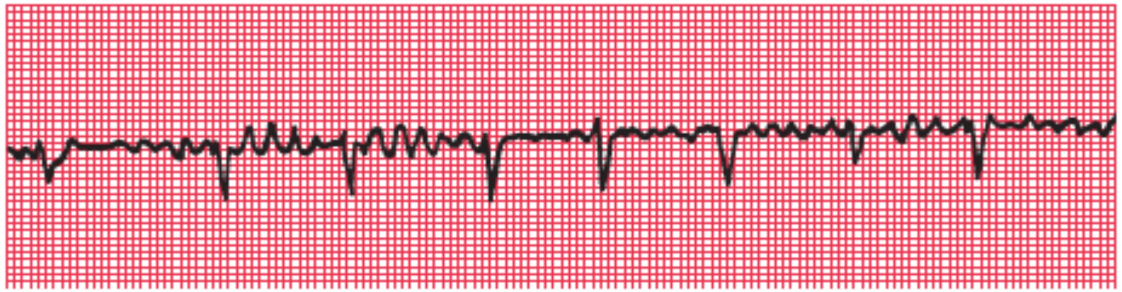
Fig. 3.25

Atrial fibrillation

Lead II:



Lead V_1:

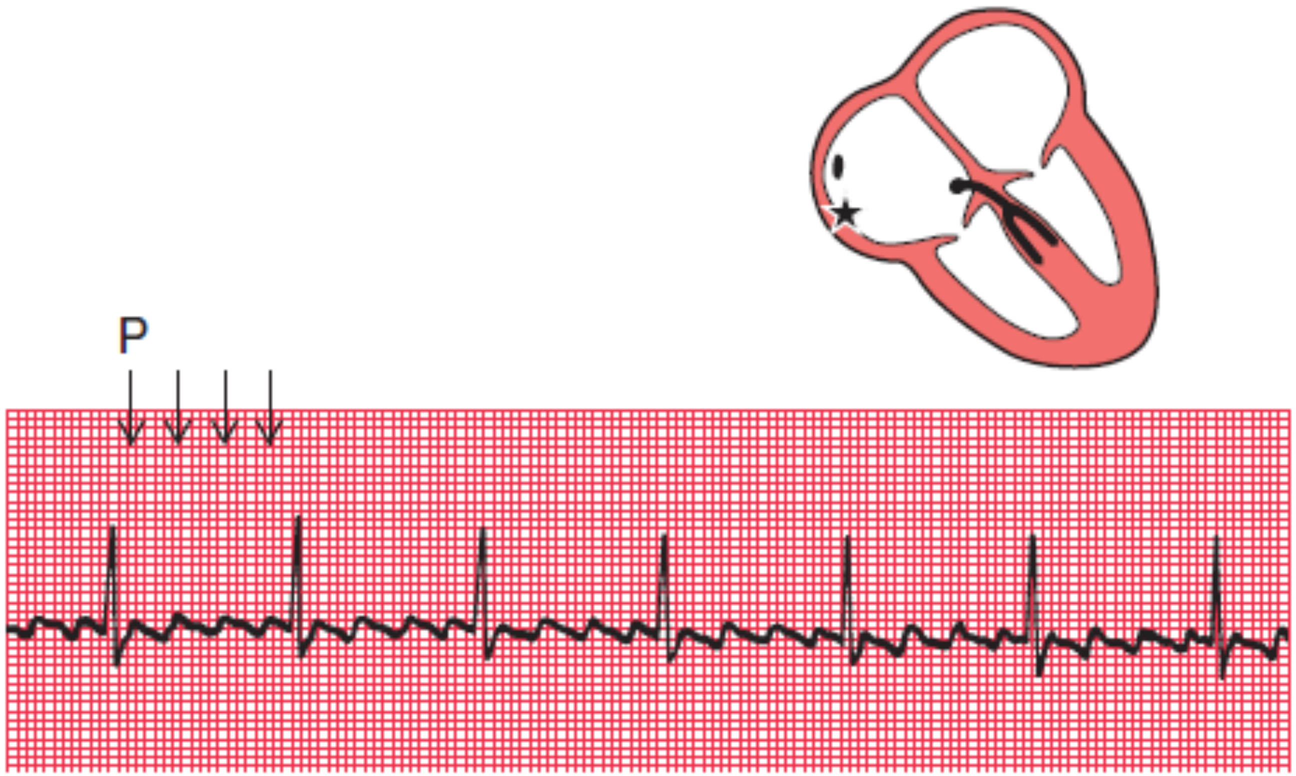


Note

- No P waves, and an irregular baseline
- Irregular QRS complexes
- Normally shaped QRS complexes
- In lead V_1, waves can be seen with some resemblance to those seen in atrial flutter – this is common in atrial fibrillation

Fig. 3.16

Atrial flutter

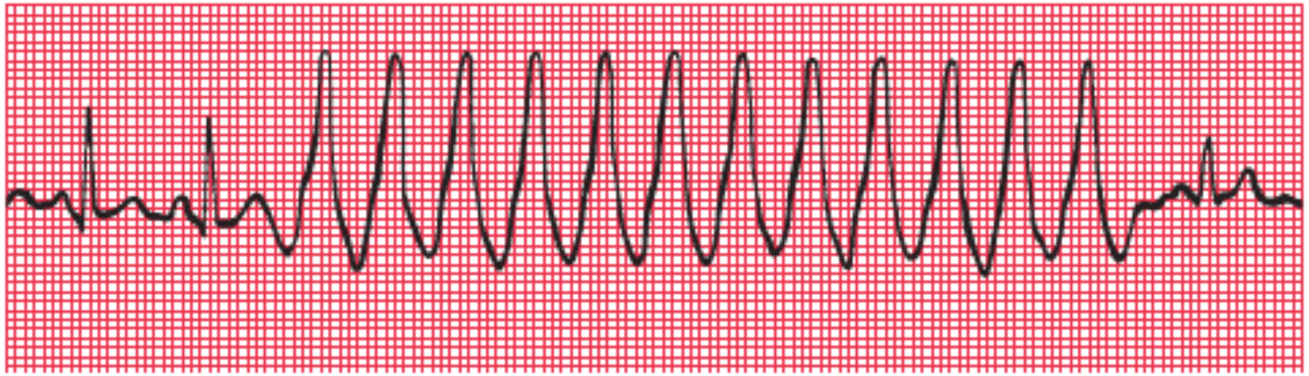


Note

- P waves can be seen at a rate of 300/min, giving a 'sawtooth' appearance
- There are four P waves per QRS complex (arrowed)
- Ventricular activation is perfectly regular at 75/min

Fig. 3.22

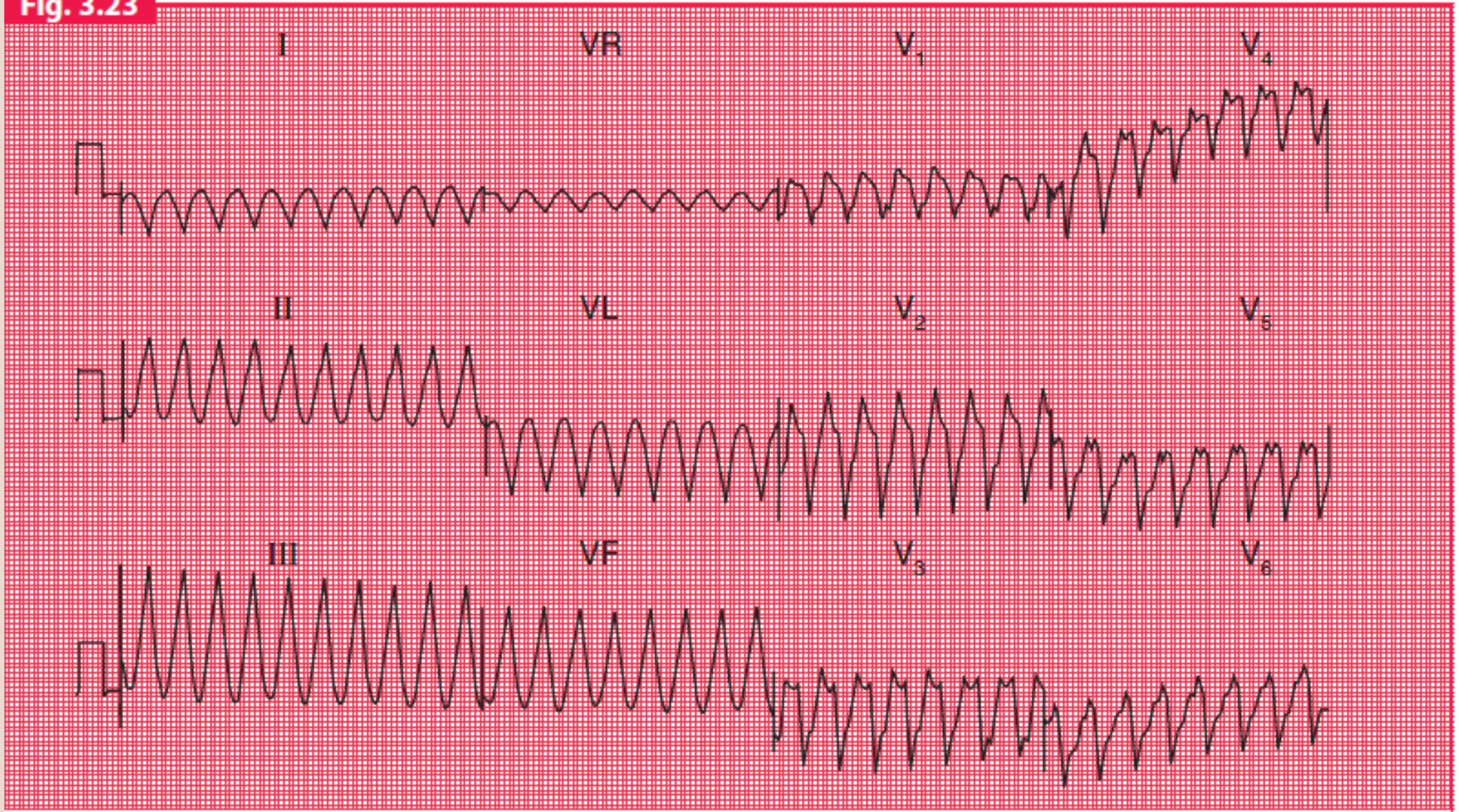
Ventricular tachycardia



Note

- After two sinus beats, the rate increases to 200/min
- The QRS complexes become broad, and the T waves are difficult to identify
- The final beat shows a return to sinus rhythm

Fig. 3.23



Ventricular tachycardia

Note

- No P waves
- Regular QRS complexes, rate 200/min
- Broad QRS complexes, duration 280 ms, with a very abnormal shape