



16th Annual

Electrocardiology Course



“Basics & Beyond”

(Sunday, 25th August 2019)

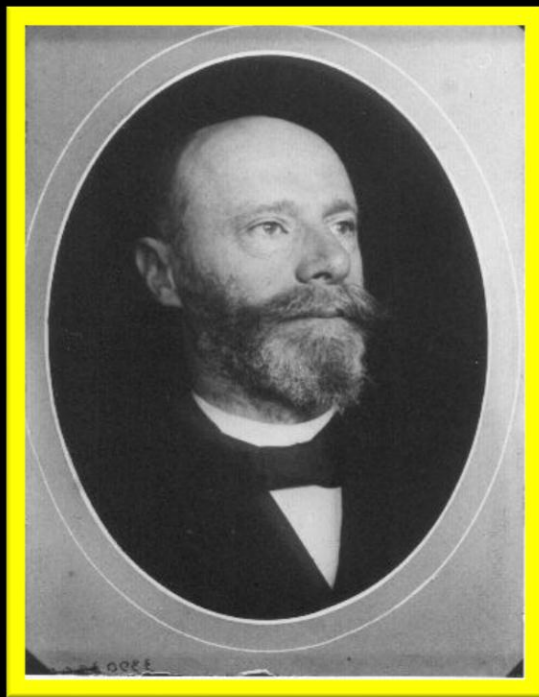
Normal ECG

Dr. Ulhas M. Pandurangi

Chief – Cardiac Electrophysiology & Pacing

Arrhythmia Heart Failure Academy

The Madras Medical Mission

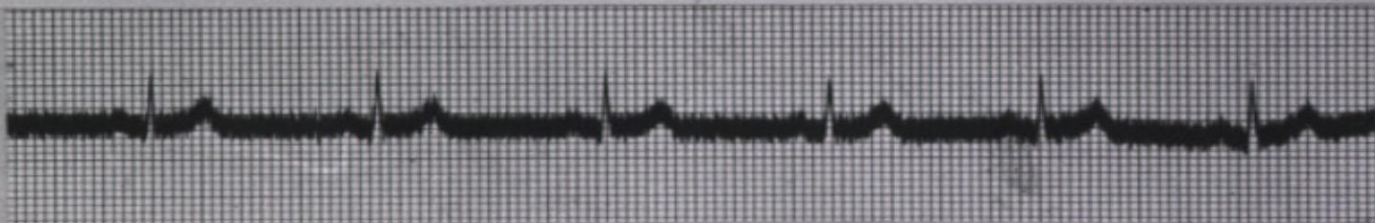


Dr. Walter D. Miles, Boston.

June 18th, 1920

Electrocardiogram taken with Einthoven's original string galvanometer.
(See the instrument on the corner of the brick pillar.)

Lead I

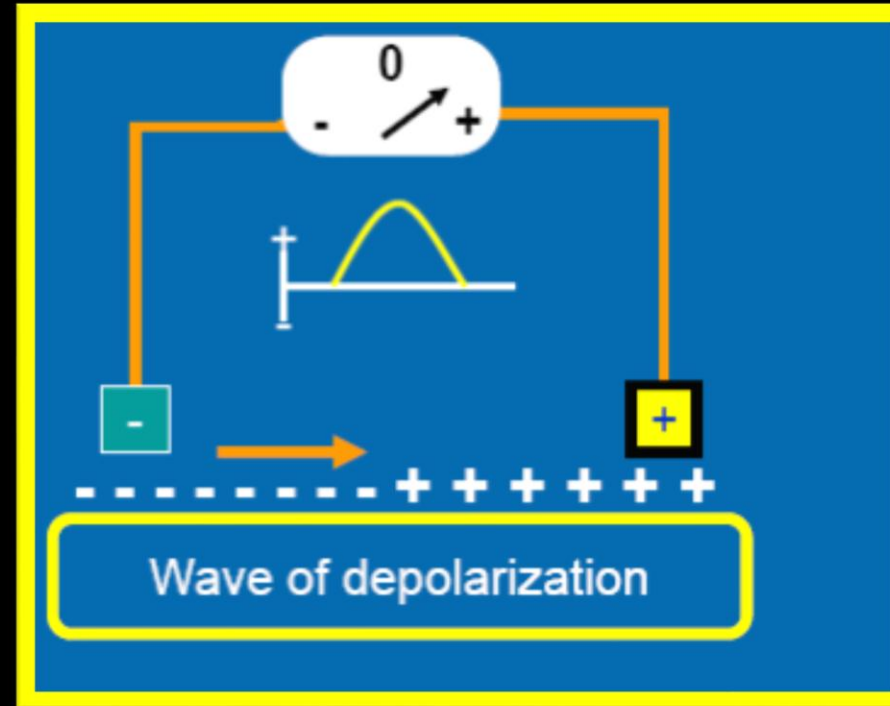
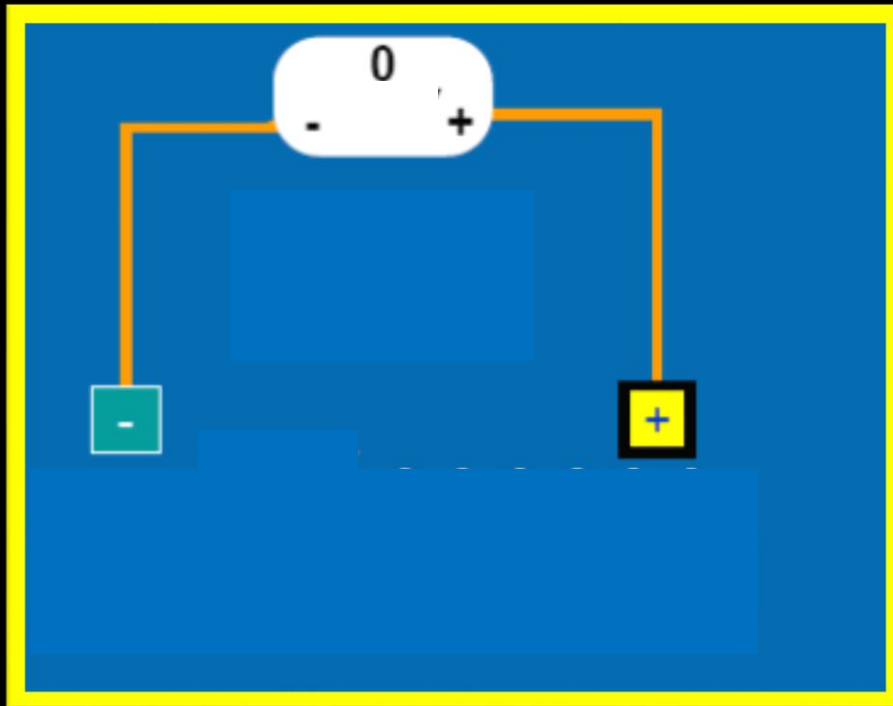


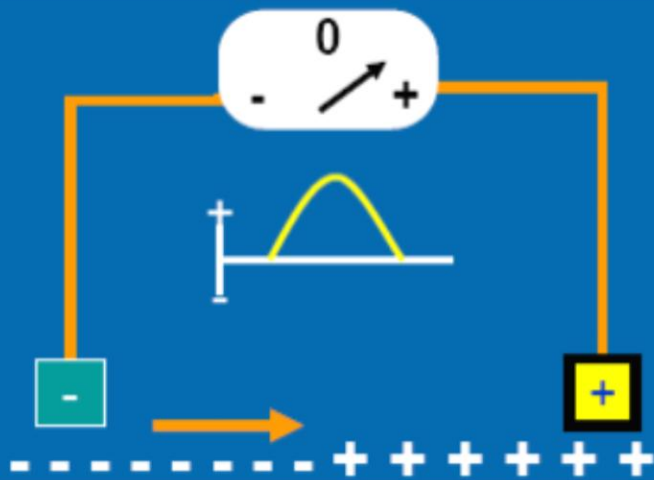
absc. 1 div. = 0.04 sec.

ordin. 1 . = 10^{-4} Volt

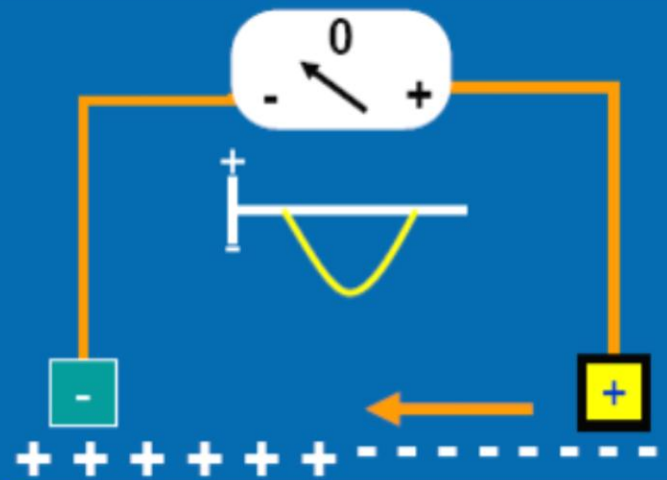
With kind regards
of W. Einthoven

ECG machine : Galvanometer



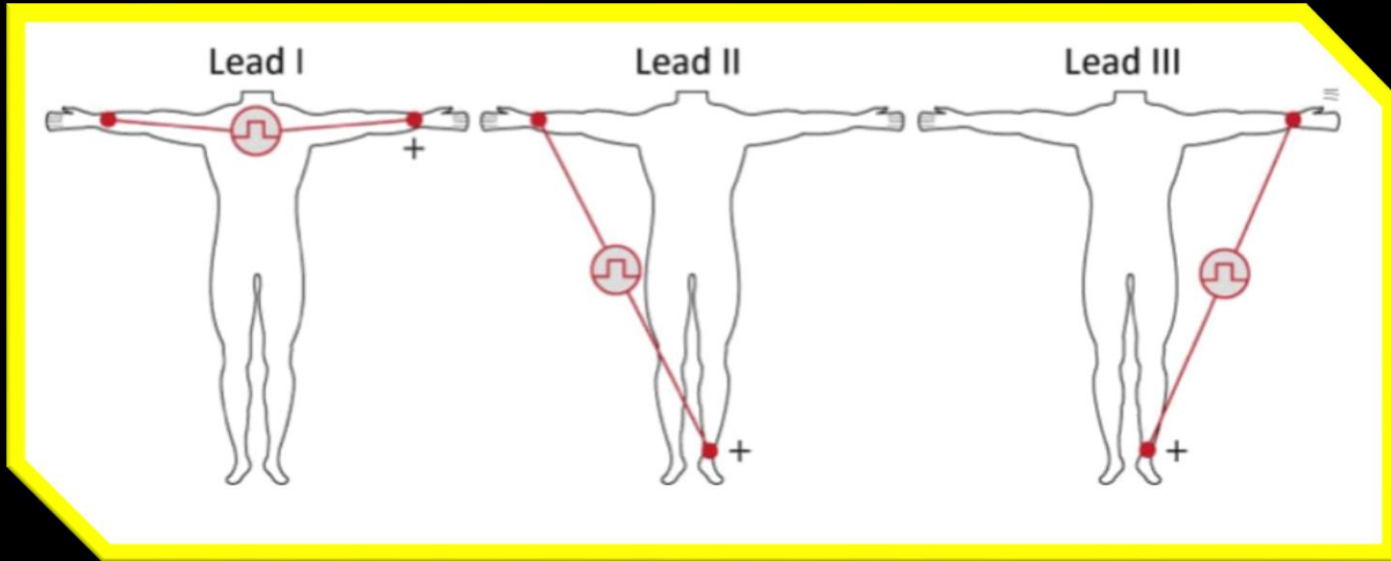


Wave of depolarization

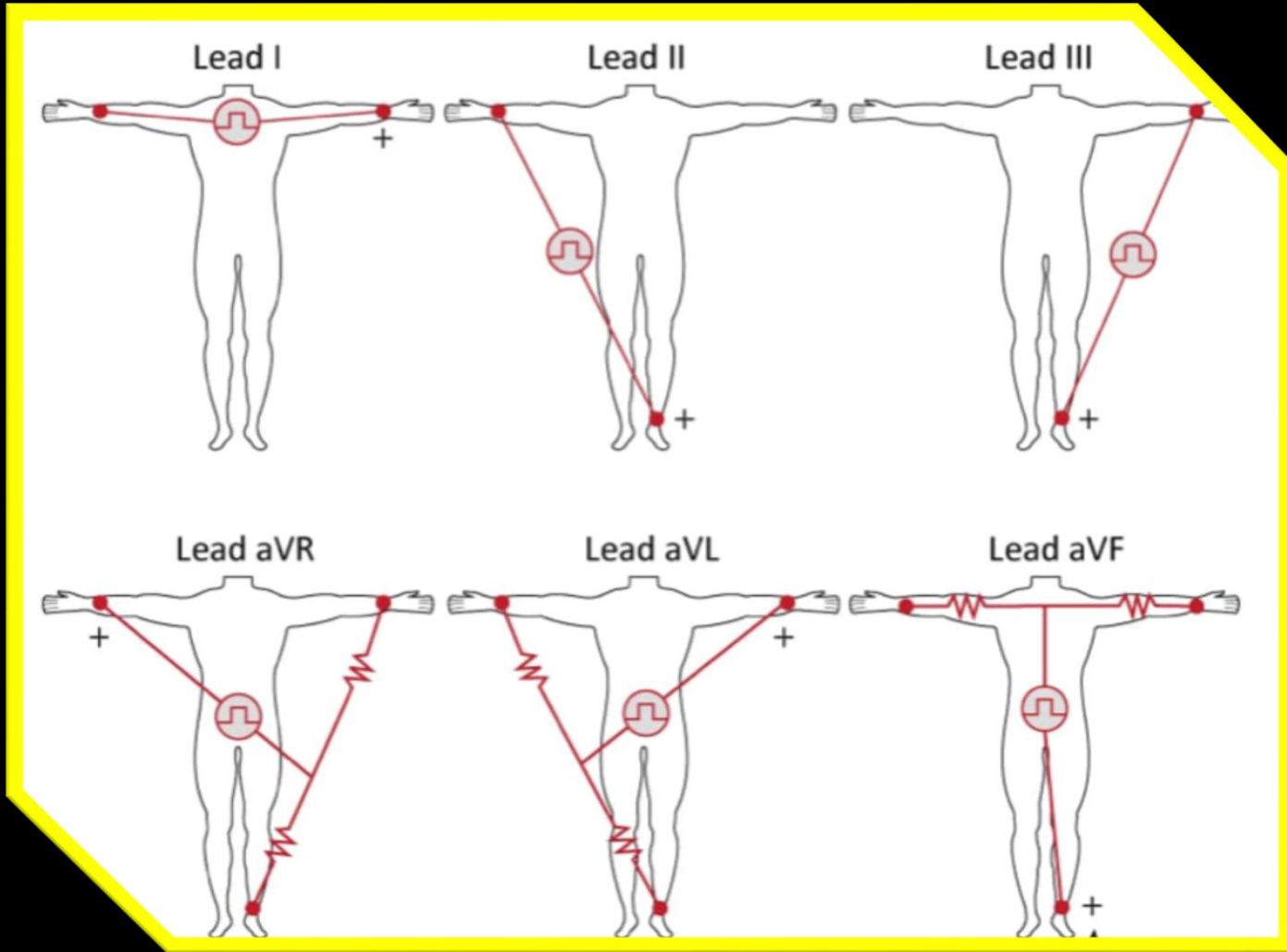


Wave of depolarization

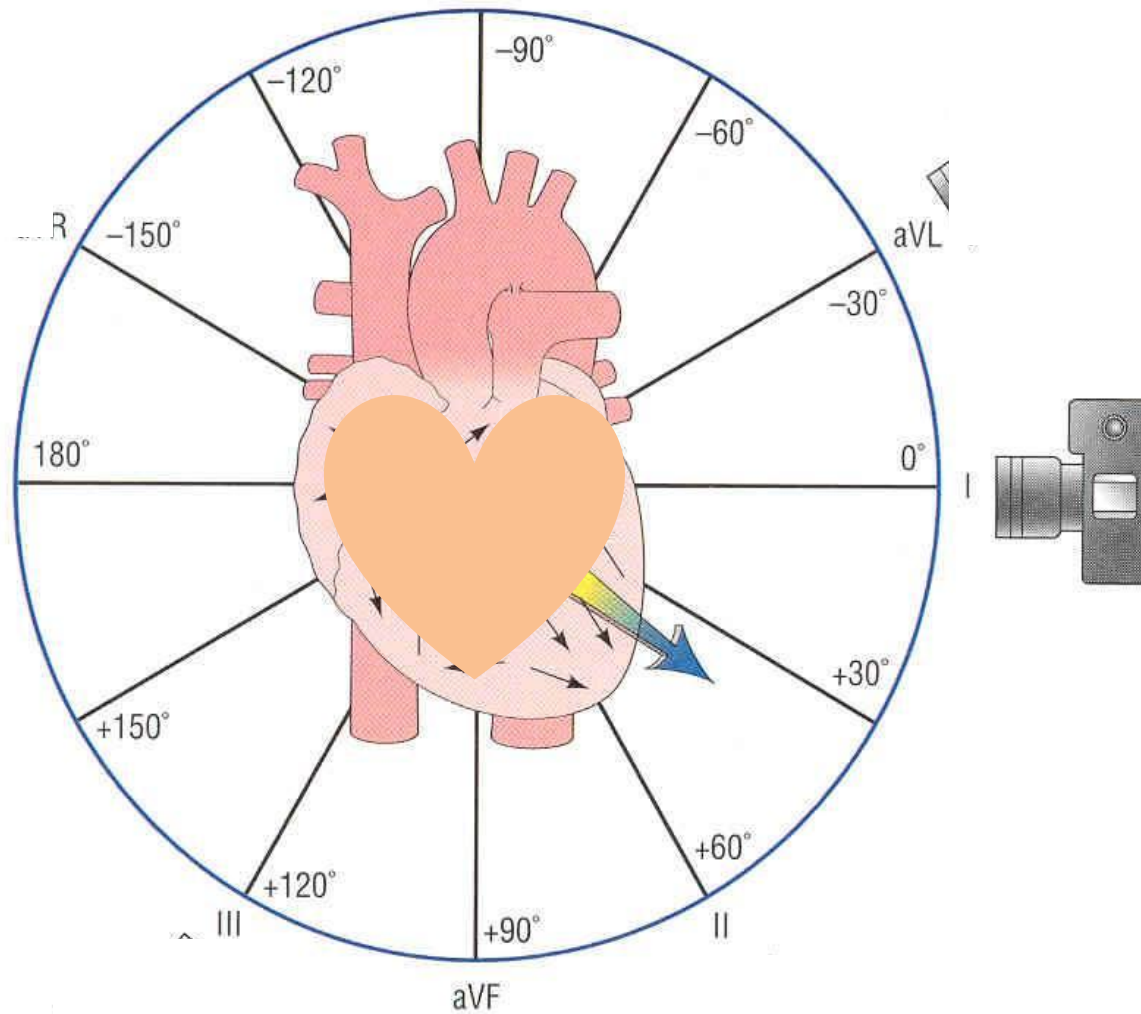
Electrode Positions: To get mainly positive complexes



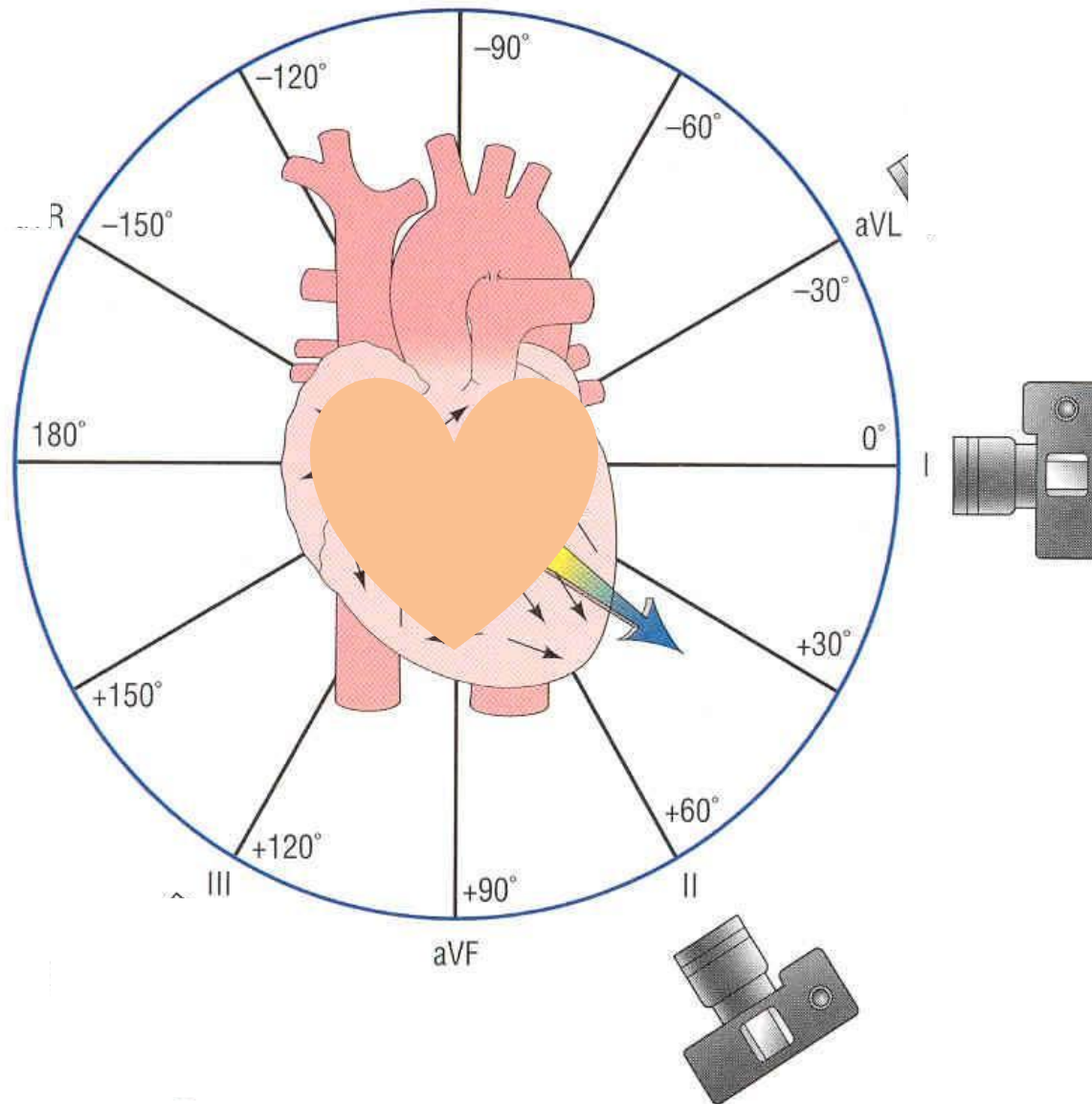
Electrode Positions: To get mainly positive complexes



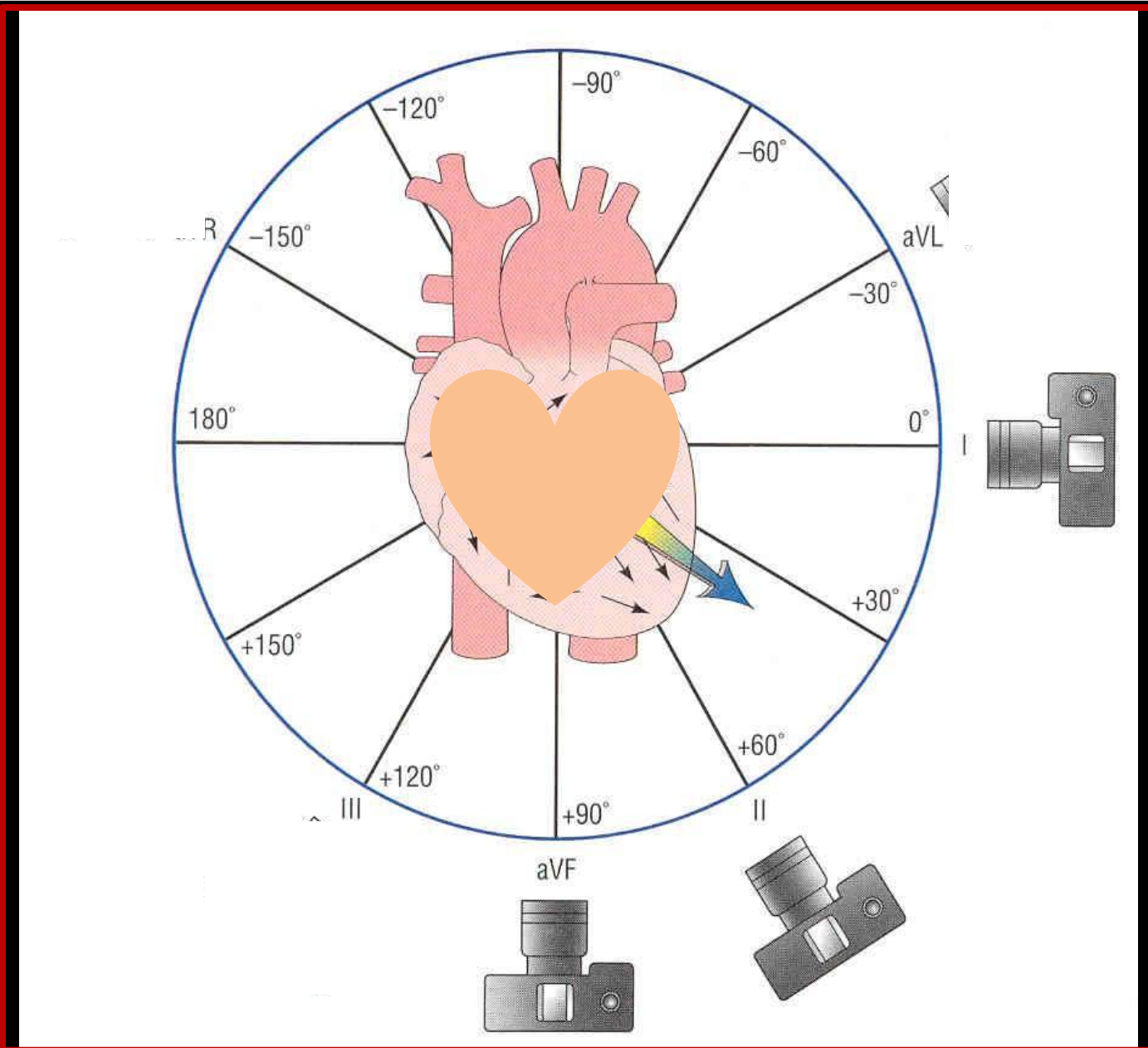
ECG leads are like Video Cameras recording from 'specific' location



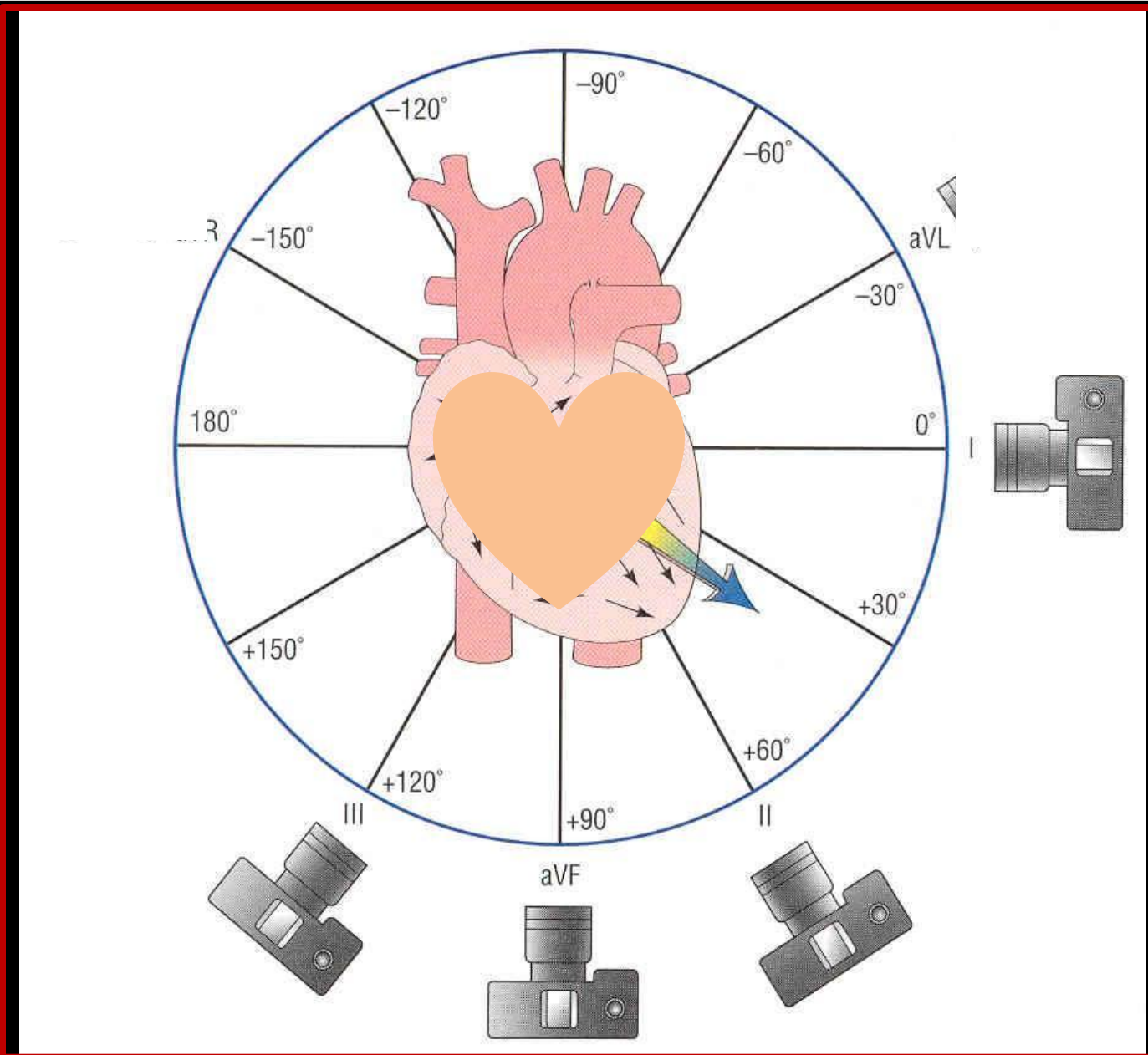
ECG leads are like Video Cameras recording from 'specific' location



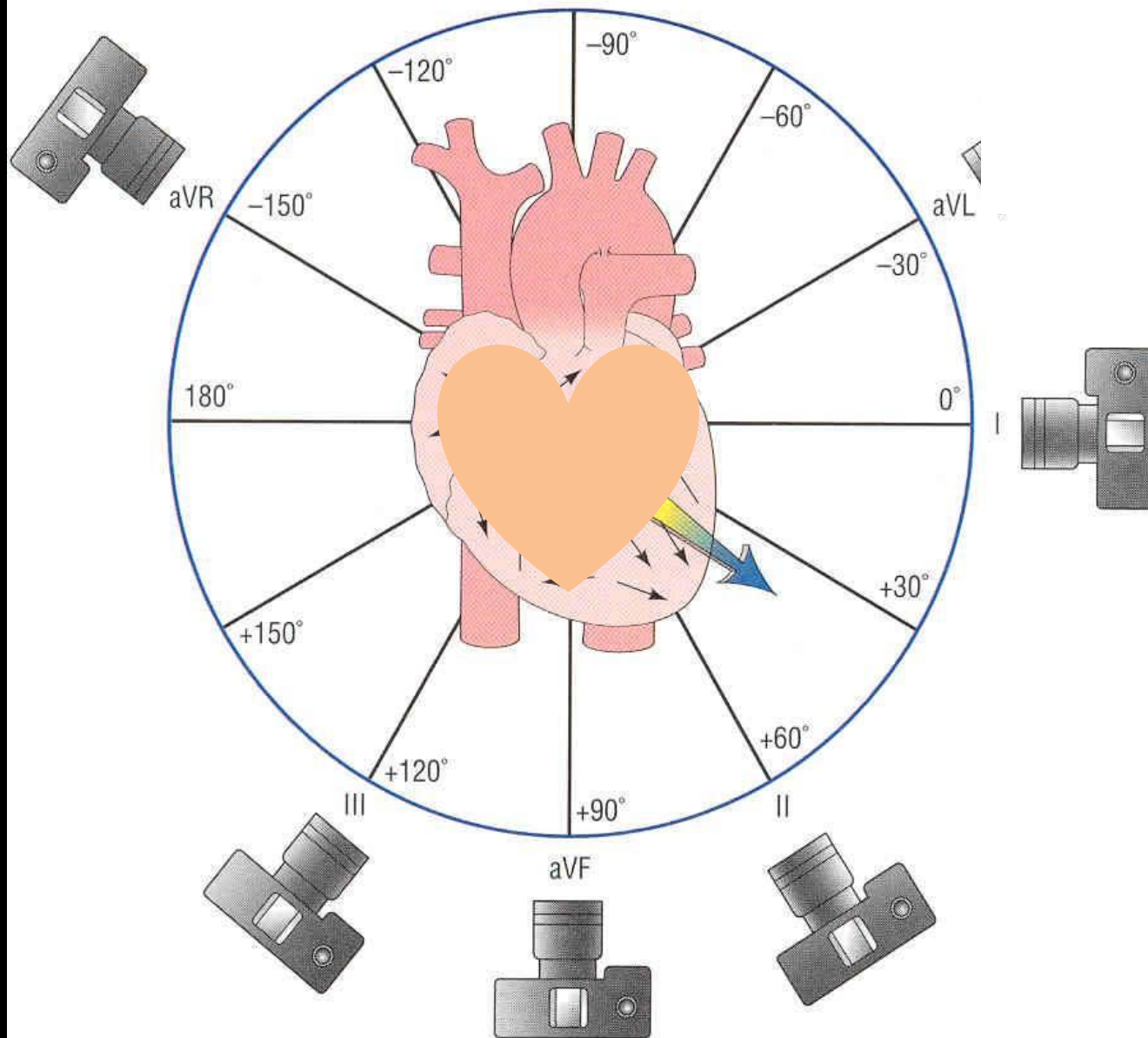
ECG leads are like Video Cameras recording from 'specific' location



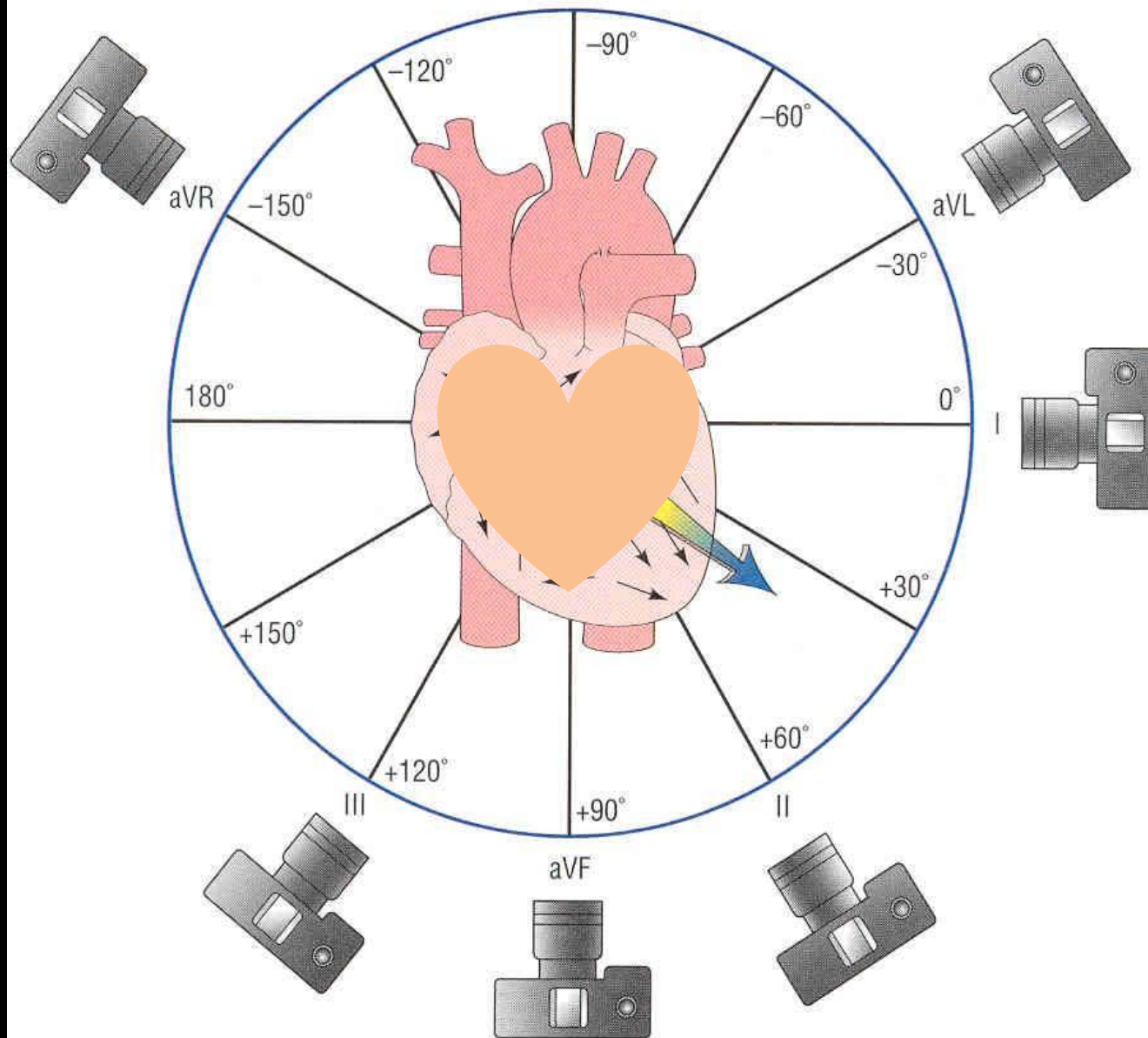
ECG leads are like Video Cameras recording from 'specific' location



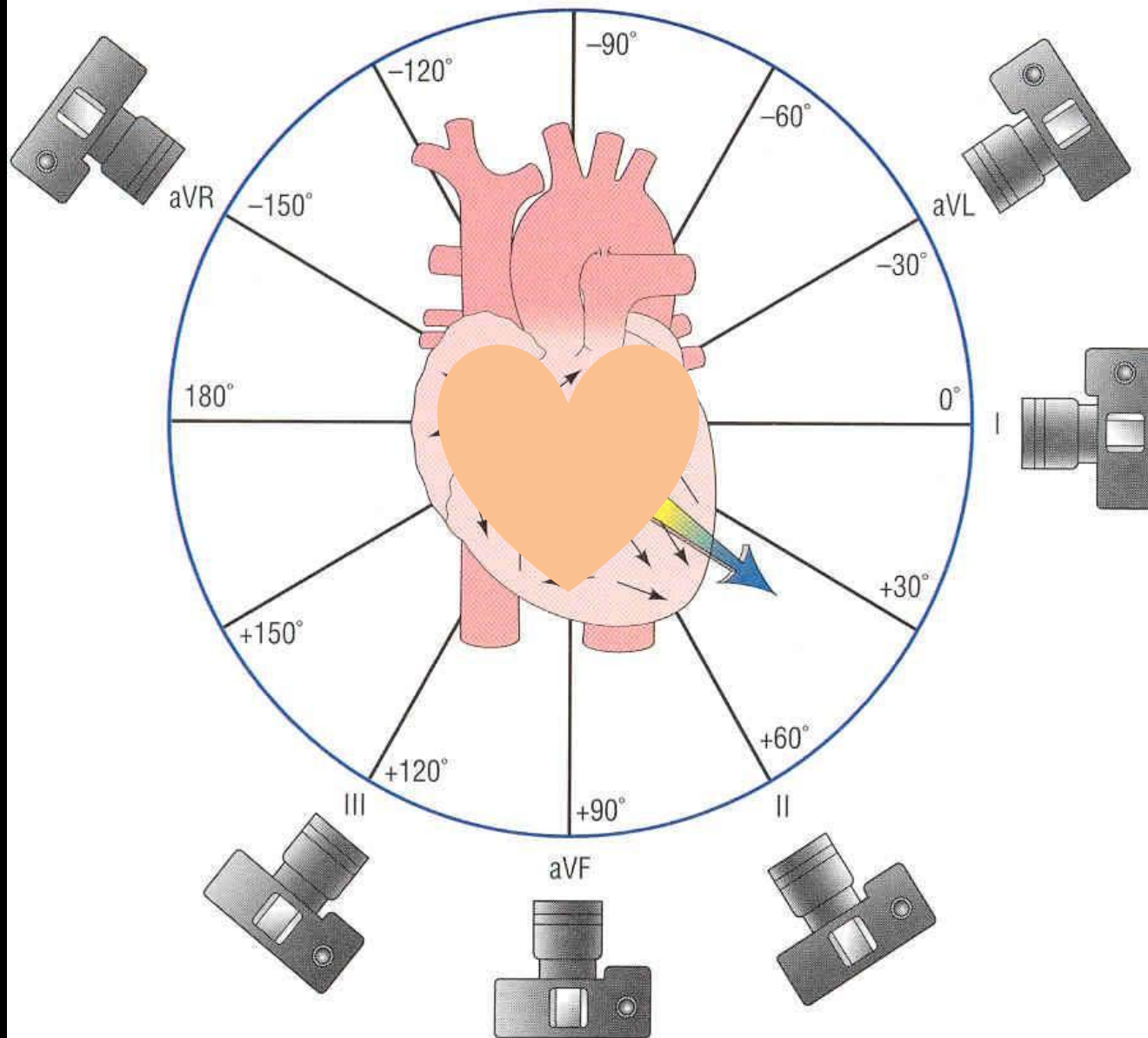
ECG leads are like Video Cameras recording from 'specific' location

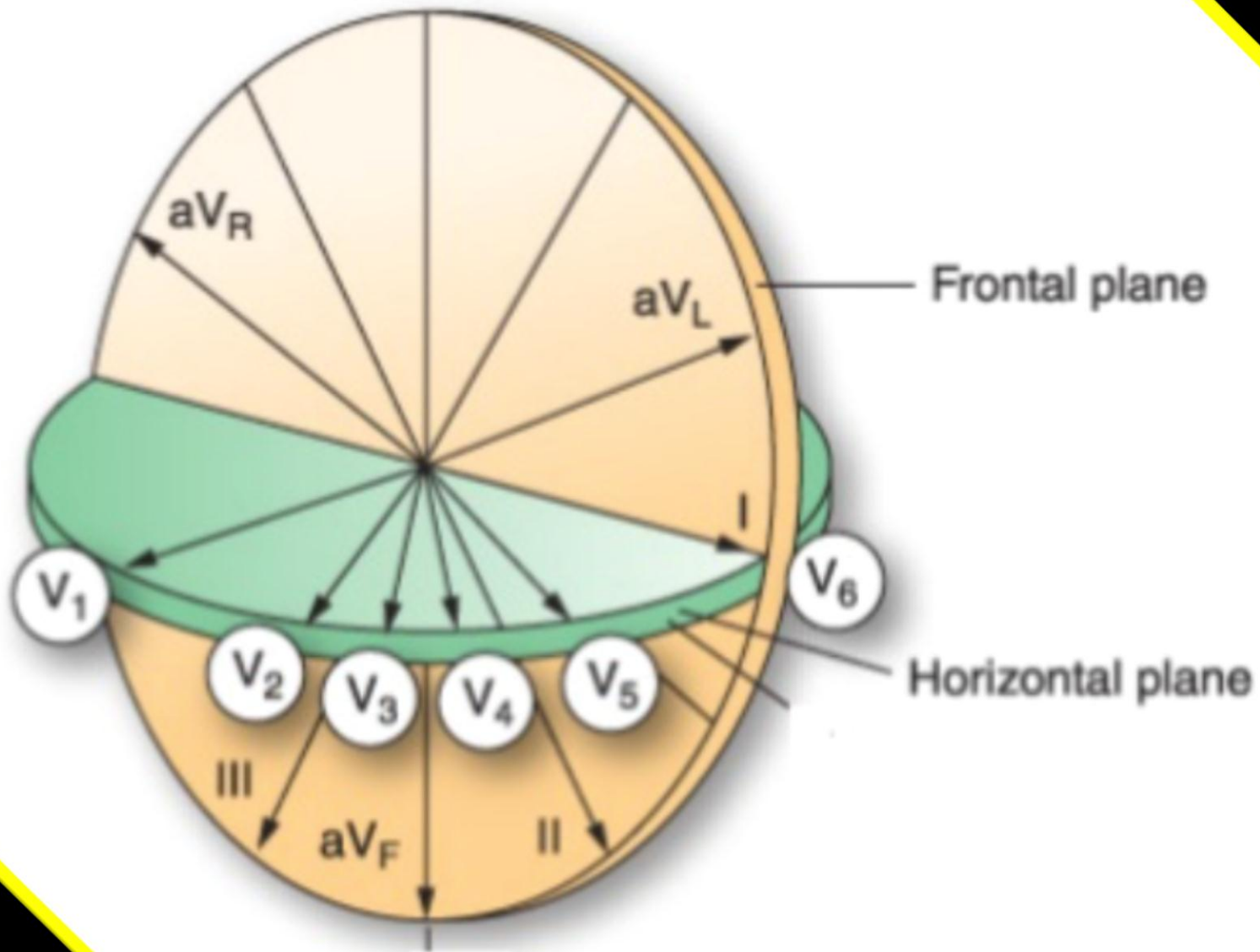


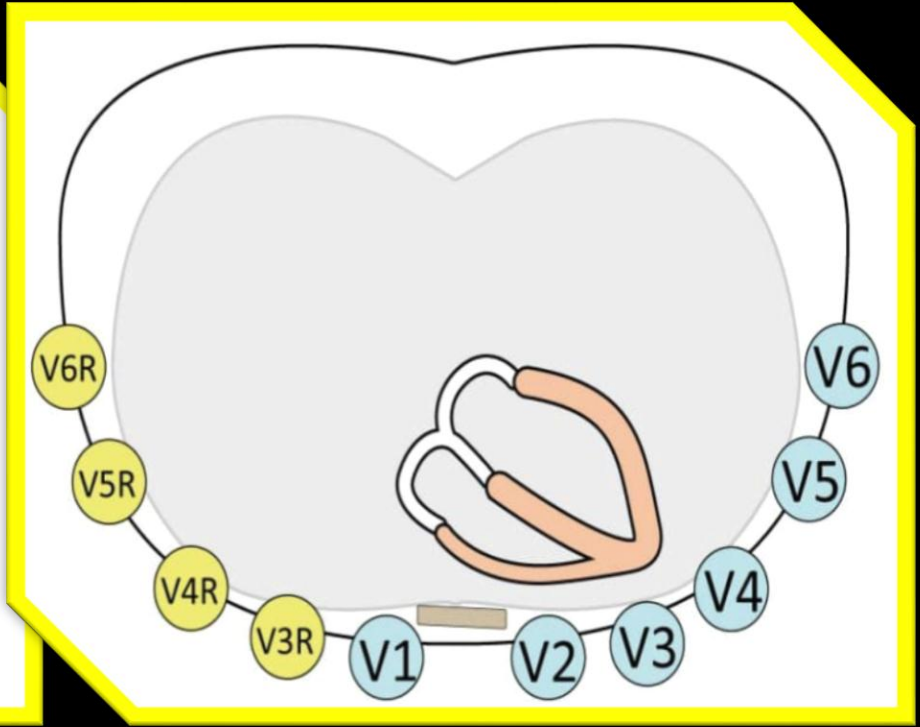
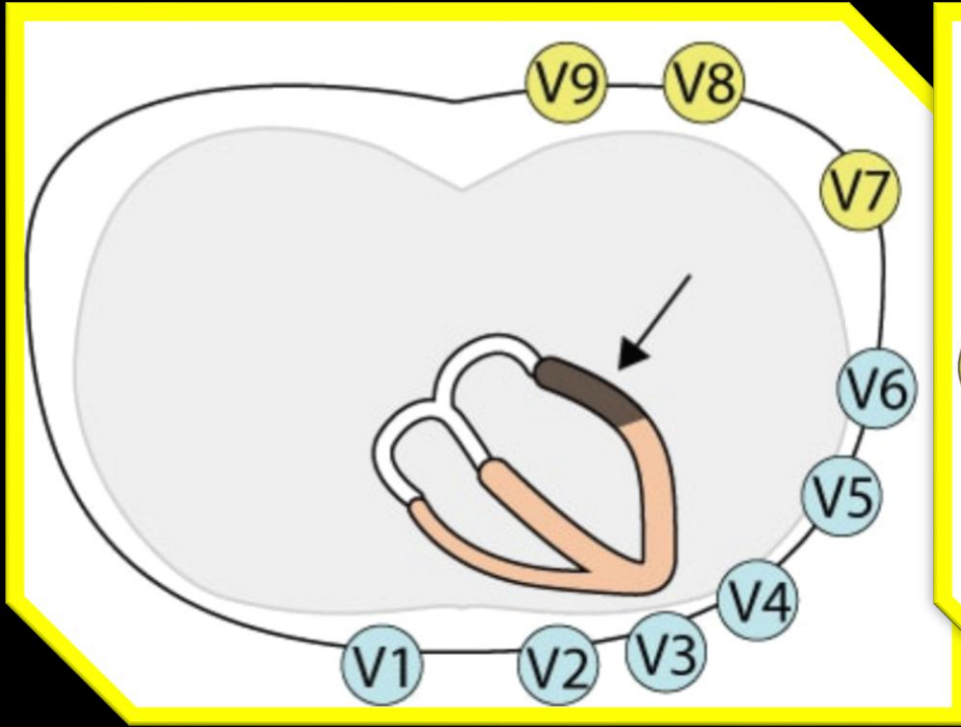
ECG leads are like Video Cameras recording from 'specific' location

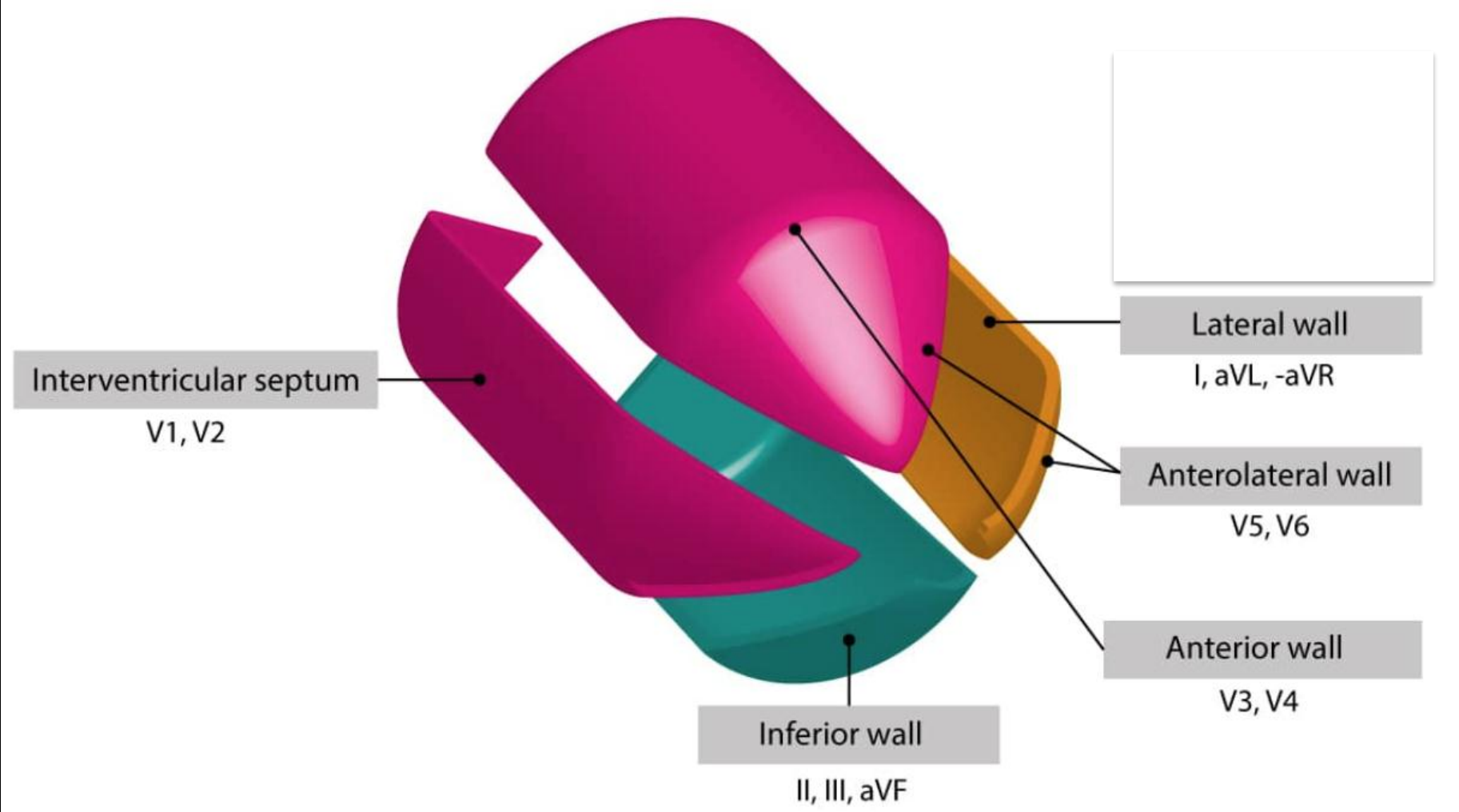


ECG leads are like Video Cameras recording from 'specific' location









ID: .

20-Jun-2012 16:19:22

MADRAS MEDICAL MISSION (ICVD)

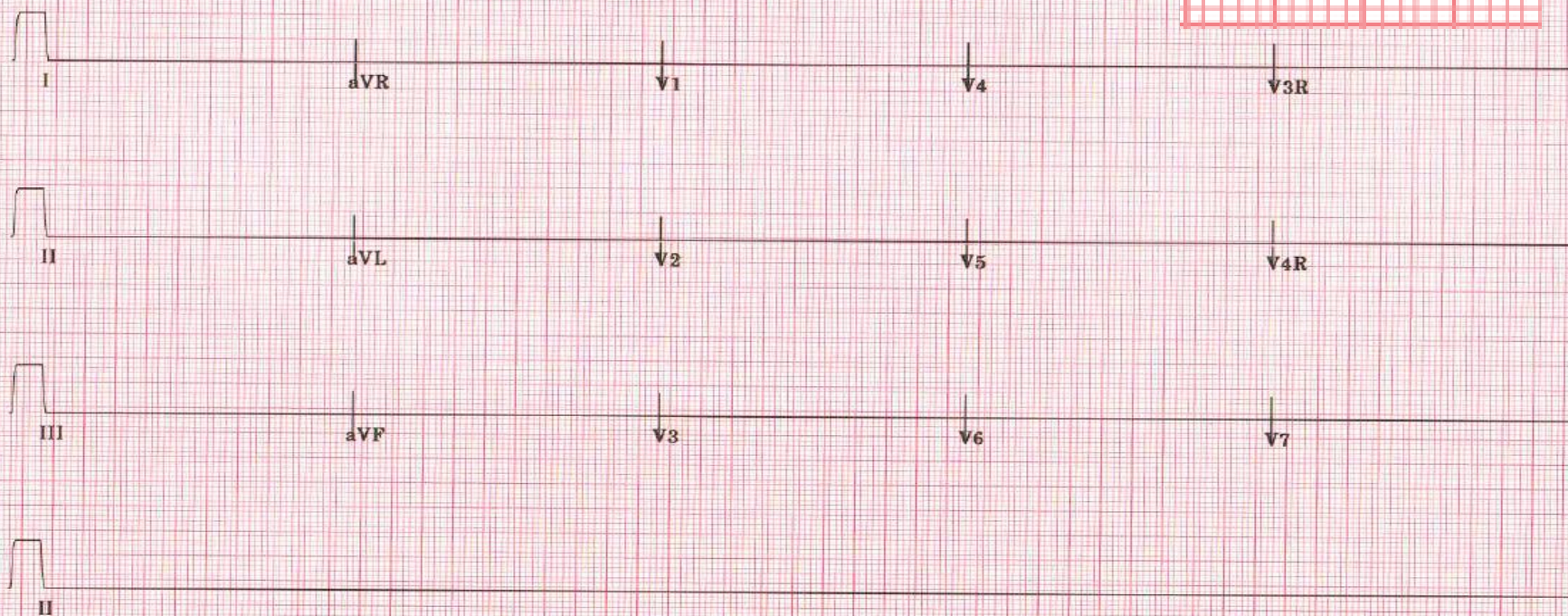
Male

Vent. rate 0 bpm
PR interval * ms
QRS duration 0 ms
QT/QTc 0/0 ms
P-R-T axes * 0 0

Technician:

Referred by:

Unconfi



40 Hz

25.0 mm/s

10.0 mm/mV

5 by 2s + 1 rhythm ld

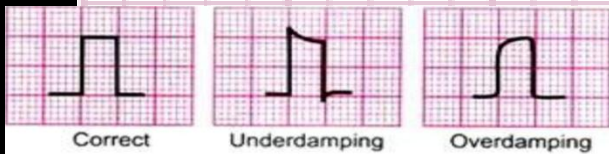
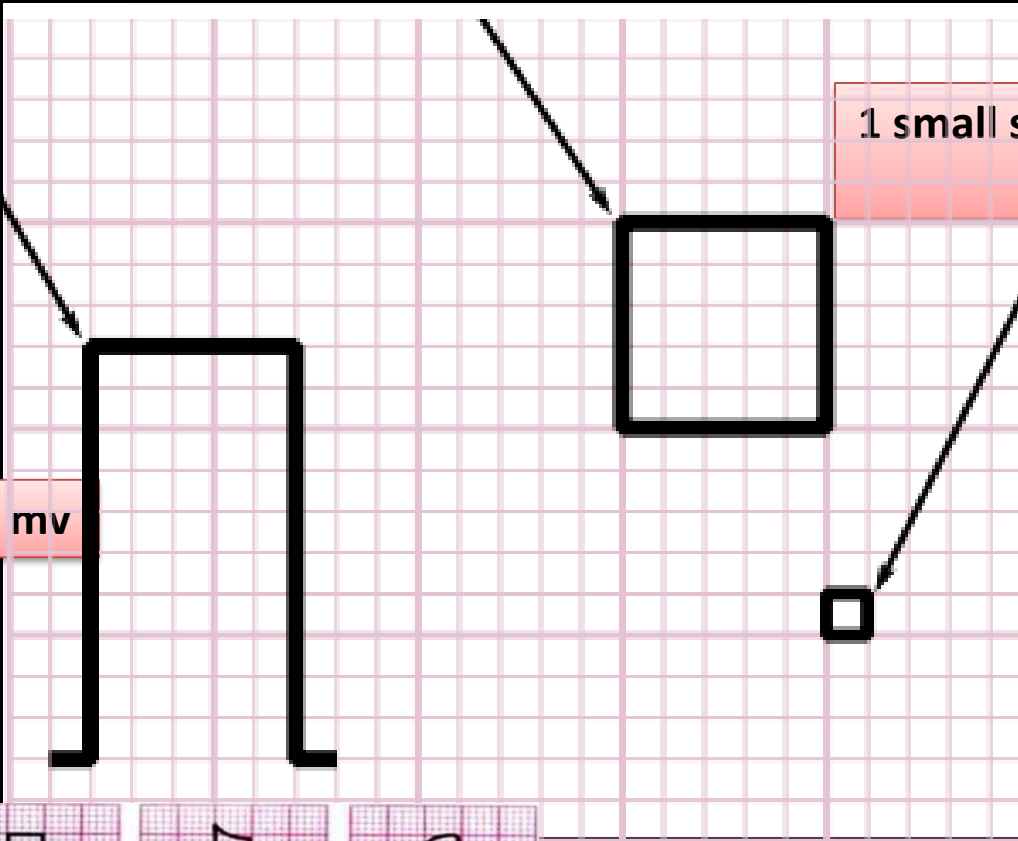
MAC 8 002C

12SL™ v250

1 large square = 5 mm, 200 ms;
0.5 mv

1 small square = 1 mm, 40 ms;
0.1 mv

10 mm = 1 mv



Correct

Underdamping

Overdamping

Quantifying the waveforms

Amplitude



Volts

Duration



Seconds

Frequency

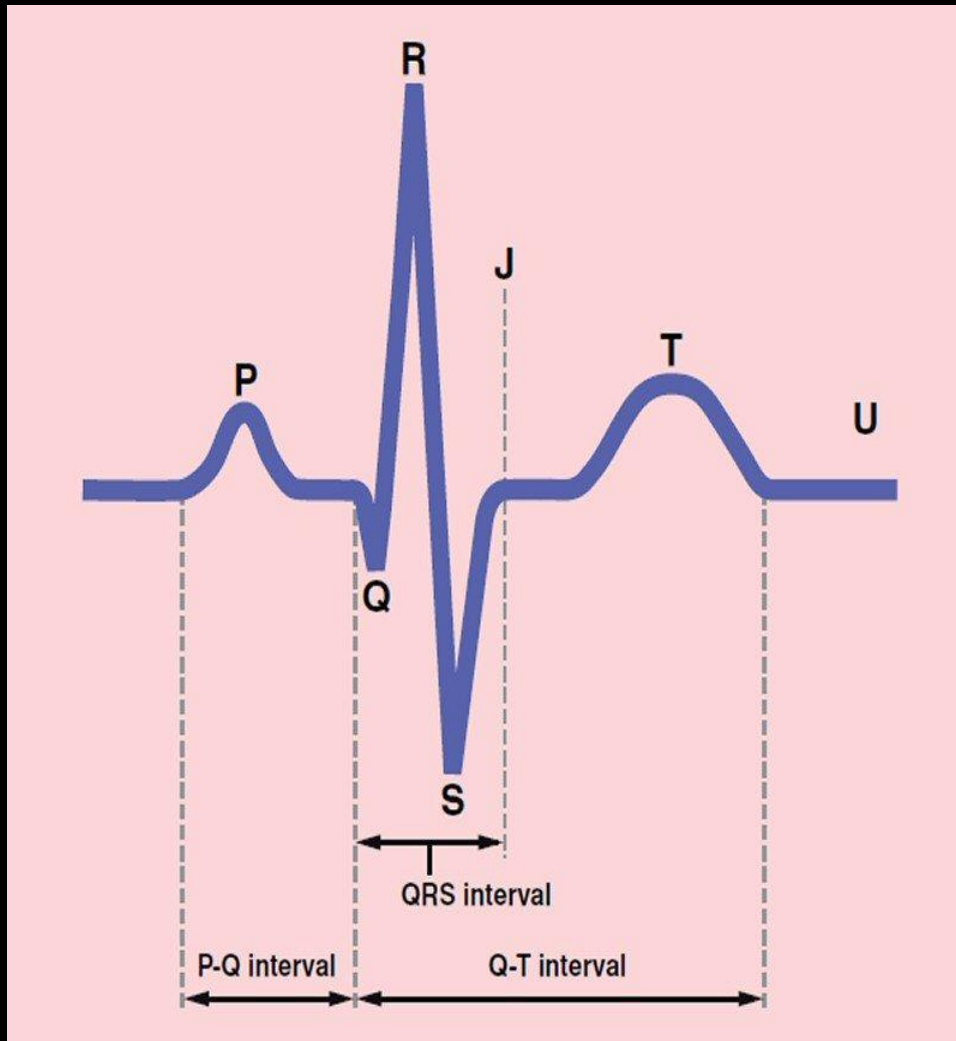


Per minute

Direction



Axis



Waveforms

P wave

QRS complex

T wave

Intervals

PR interval

QRS interval

QT interval

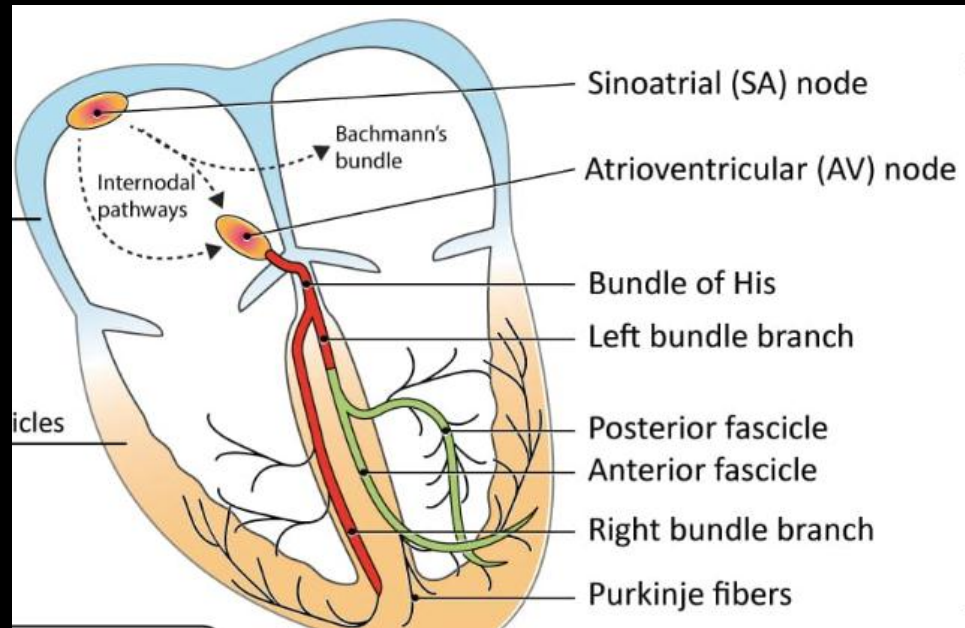
Segments

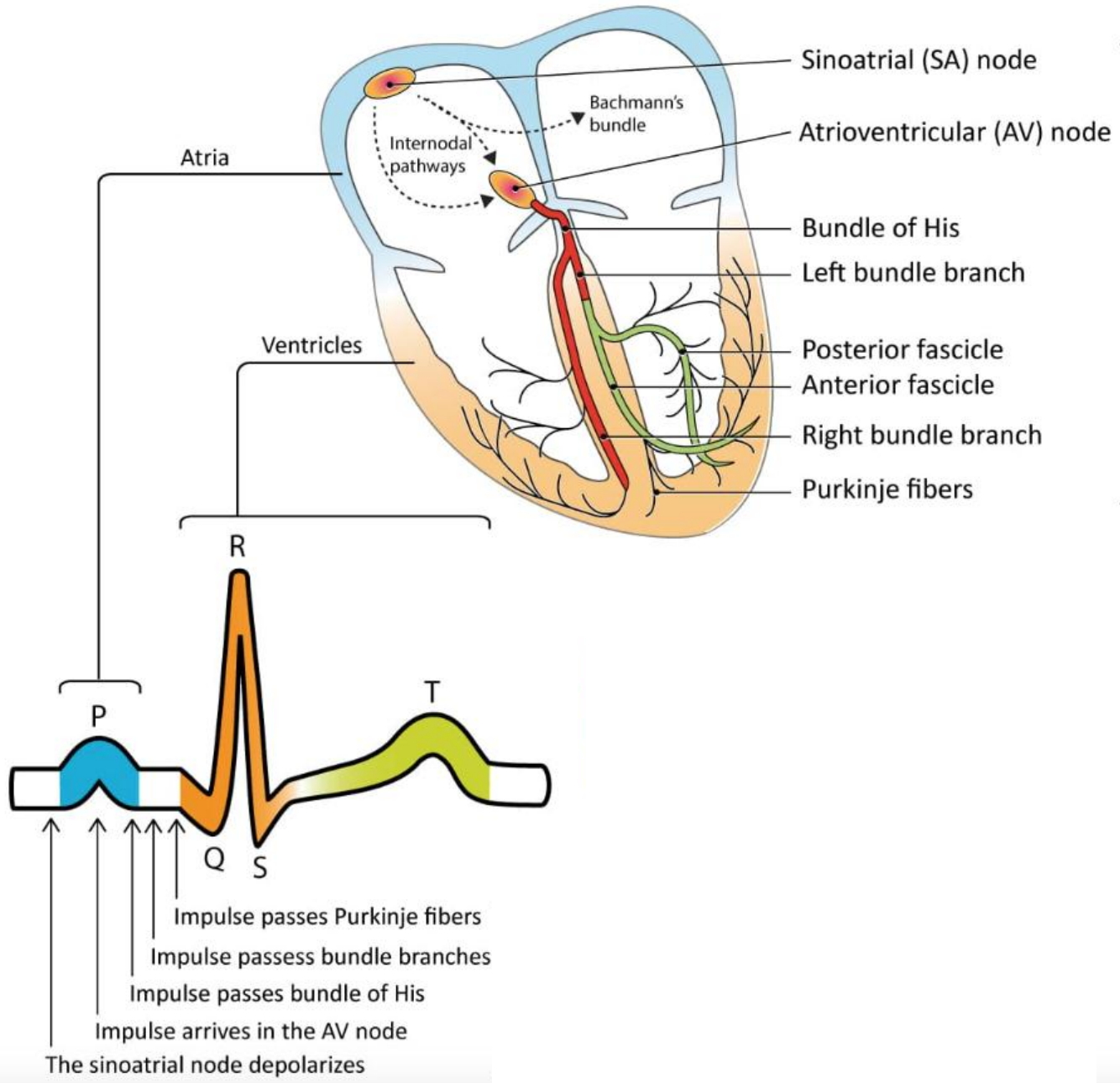
ST segment

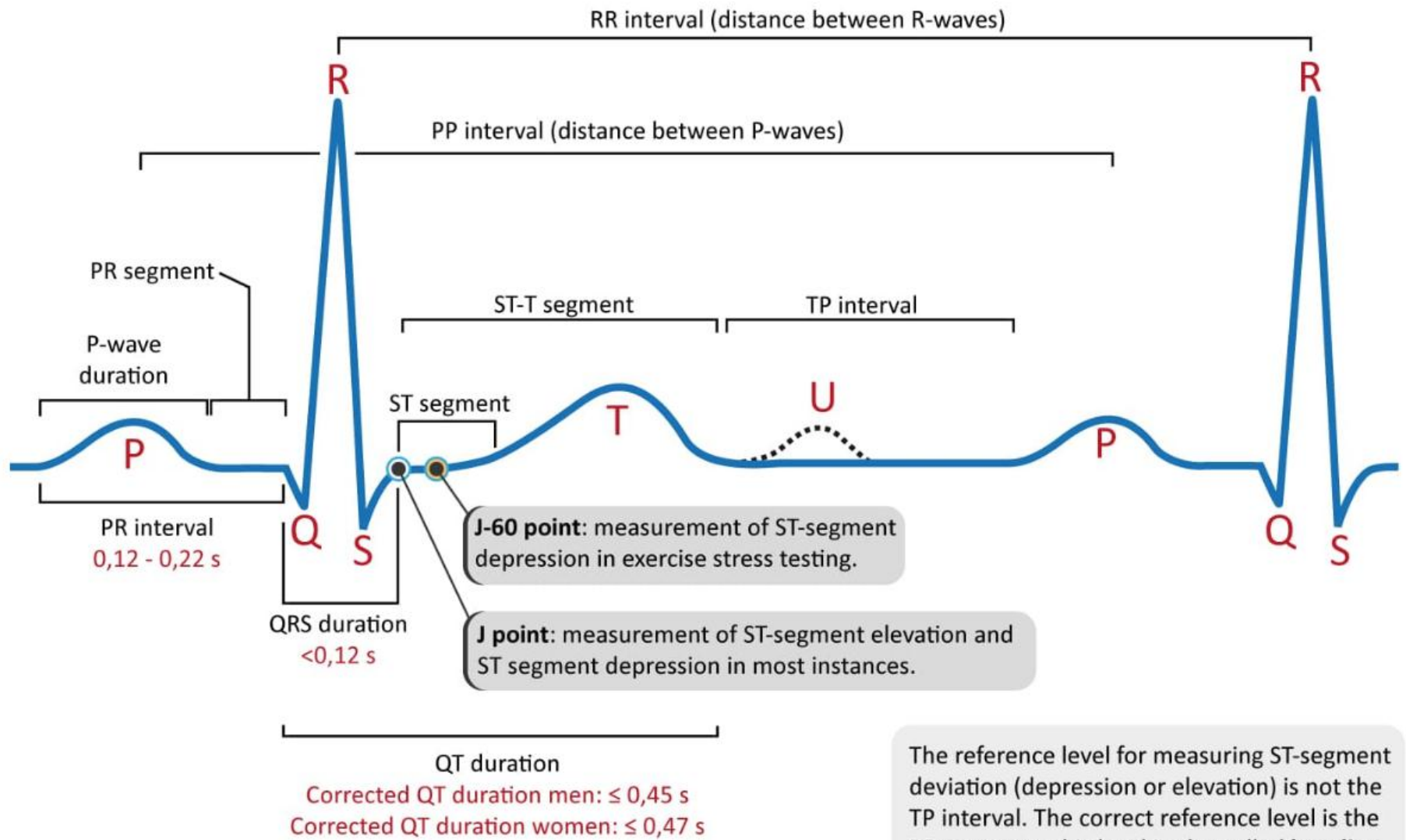
TP segment

Point

J' Point

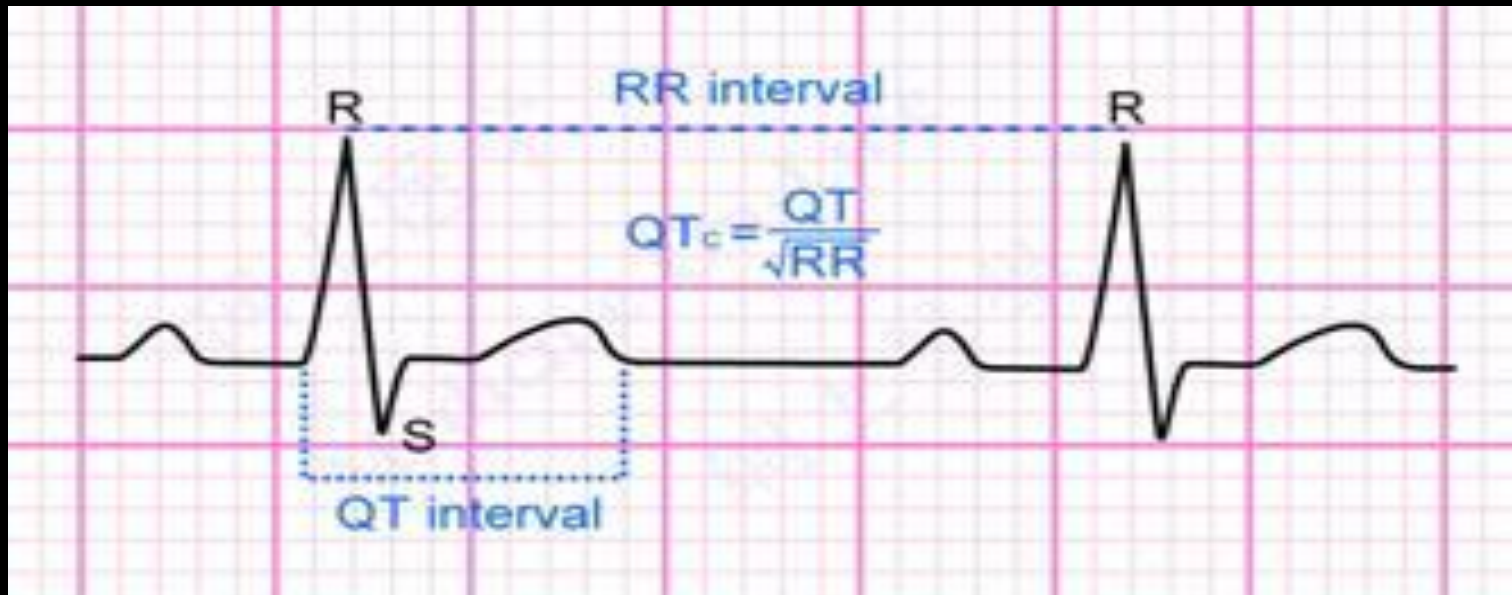






The reference level for measuring ST-segment deviation (depression or elevation) is not the TP interval. The correct reference level is the **PR segment**. This level is also called **baseline level** or **isoelectric level**.

'QT' interval

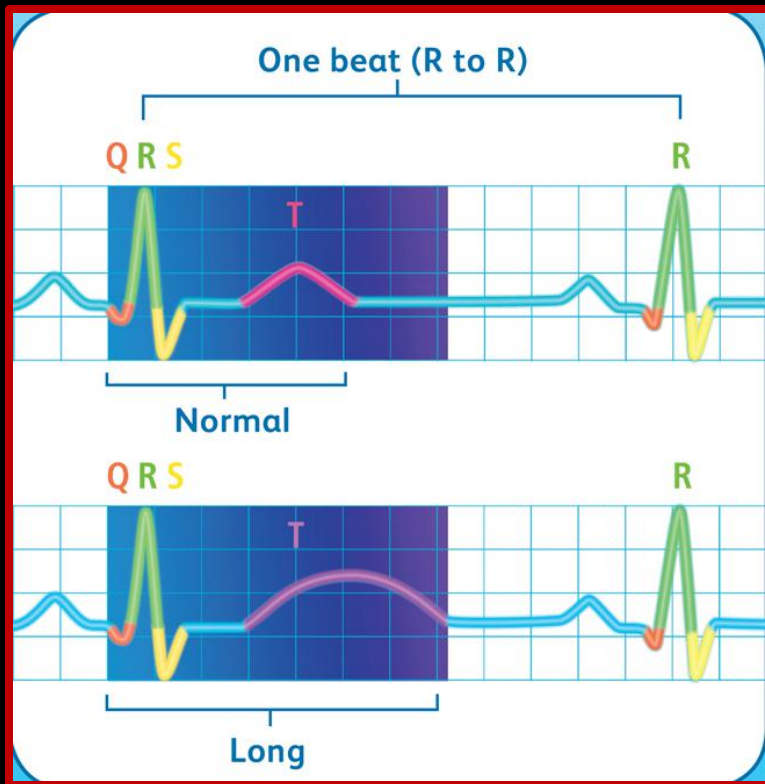


Beginning of the QRS to the end of T wave, (Depolarization + repolarization time)

Decreases with increasing heart rate, influenced by gender / age

Not more than half of the R-R interval

'QT' interval

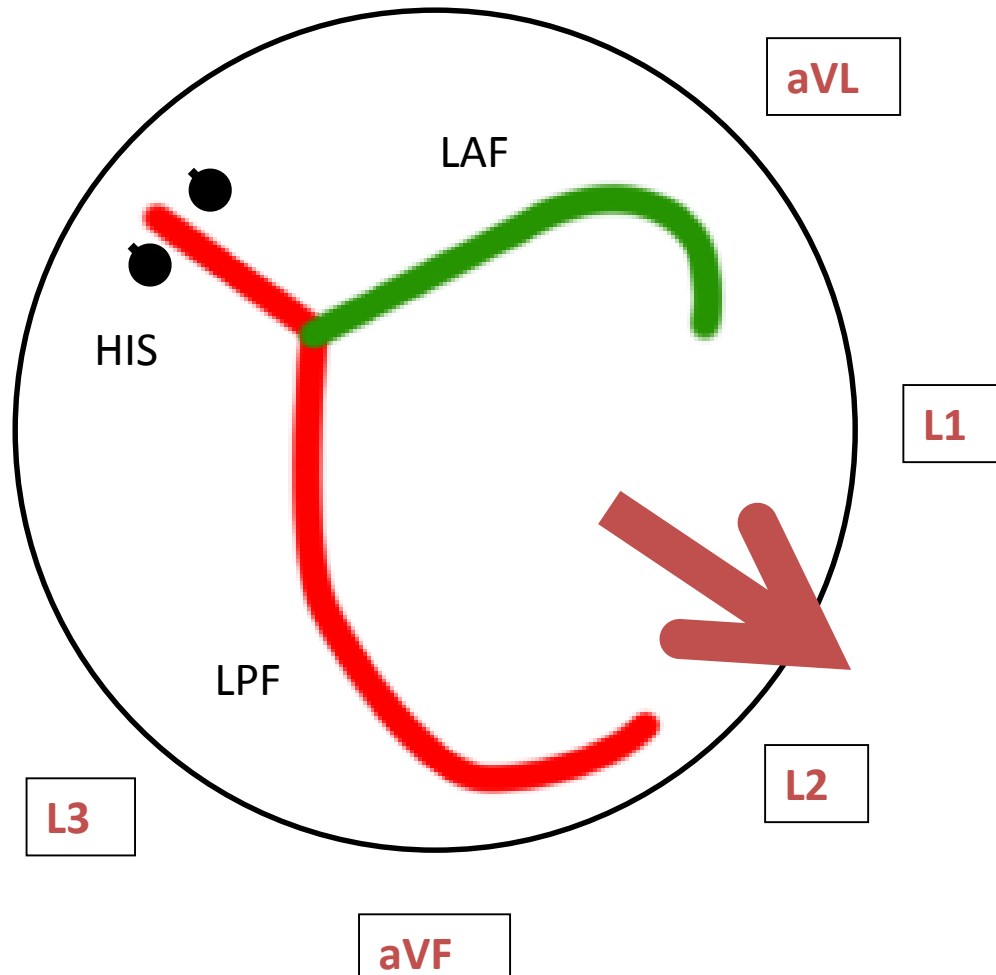


	Normal Corrected QT Values (QTc)		
	1 to 15 yrs	Female	Male
Normal	<0.44 sec	<0.45 sec	<0.43 sec
Borderline	0.44 - 0.46 sec	0.45 - 0.47 sec	0.43 - 0.45 sec
Prolonged	>0.46 sec	>0.47 sec	>0.45 sec

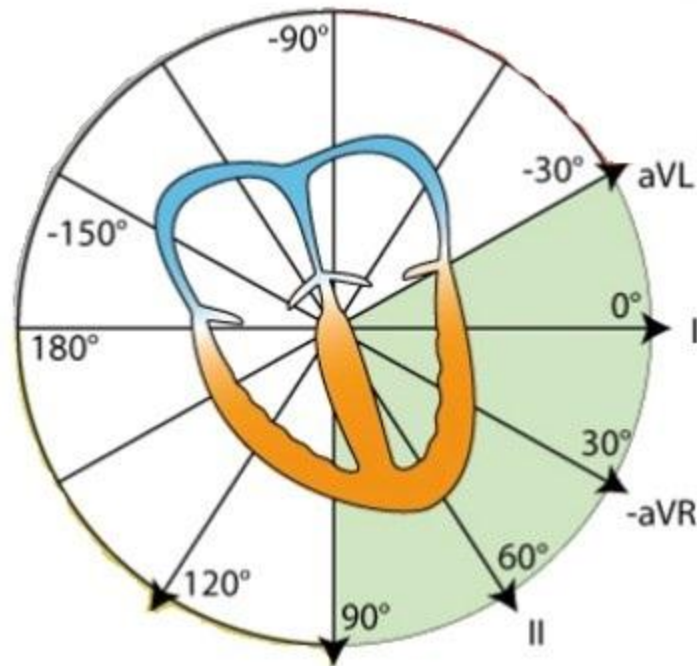
>0.32 sec

Axis determination

Normal Ventricular Activation

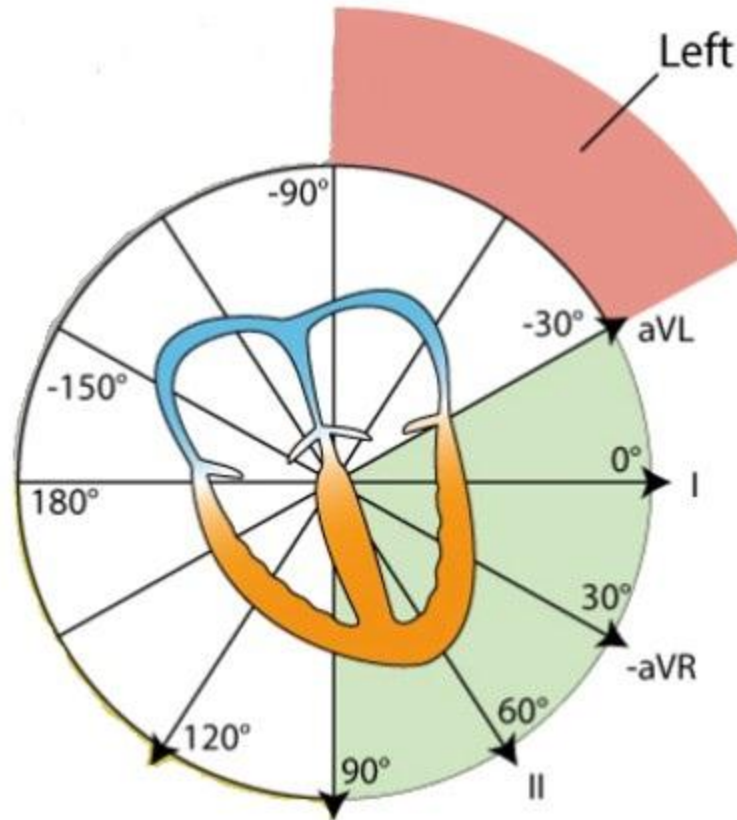


Electrical Axis



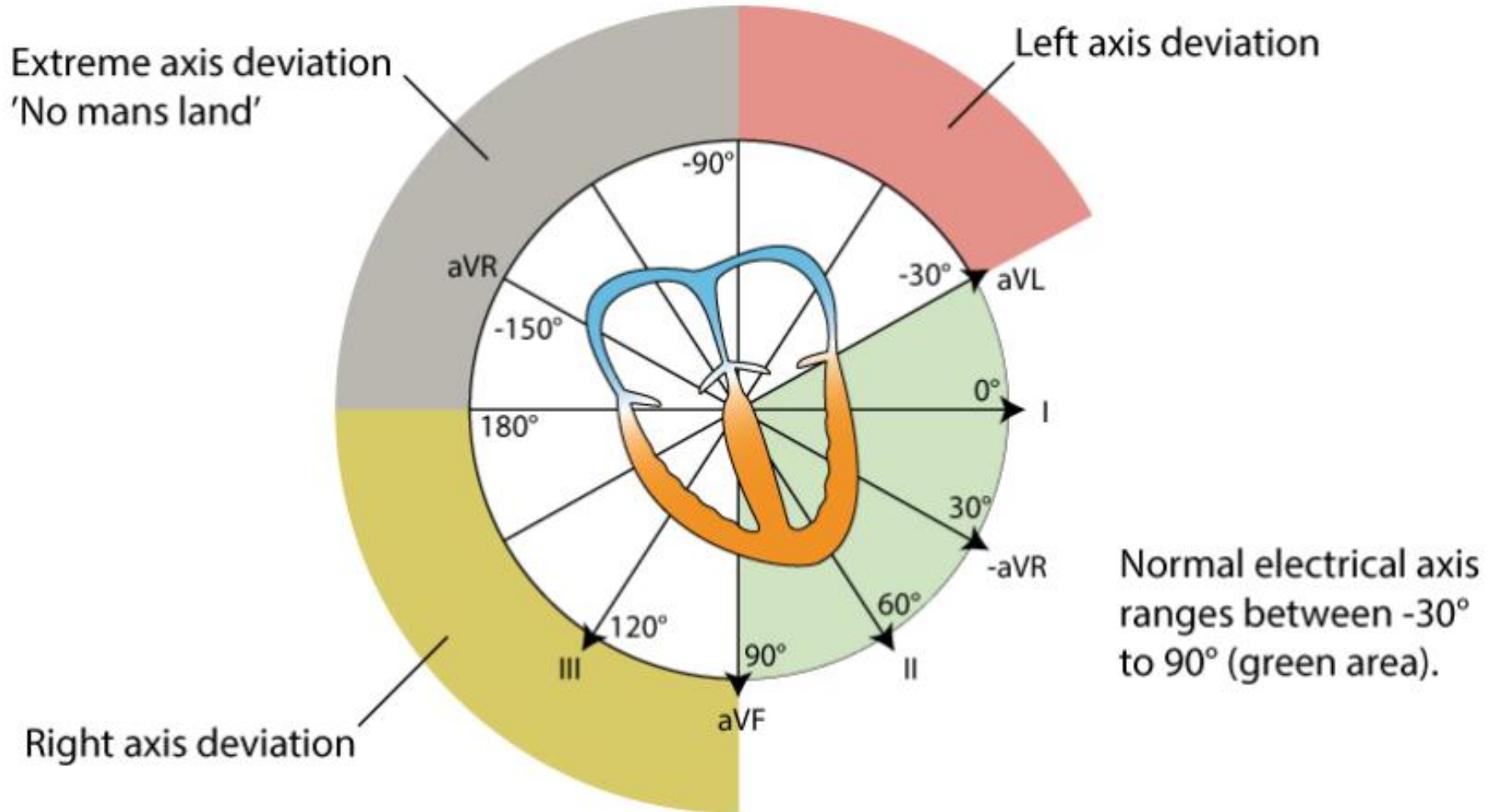
Normal electrical axis ranges between -30° to 90° (green area).

Electrical Axis



Normal electrical axis ranges between -30° to 90° (green area).

Electrical Axis



Normal P wave

'Always' positive in Lead II

Most often positive in leads I, aVL

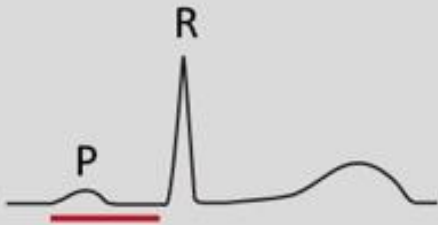
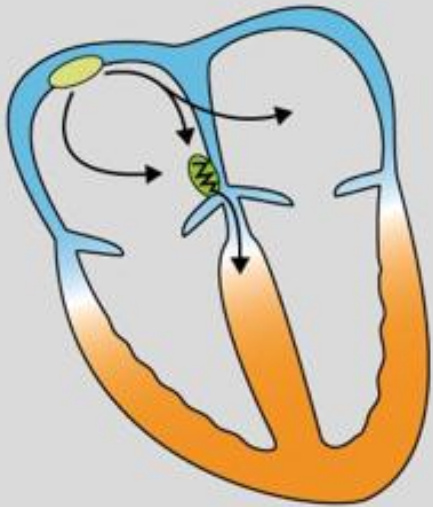
Negative in aVR

Duration < 0.12secs

Height < 2.5mm

Normal PR Interval

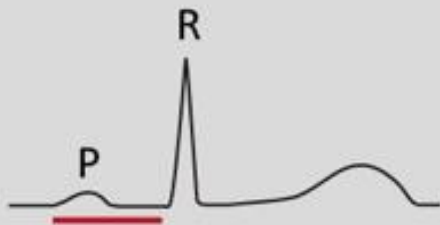
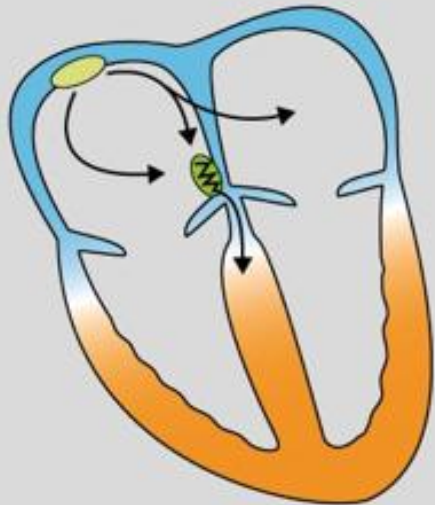
Normal atrioventricular
impulse transmission



Normal PR interval (0.12–0.22 s)

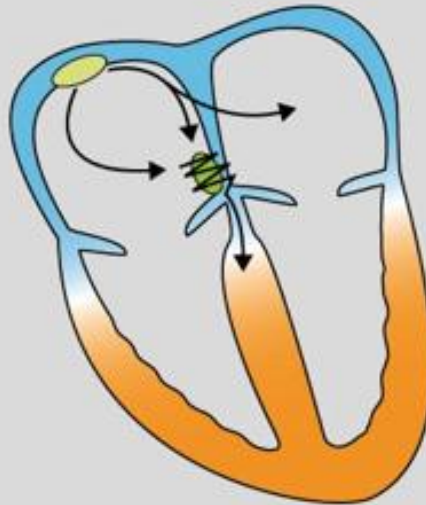
PR Interval

Normal atrioventricular
impulse transmission



Normal PR interval (0.12–0.22 s)

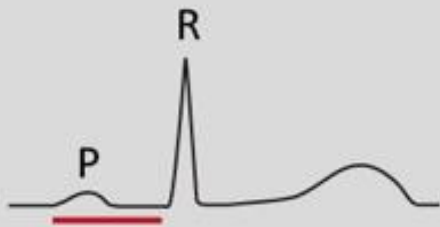
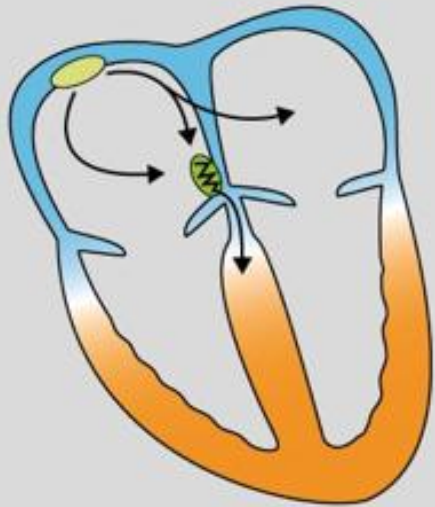
First-degree AV block



Prolonged PR interval (>0.22 s)

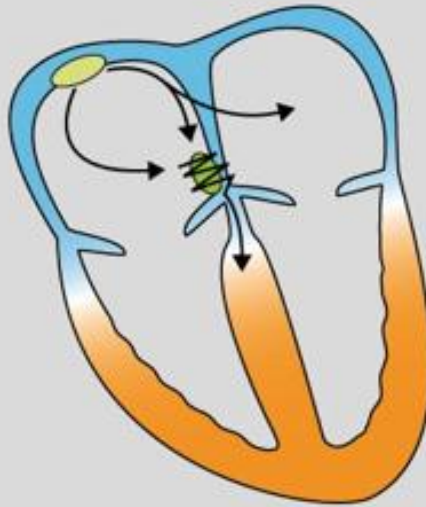
PR Interval

Normal atrioventricular
impulse transmission



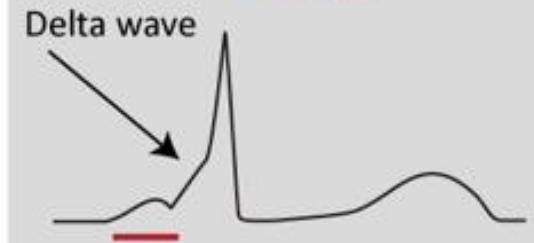
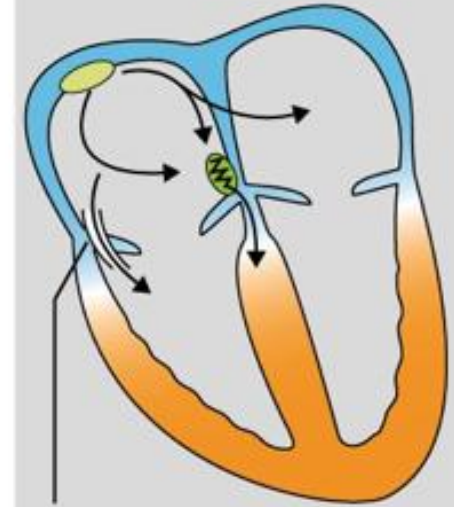
Normal PR interval (0.12–0.22 s)

First-degree AV block



Prolonged PR interval (>0.22 s)

Pre-excitation



Short PR interval (<0.12 s)

Normal QRS

Duration < 0.12secs

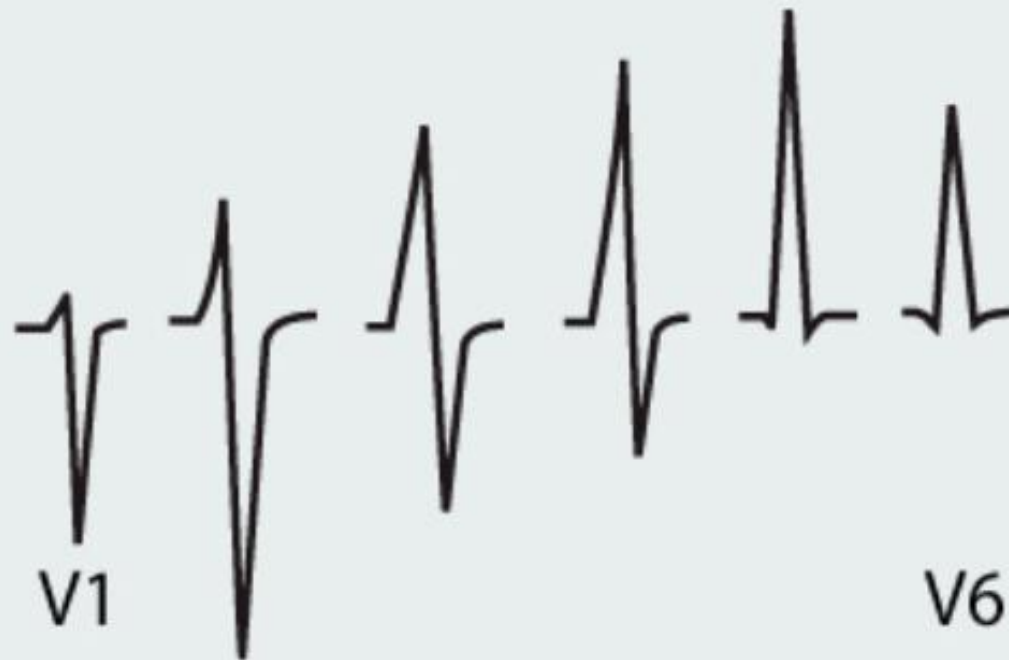
At least one limb lead with R wave height > 5mm and one chest lead > 10mm (otherwise it is low voltage)

S wave in V1 or V2 + or in V5 < 35mm (otherwise it is high voltage)

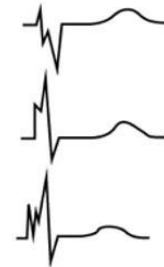
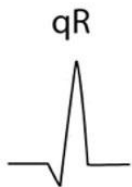
R wave transition in V2/V3

Q wave : < 0.03 sec and < 25% of R wave

QRS Pattern Precordial Leads

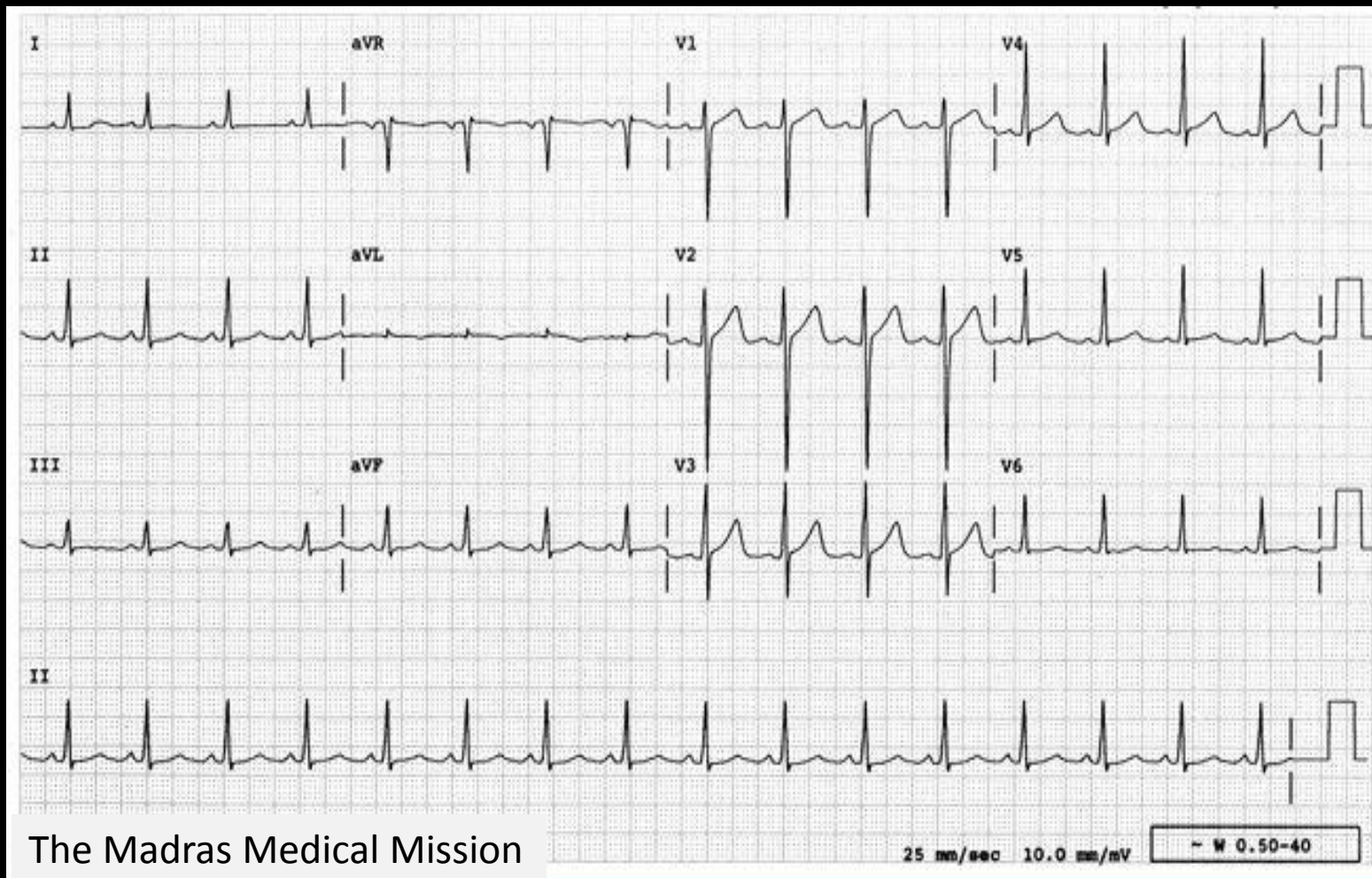


QRS Morphology

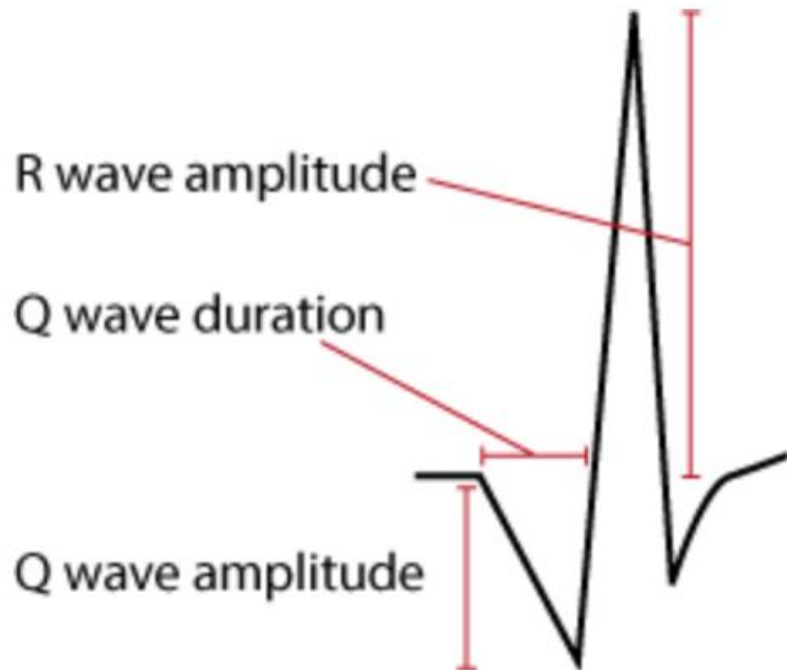


Examples of fragmented QRS-complexes.

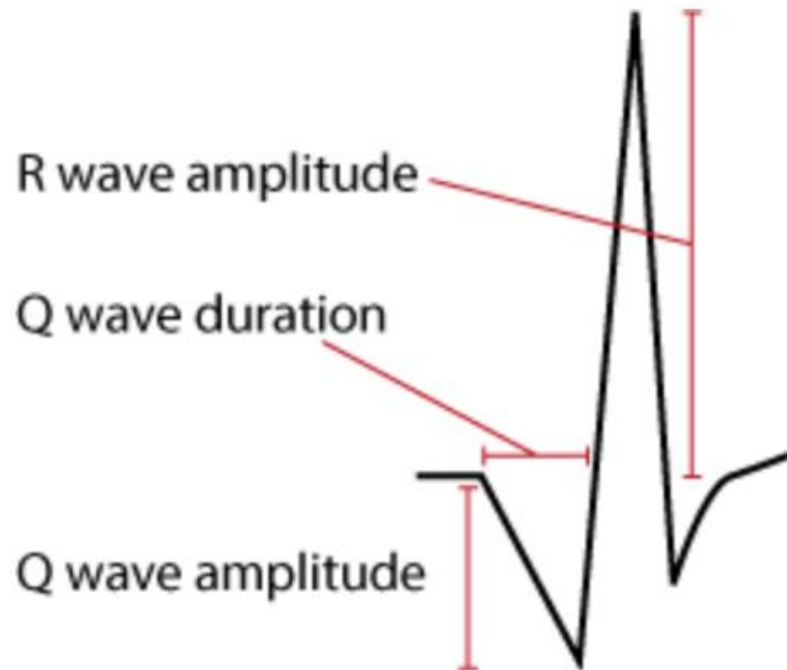
A Normal ECG



Q Wave



Abnormal Q Wave

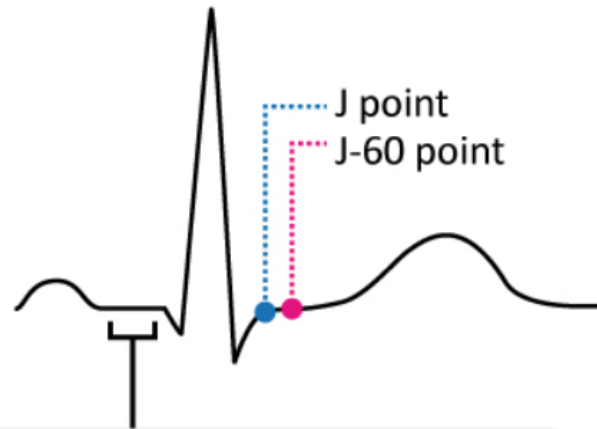


Definition of pathological Q wave

- Duration >0.03 seconds and/or
- Amplitude $>25\%$ of R wave amplitude

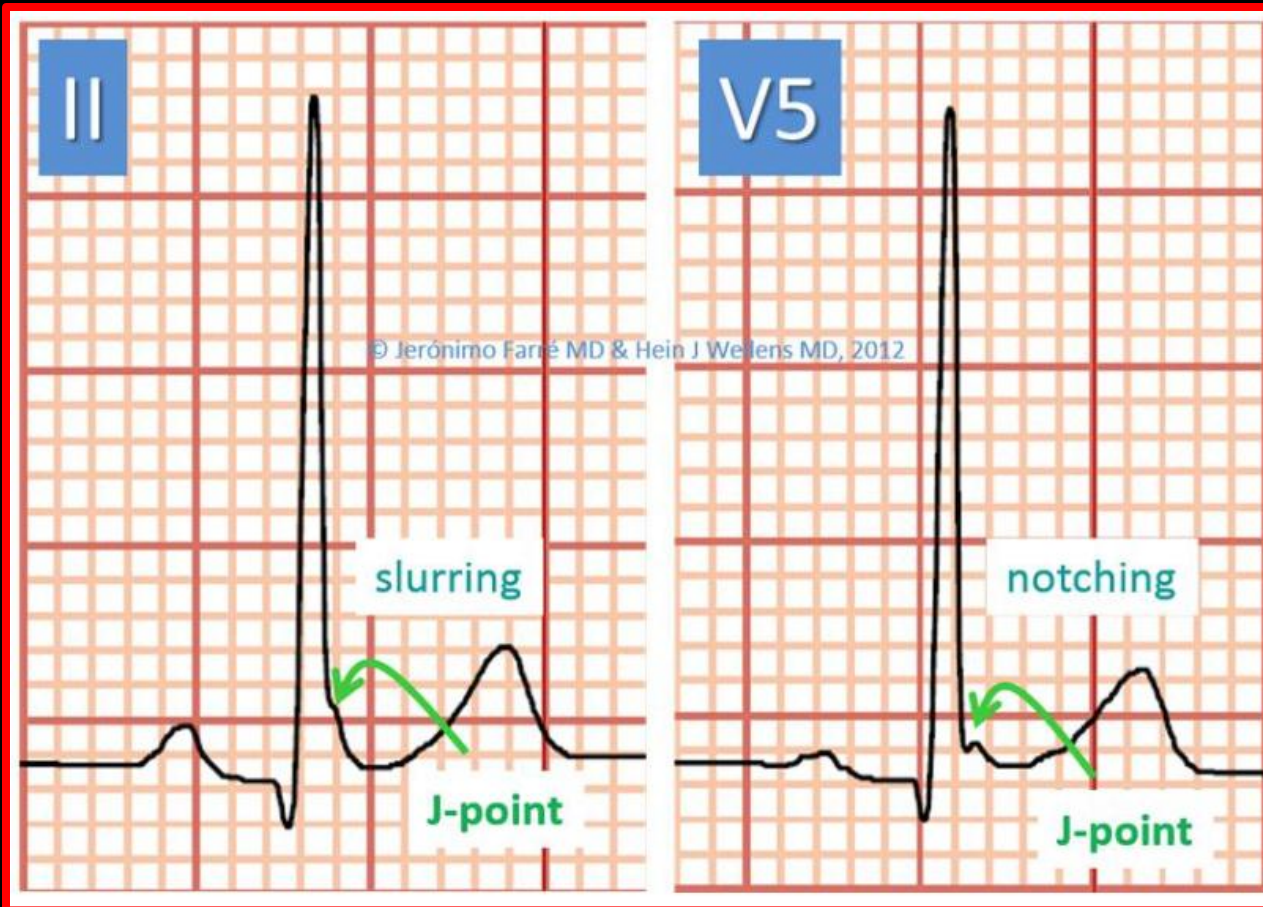
Hence, the Q wave visible here does fulfill criteria for pathological Q waves.

J Point

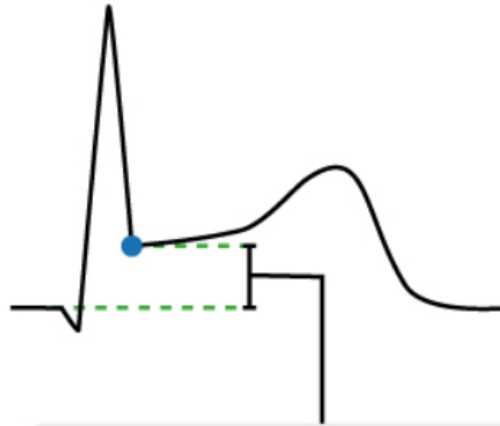


The PR segment is the baseline (reference line) for measuring deviation of the ST segment.

J Point : Slur/Notch

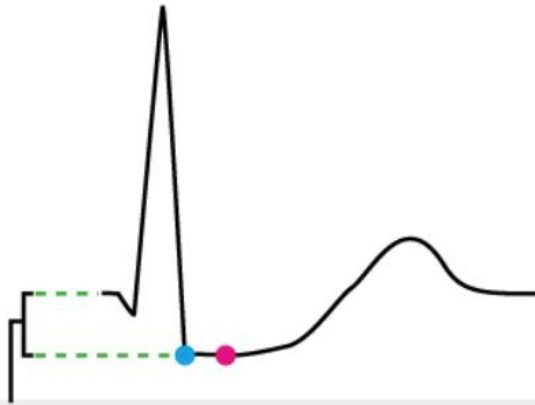


ST Segment : Elevation



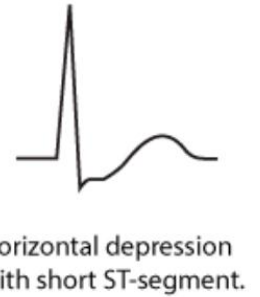
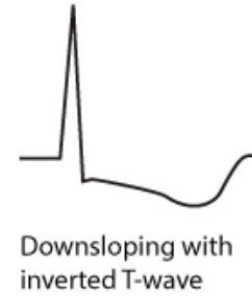
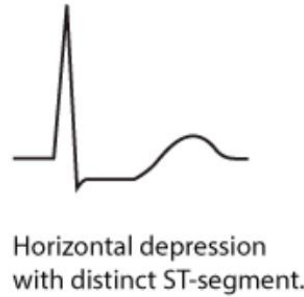
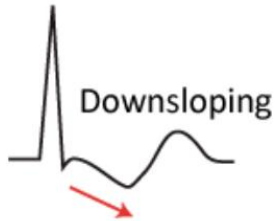
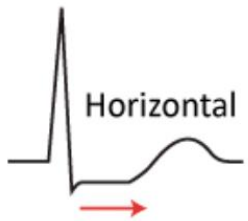
The magnitude of ST segment elevation is measured in the J point.

ST Segment : Depression



The magnitude of ST segment depression is measured in the J point in most instances. Occasionally it is advised that the J-60 point be used instead (particularly during exercise stress testing). If the ST segment is horizontal, then there is no difference in the magnitude of the ST depression in J and J-60.

ST Segment Depression : Patterns



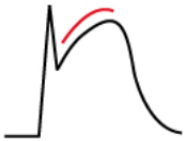
ST Segment Elevation : Patterns



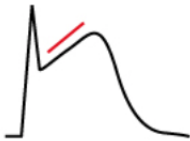
ST-segment elevations caused by ischemia typically displays a convex or straight ST-segment. Such ST-segment elevations in presence of chest discomfort are strongly suggestive of transmural myocardial ischemia. Note that the straight downsloping variant is unusual.

ST Segment Elevation : Patterns

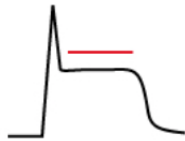
Convex



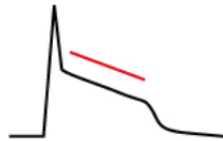
Straight upsloping



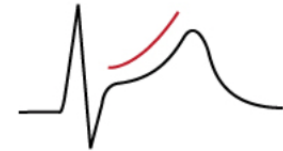
Straight horizontal



Straight downsloping



Concave



ST-segment elevations caused by ischemia typically displays a convex or straight ST-segment. Such ST-segment elevations in presence of chest discomfort are strongly suggestive of transmural myocardial ischemia. Note that the straight downsloping variant is unusual.

Non-ischemic ST-segment elevations are extremely common in all populations. They are characterized by a concave ST-segment and a greater distance between the J point and the T wave apex.

Normal T wave

Positive in leads I, II, V5 and V6

Negative in aVR

May be inverted in lead III and/or aVL

May be inverted in leads V1 to V3

T waves : Patterns



Normal T wave

Smooth transition from ST-segment to T wave. T wave is slightly asymmetric with a steeper downslope.

T waves : Patterns



Normal T wave

Smooth transition from ST-segment to T wave. T wave is slightly asymmetric with a steeper downslope.



Normal variant

Large, asymmetric T wave with broad base. Often in conjunction with slight J point elevation in leads V2-V4.

T waves : Patterns



Normal T wave

Smooth transition from ST-segment to T wave. T wave is slightly asymmetric with a steeper downslope.



Normal variant

Large, asymmetric T wave with broad base. Often in conjunction with slight J point elevation in leads V2-V4.



Hyperkalemia

Large, symmetric, pointed with short base.

T waves : Patterns



Normal T wave

Smooth transition from ST-segment to T wave. T wave is slightly asymmetric with a steeper downslope.



Normal variant

Large, asymmetric T wave with broad base. Often in conjunction with slight J point elevation in leads V2-V4.



Hyperkalemia

Large, symmetric, pointed with short base.



Hyperacute T wave

can be seen in transmural ischemia. High, broad based, symmetric, not pointed. Almost always seen in conjunction with ST-segment elevation.

U wave

Occasionally seen after the T wave

Genesis ?

Usually prominent in V2 and V3, young, athlete, slow heart rates

Height $\frac{1}{3}$ rd of the T wave

U wave inversion : Rare, indicates CAD/HTN



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Electrocardiology Course



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(Sunday, 25th August 2019)

Thank You!

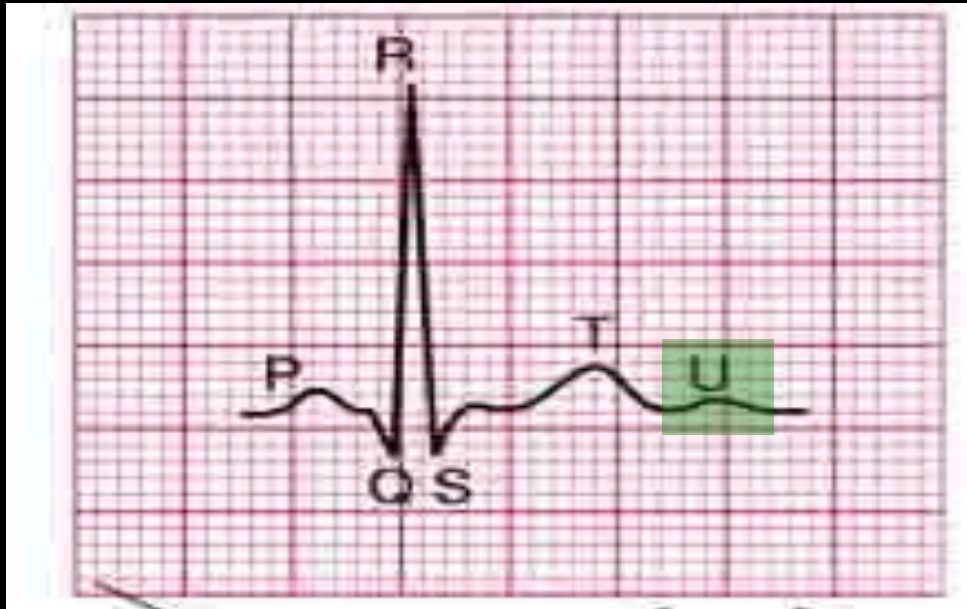
Dr. Ulhas M. Pandurangi

Chief – Cardiac Electrophysiology & Pacing

Arrhythmia Heart Failure Academy

The Madras Medical Mission

'U' Wave

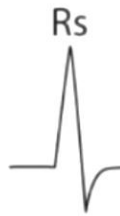


Normally not seen

Significance & source of origin - uncertain



The first (and only) wave is positive and thus an R wave.



The first wave is large and positive (R), followed by a small negative wave (s).



Initially a small positive wave (r), followed by a large negative wave (S).



The first wave is negative and small (q), followed by a large positive wave (R), and finally a small negative wave (s).



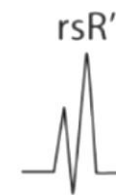
Initially a large negative (Q), then a large positive wave (R).



A single negative wave is called a QS-complex.



A large negative wave (Q), followed by a small positive wave (r).



The negative wave manages to pass the baseline, and is therefore qualified as an S wave.



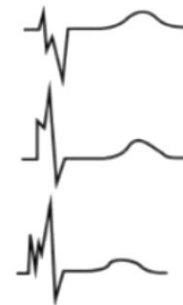
Initially a small negative wave (q), followed by a large positive wave (R).



Notching on the upstroke of the R wave.

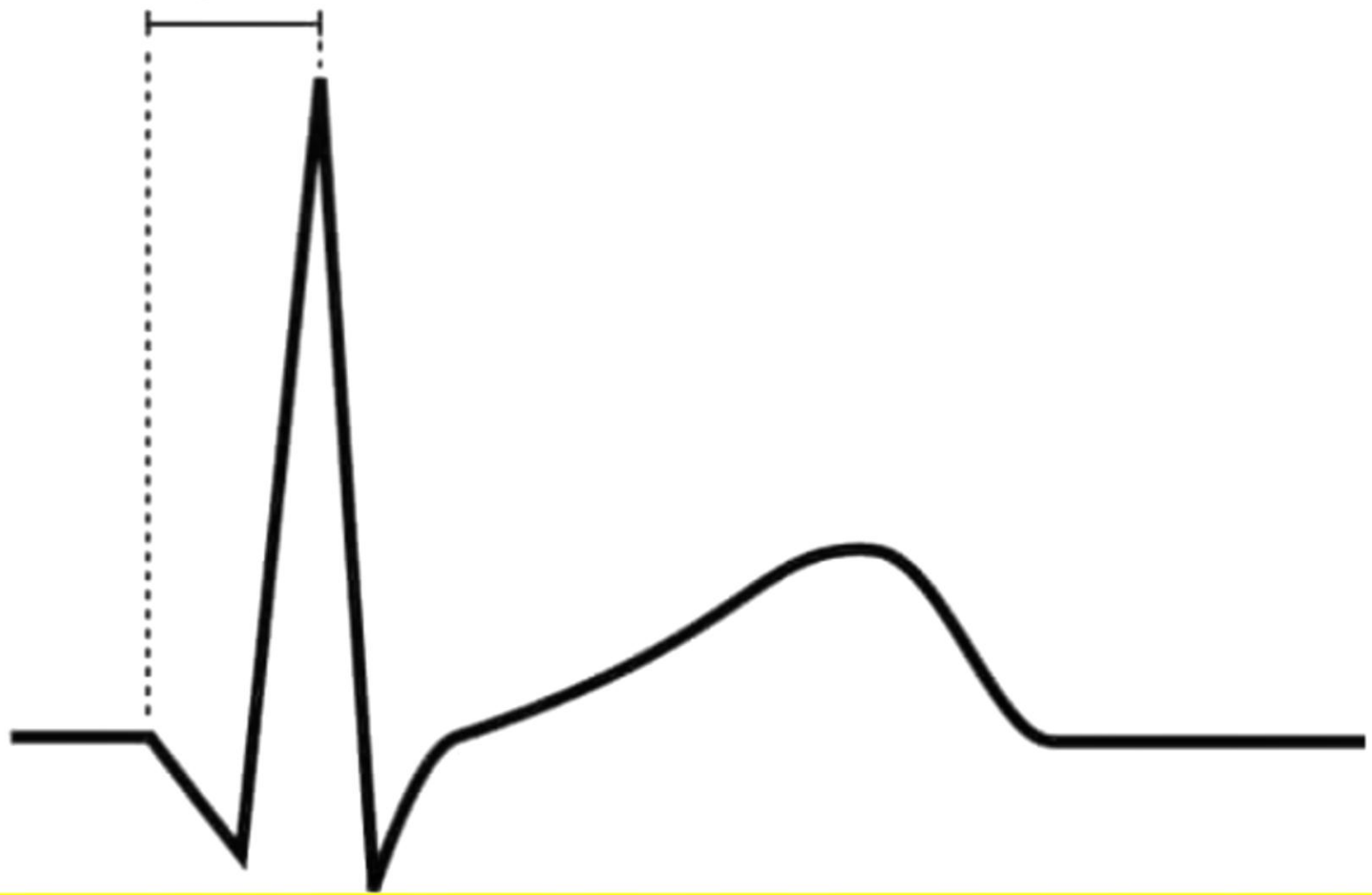


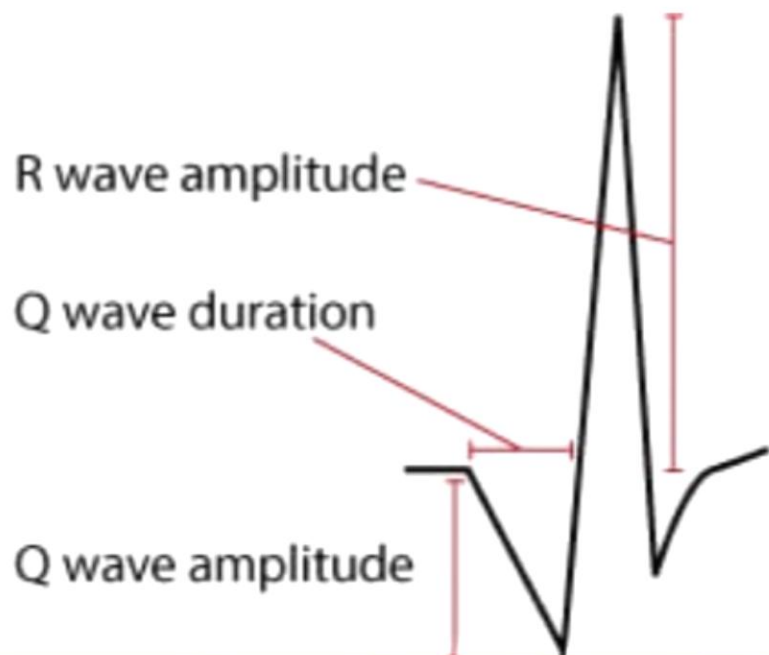
The negative deflection does not manage to pass the baseline and can therefore qualify as an s wave.



Examples of fragmented QRS-complexes.

R wave peak time

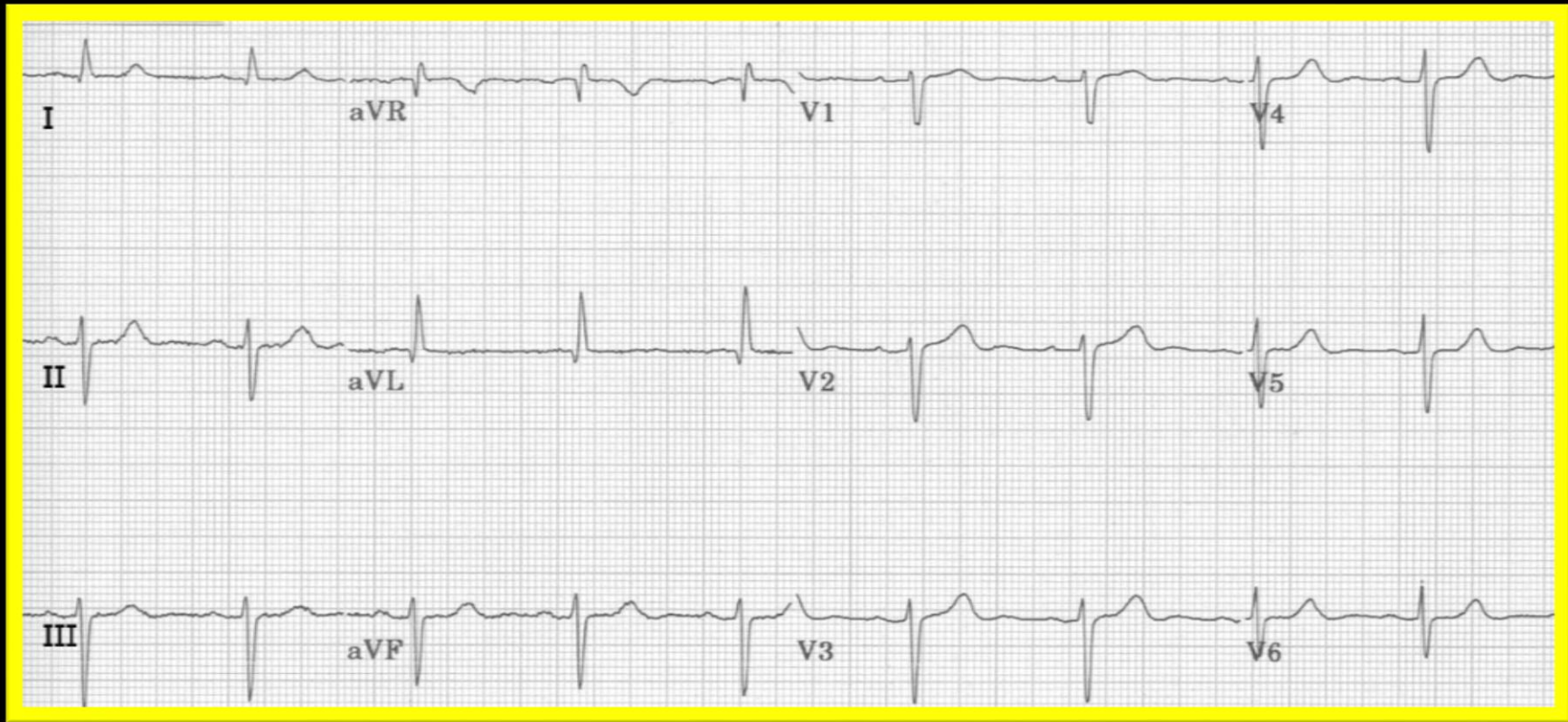




Definition of pathological Q wave

- Duration >0.03 seconds and/or
- Amplitude $>25\%$ of R wave amplitude

Hence, the Q wave visible here does fulfill criteria for pathological Q waves.



Normal variants

Normal Variants (vs) Normal Accompaniments

Normal Variants:

Asymptomatic Alteration in the shape, size, duration, regularity of one or more components of the ECG waveforms in a structurally normal heart by clinical examination

Normal Accompaniments:

Secondary changes in the ECG waveform due to primary depolarization abnormality.

Normal Variants

Sinus bradycardia

**Wenckebach
phenomenon**

**Low voltage
complexes**

**Wandering atrial
pacemaker**

**Premature Atrial /
Ventricular Ectopics**

T/U variants

Low atrial rhythm

Non specific IVCD

QTc Variants

Ectopic atrial rhythm

RBBB/LBBB

Sinus arrhythmia

Abnormal axis

Early repolarization

Sinus tachycardia

First-degree AV block

LVH by voltage criteria

LAE/RAE

Frequent normal-variant arrhythmias

Sinus bradycardia: minimal rate about 45/min; minimal instantaneous rate during sleep about 35/min

Sinus tachycardia: maximal rate about 110/min

Sinus arrhythmia

Isolated ventricular pauses: < 2 sec during sleep

Isolated AV-junctional (AV-nodal) escape beats (during sinus arrhythmia or after a premature beat)

Short episodes of AV-nodal rhythm (with retrograde atrial activation)

Short episodes (< 10 beats?) of 'AV dissociation' (with accrochage, with synchronization)

Short episodes of accelerated idionodal rhythm

Episodes of normocardic ectopic atrial rhythm
(e.g. so-called 'coronary sinus rhythm')

Supraventricular premature beats (PBs) (in most cases atrial PBs), if:

- a) isolated (< 200/min?)
- b) < 5 salvos (or < 20?) of maximal three beats
- c) instantaneous rate (beat-to-beat interval) < 160/min
- d) isolated *early* atrial PBs with functional complete AV block

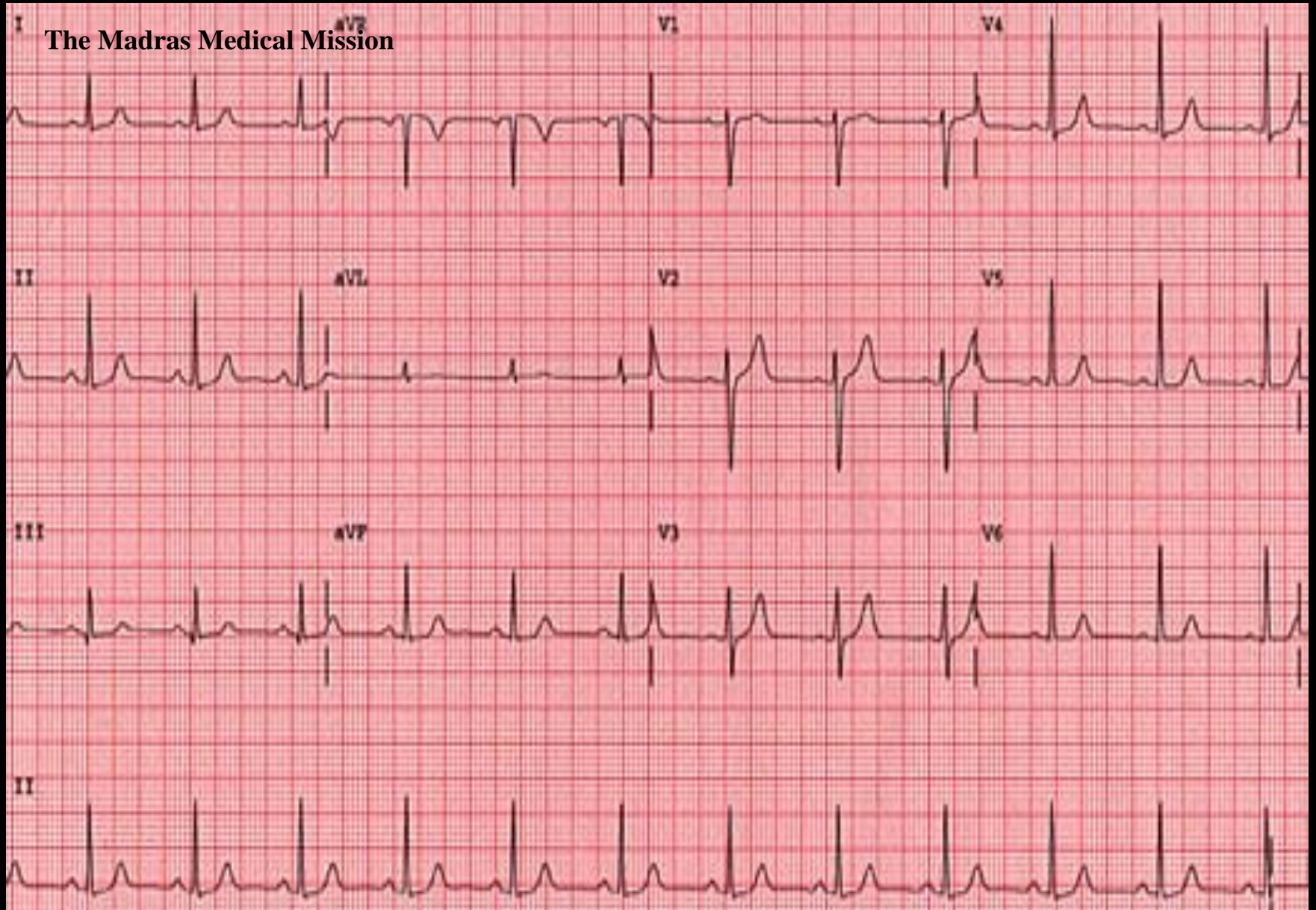
Ventricular PBs (VPBs), if:

- a) isolated (< 200/24 h?)
- b) monomorphic
- c) isolated 'couplets' (< 20/24 h?), instantaneous rate < 160/min
- d) isolated VPBs with 'pseudo-R-on-T phenomenon' (VPB *after* 90% of the preceding QT interval: 'supernormal period')



Normal ECG

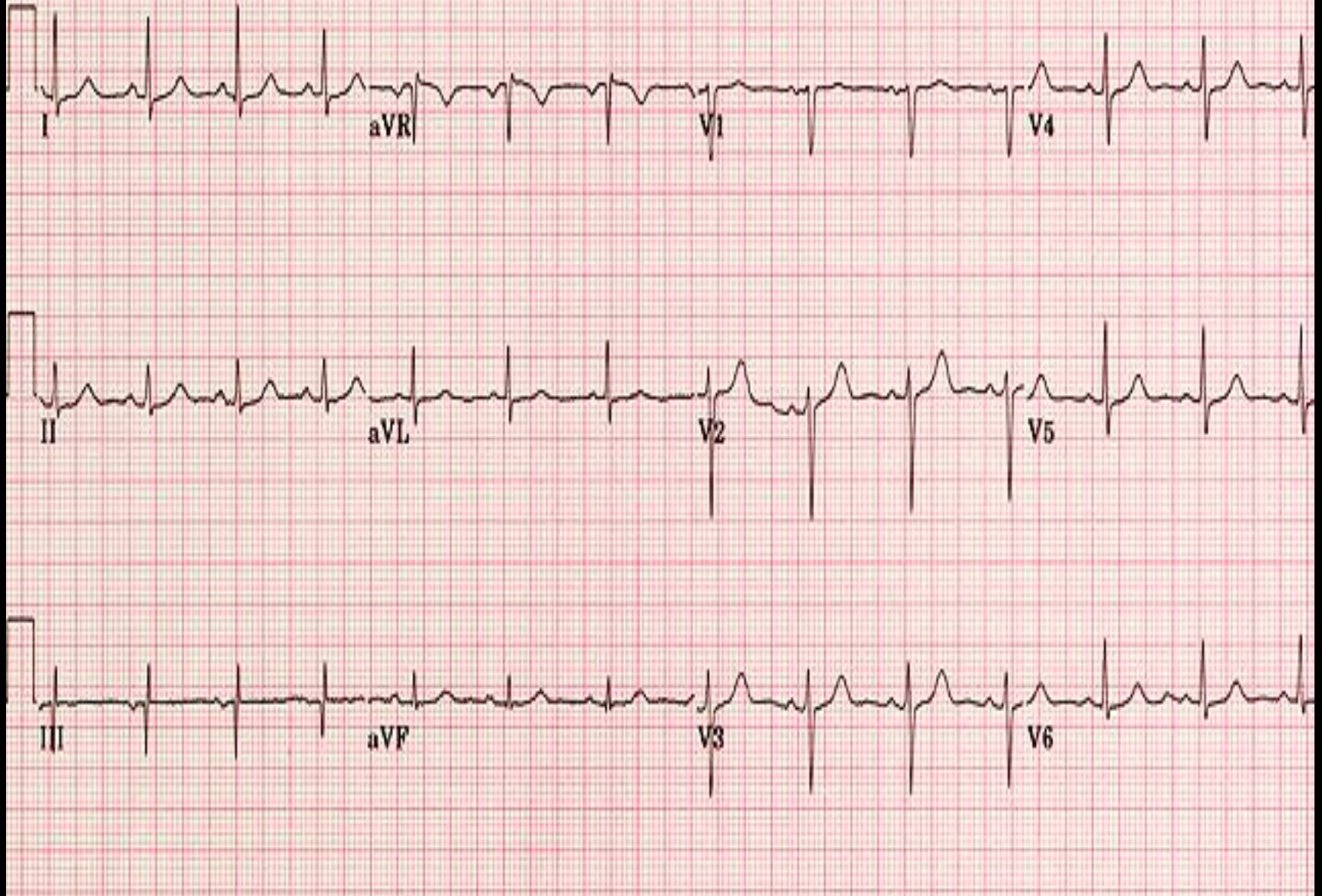
The Madras Medical Mission

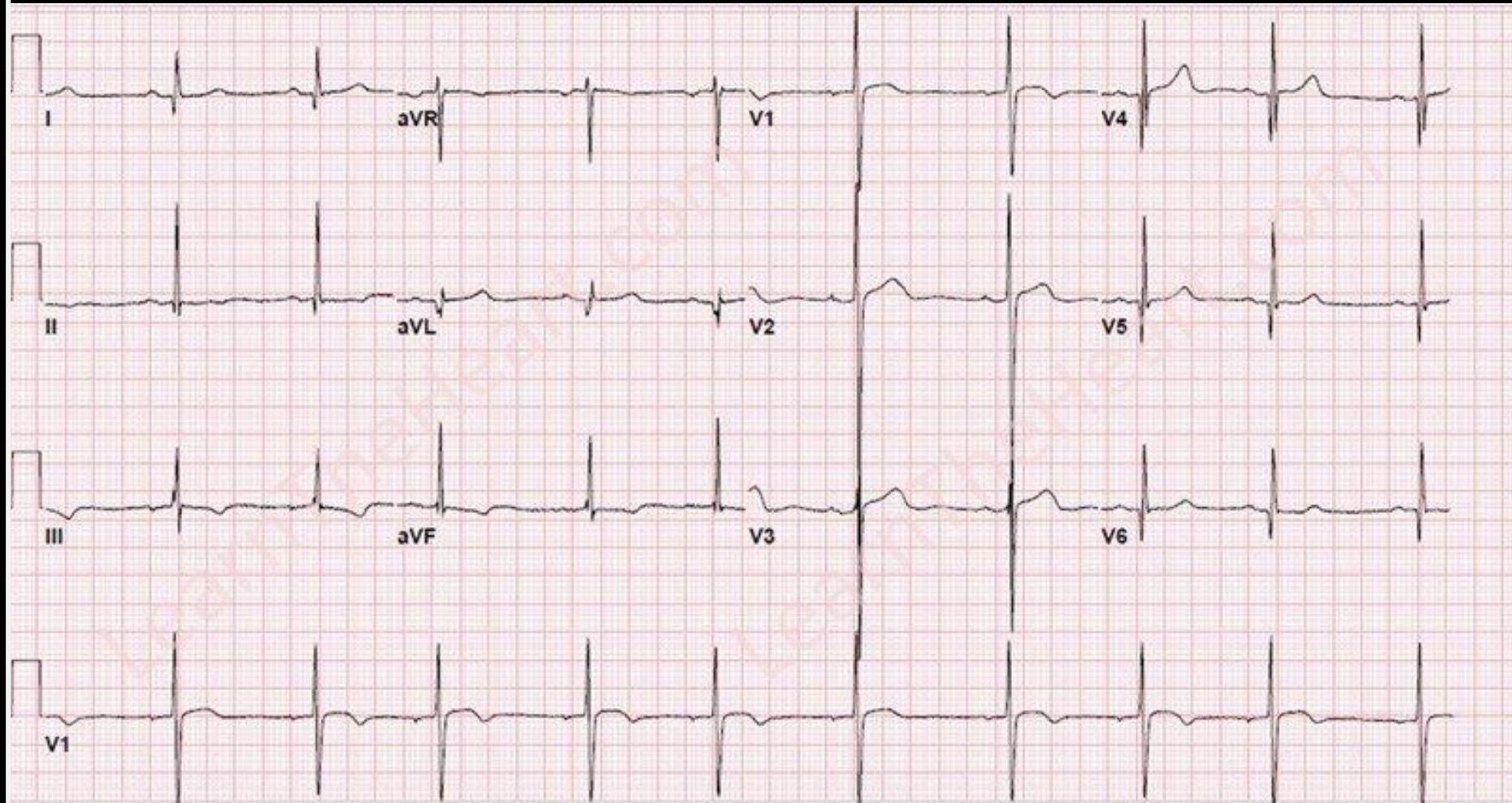


A light pink, wavy-edged shape, resembling a stylized wave or a piece of paper with irregular edges, is centered on a black background. The shape has a white outline and a soft pink fill. The text "Q waves" is written in a black serif font in the center of the shape.

Q waves

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Juvenile T wave

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Sinus Arrhythmia

54 years
Male

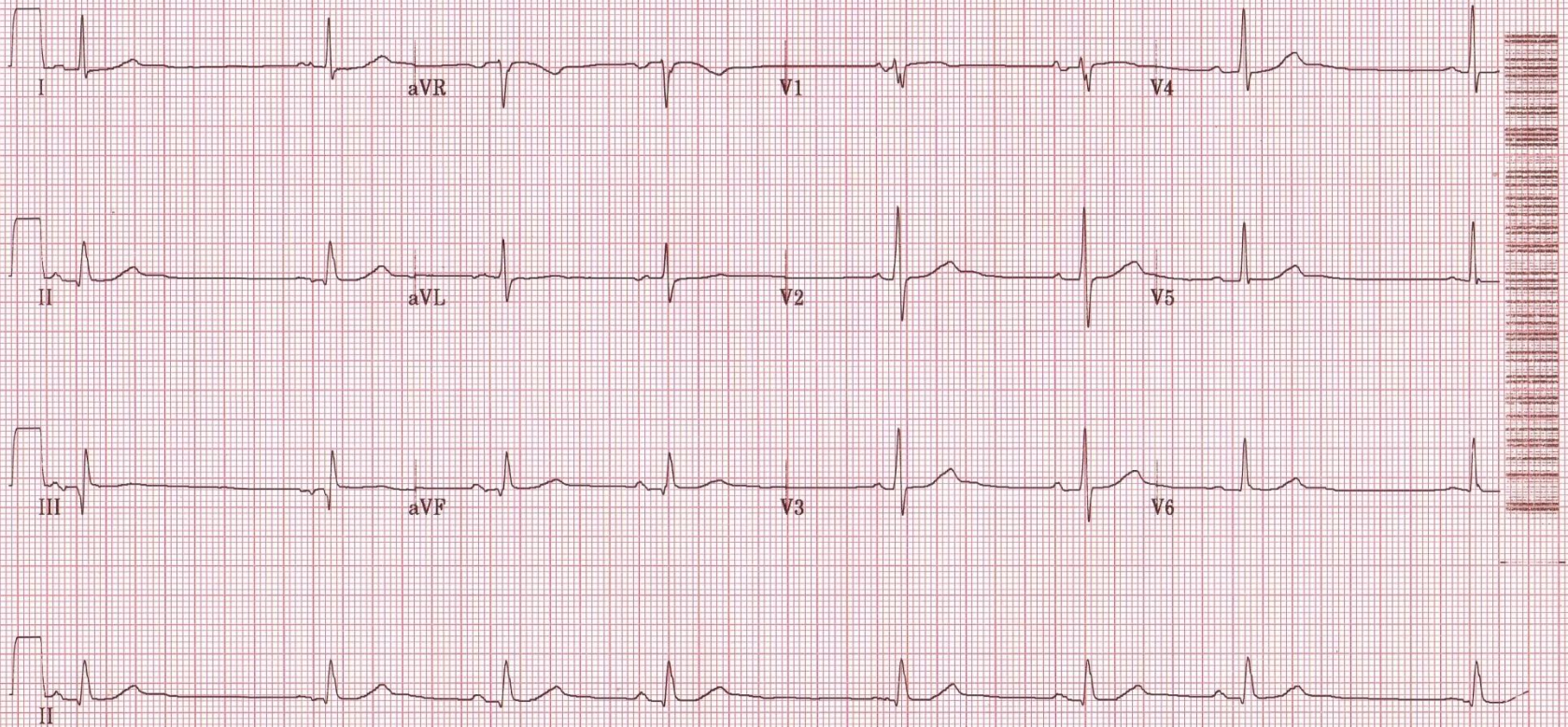
Vent. rate 45 bpm
PR interval 194 ms
QRS duration 88 ms
QT/QTc 470/406 ms
P-R-T axes 47 43 55

THE MADRAS MEDICAL MISSION

Technician: A.K.B

Referred by:

Unconfirmed



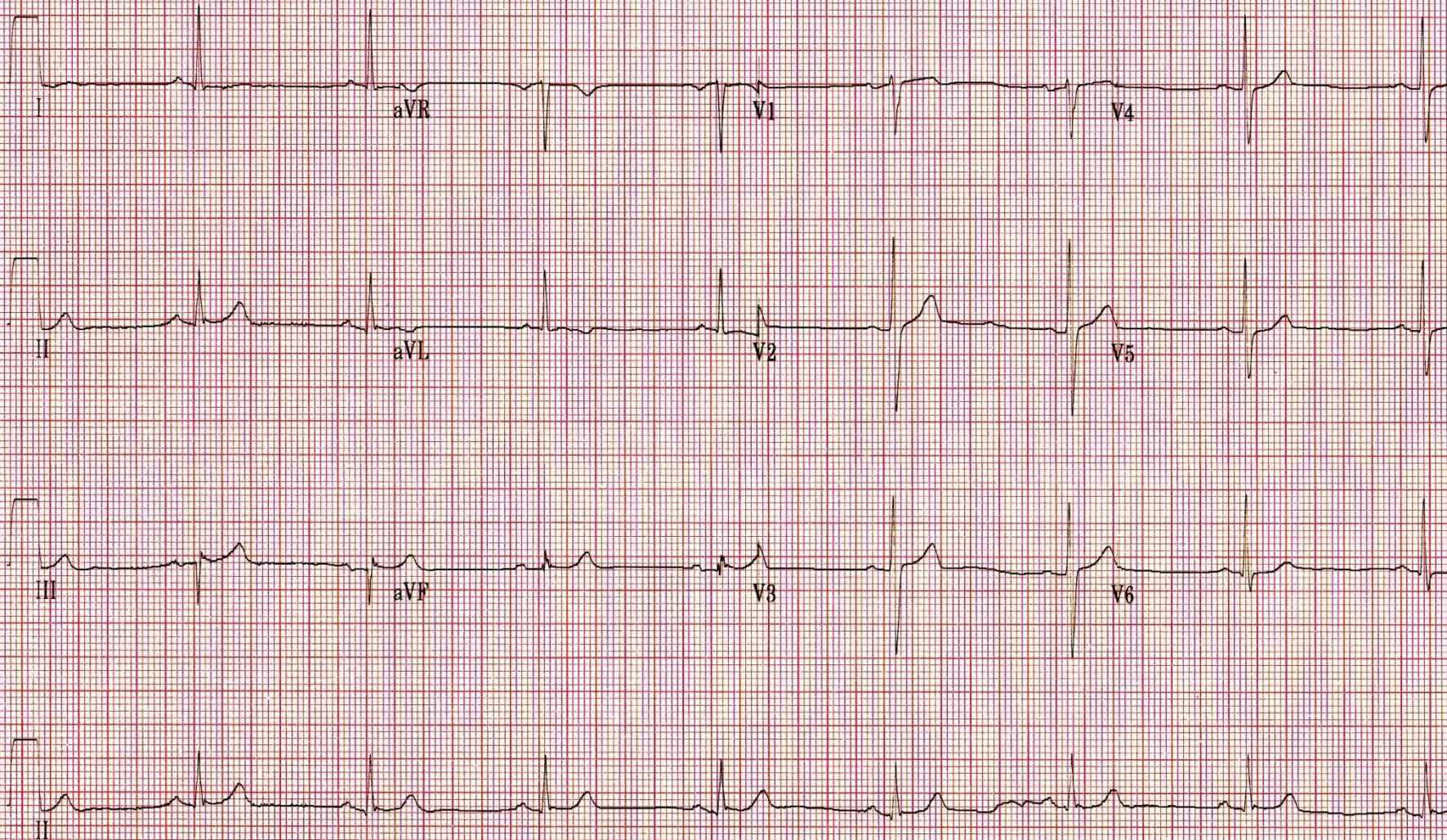
40 Hz 25.0 mm/s 10.0 mm/mV

4 by 2.5s + 1 rhythm ld

MAC55 009A

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Sinus Bradycardia

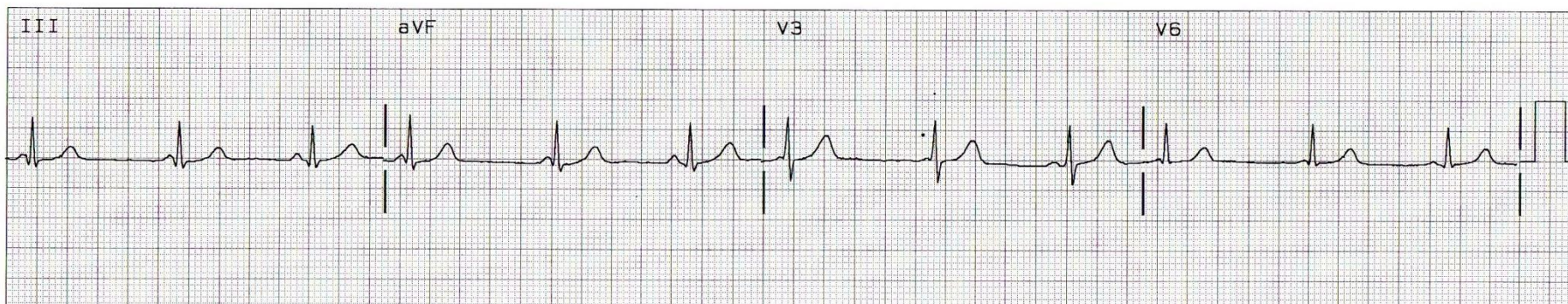
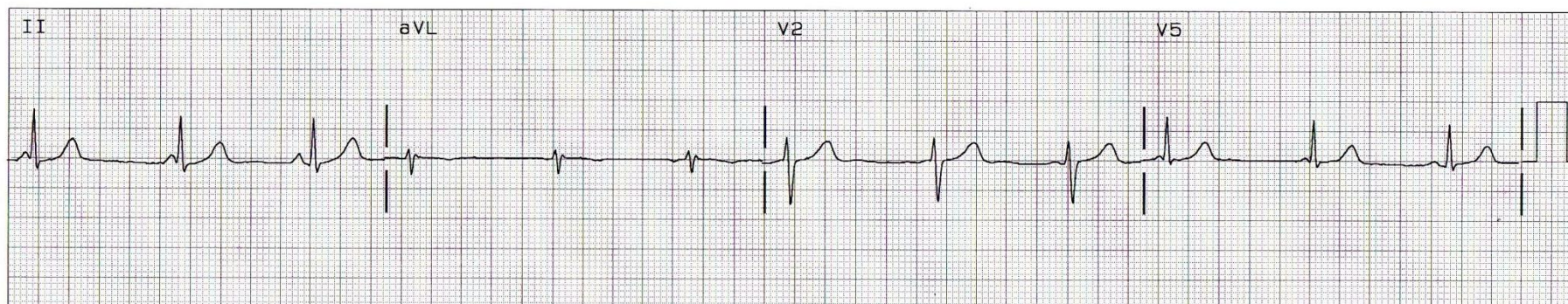
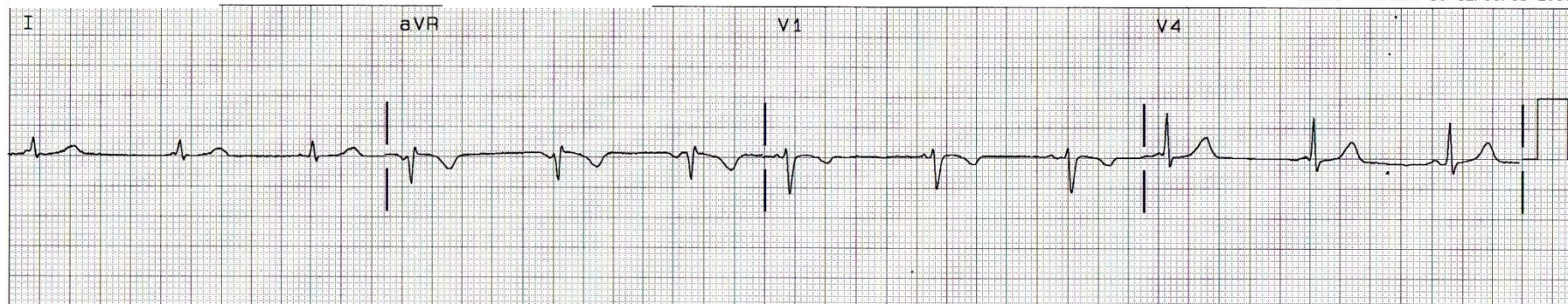


Sinus Tachycardia





Isorhythmic
AV Dissociation





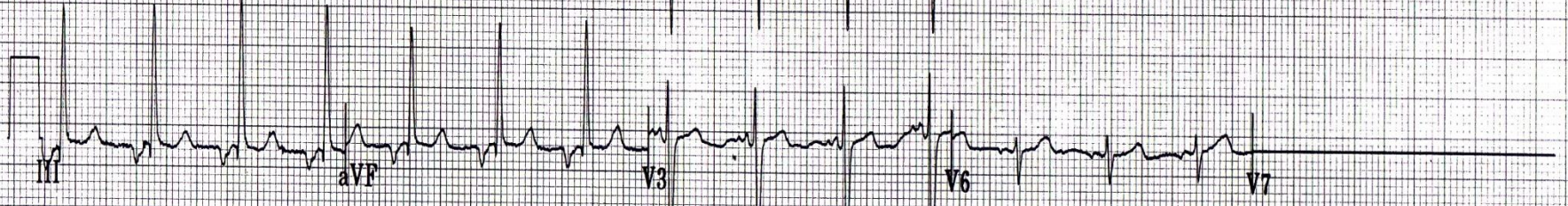
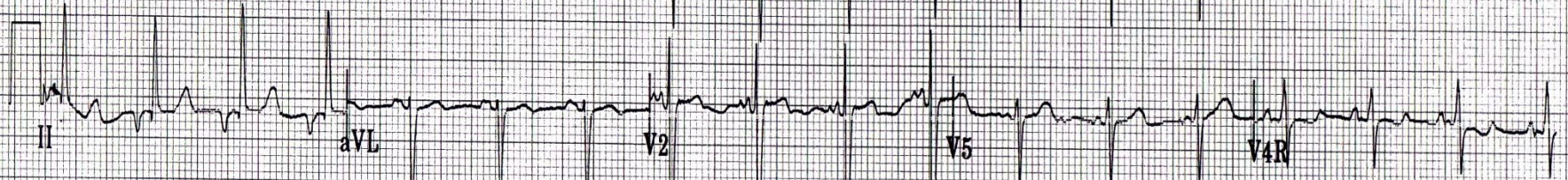
Ectopics

THE MADRAS MEDICAL MISSION





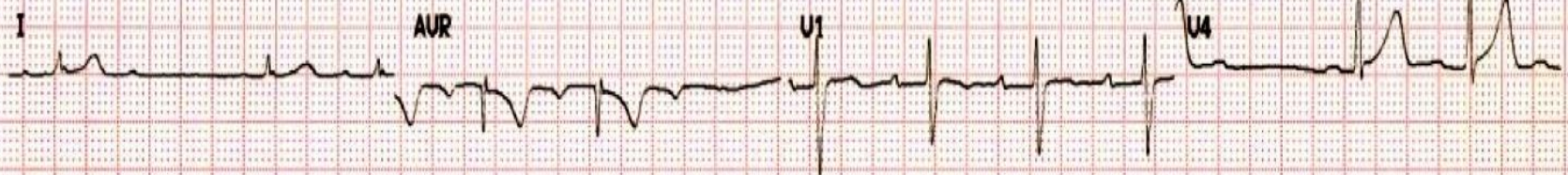
Ectopic Atrial Rhythms



First Degree A-V Block

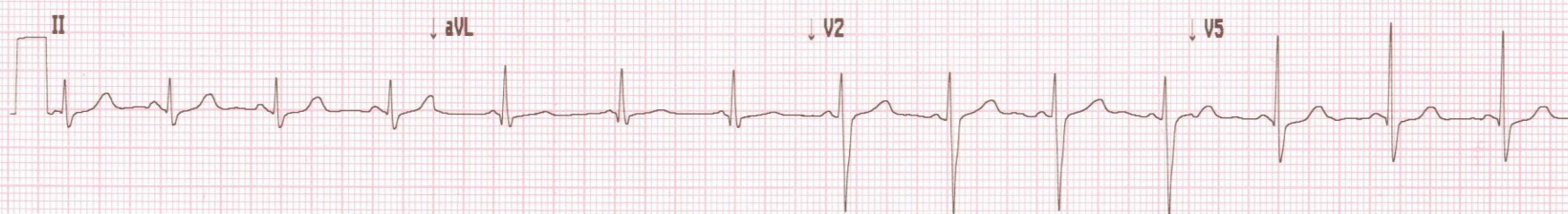


AV Wenckebach

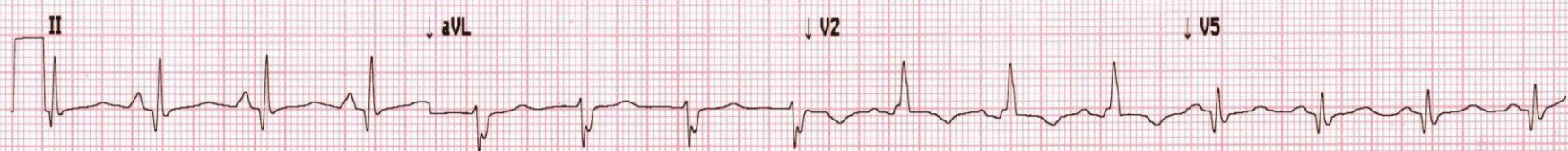




RBBB

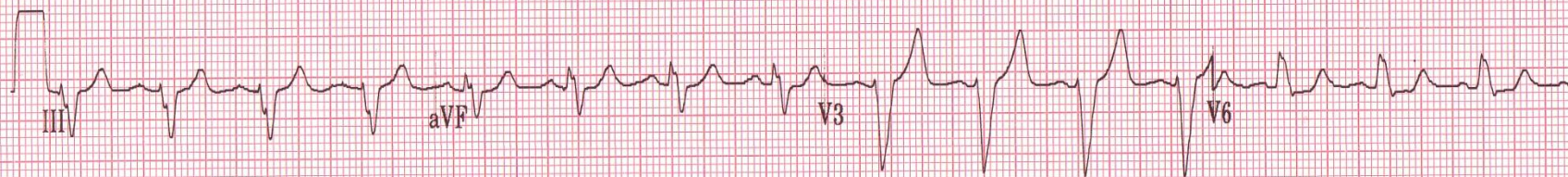
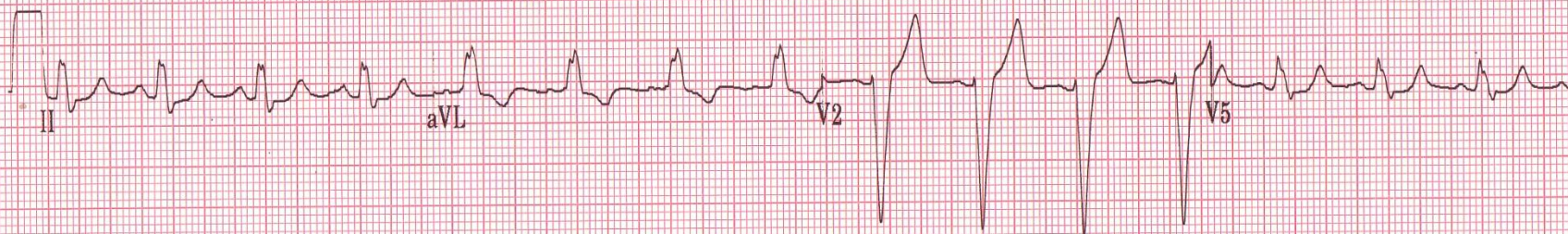


THE MADRAS MEDICAL MISSION

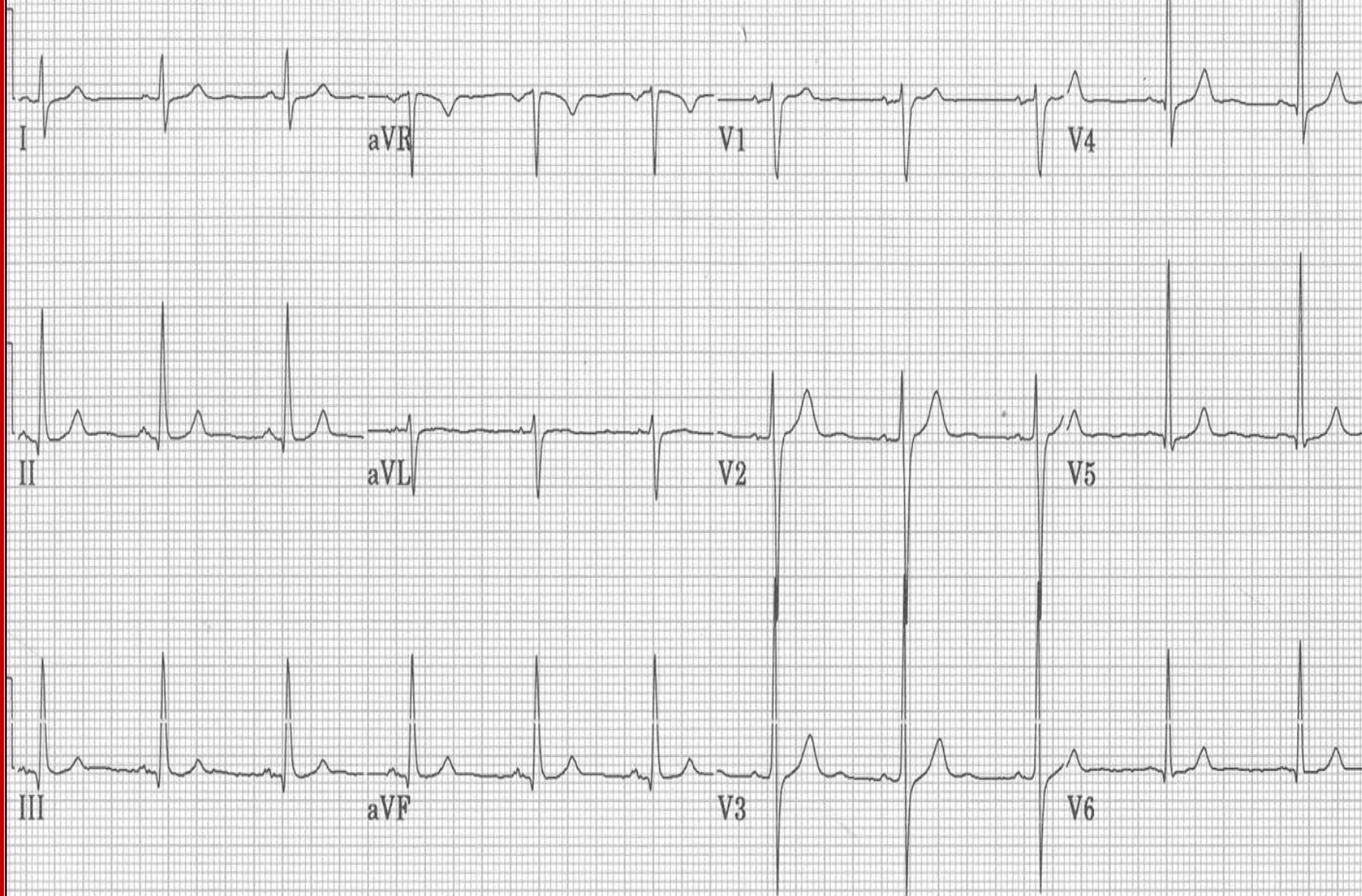




LBBB



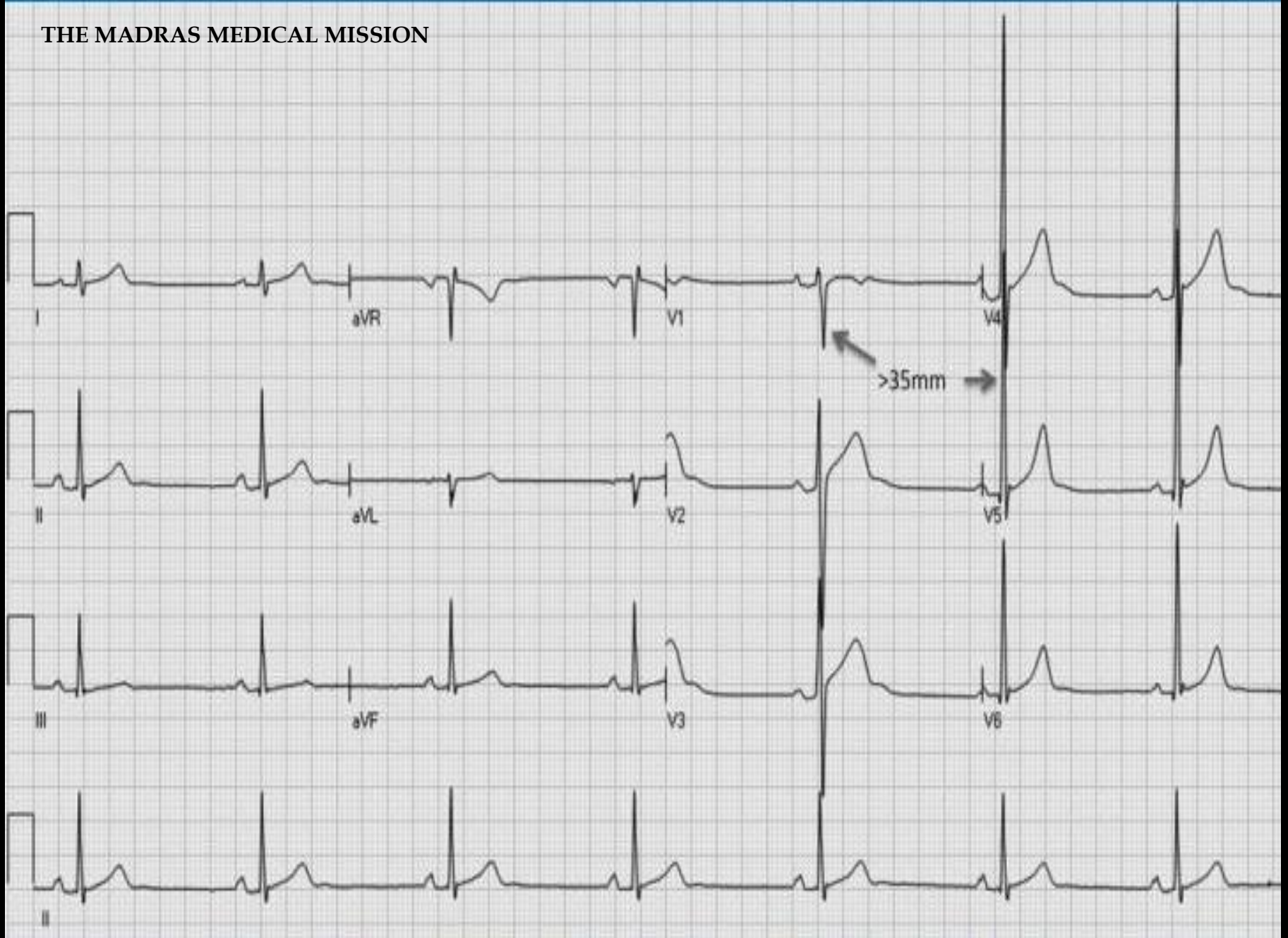
Axis Deviation,
Large Voltages



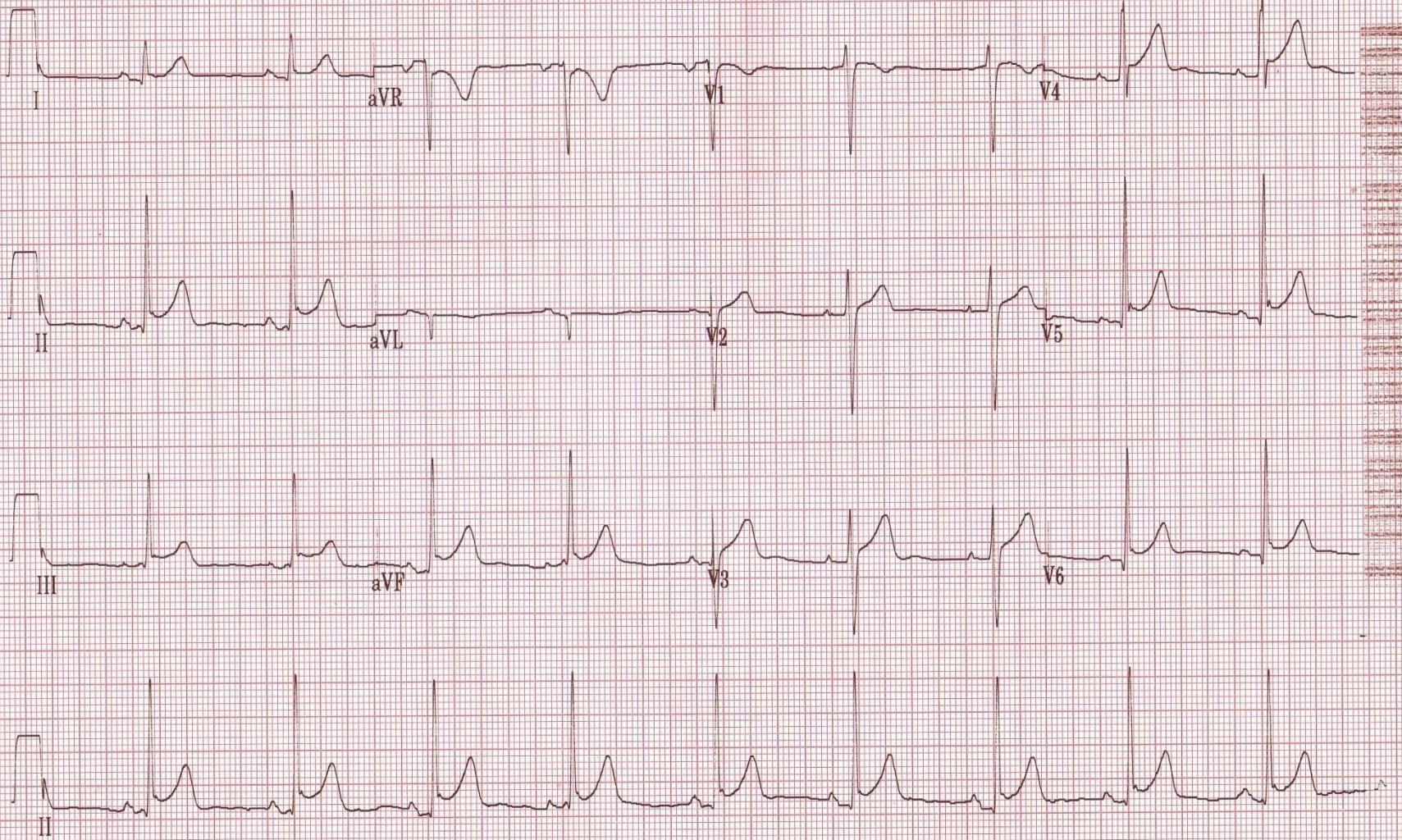


Benign LVH

THE MADRAS MEDICAL MISSION



Early Repolarization Pattern



40 Hz 25.0 mm/s 10.0 mm/mV

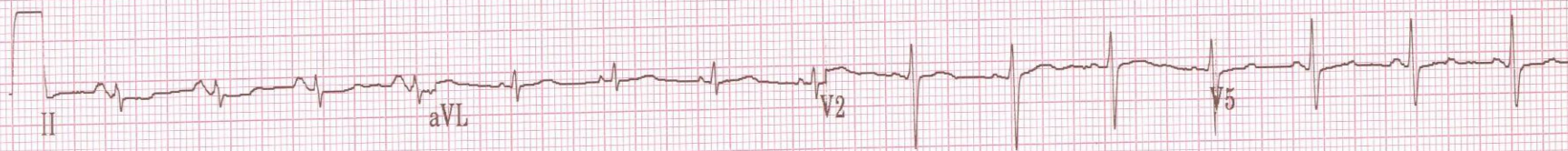
4 by 2.5s + 1 rhythm ld

MAC55 009A

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Low Voltage Complexes



ARRHYTHMIA HEART FAILURE ACADEMY

&

EMCURE Pharma

THANK YOU!

10th June, 2018

Dr. Ulhas M. Pandurangi

Chief – Cardiac Electrophysiology & Pacing

Arrhythmia Heart Failure Academy

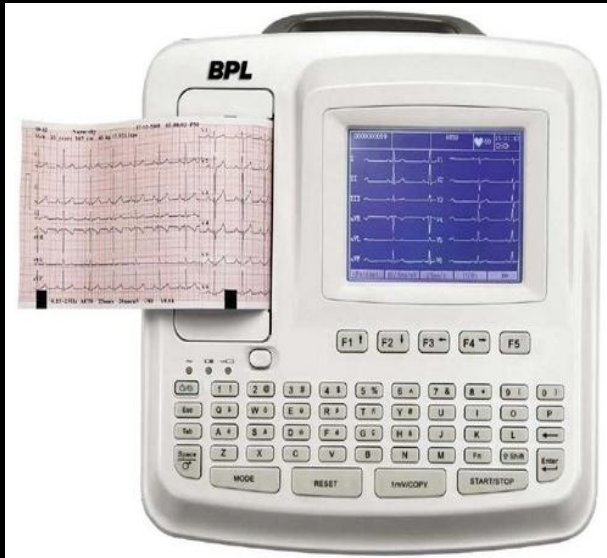
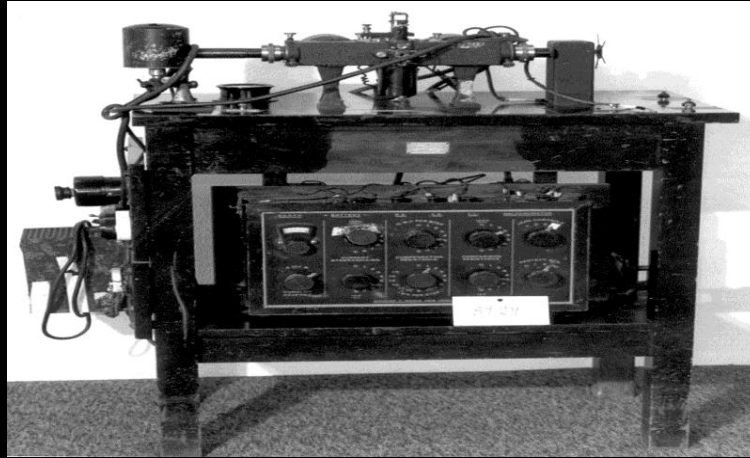
The Madras Medical Mission

ARRHYTHMIA HEART FAILURE ACADEMY
12TH ANNUAL CONFERENCE

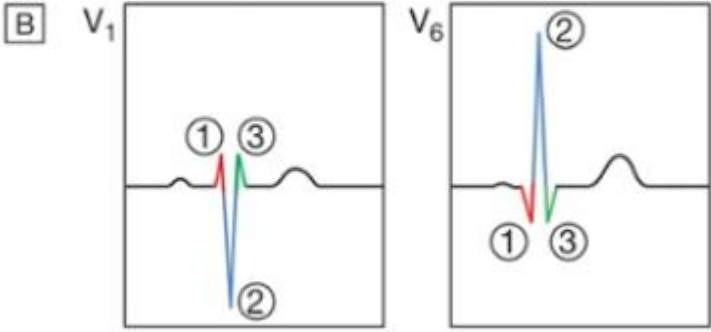
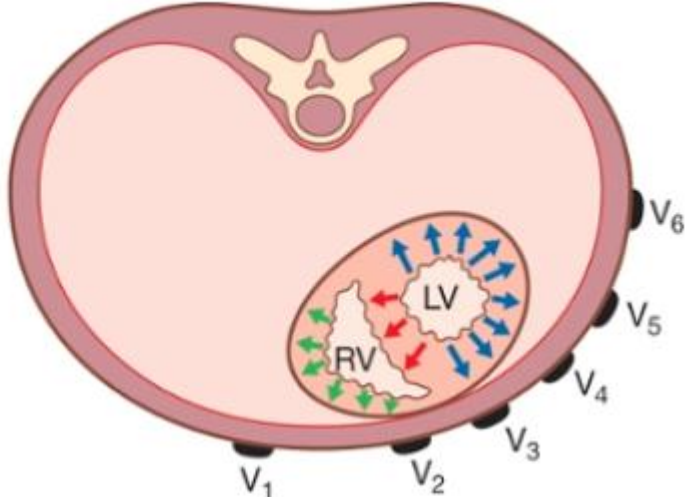
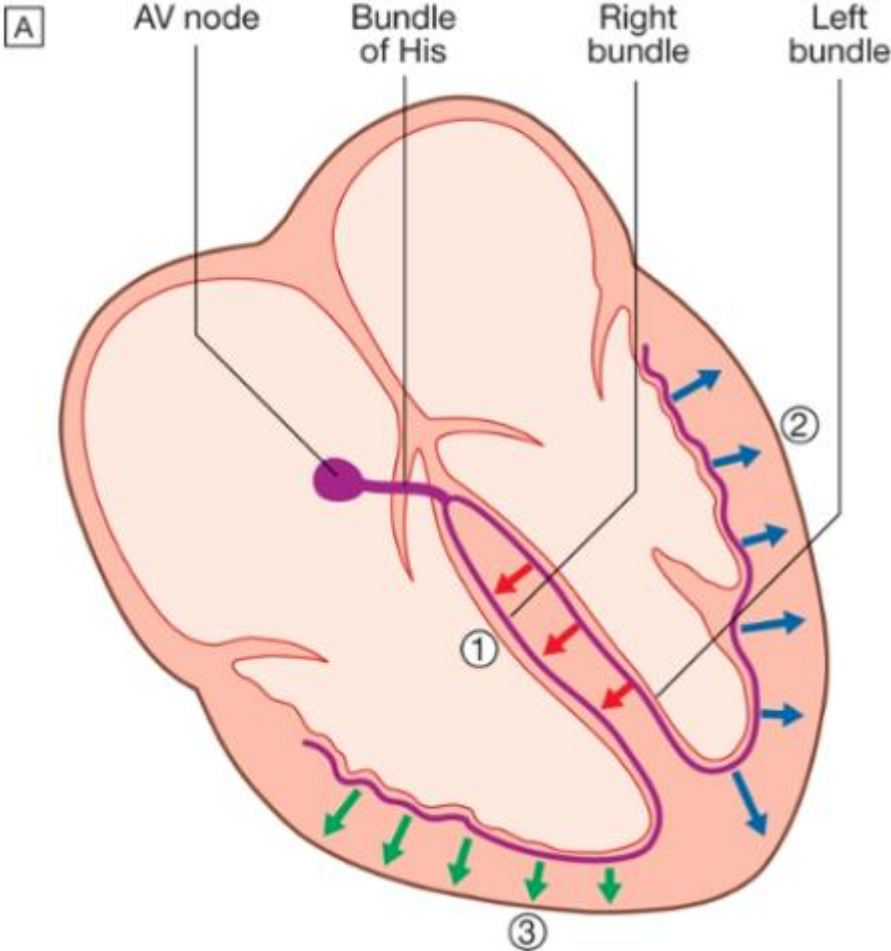
11th September 2016

THANK YOU



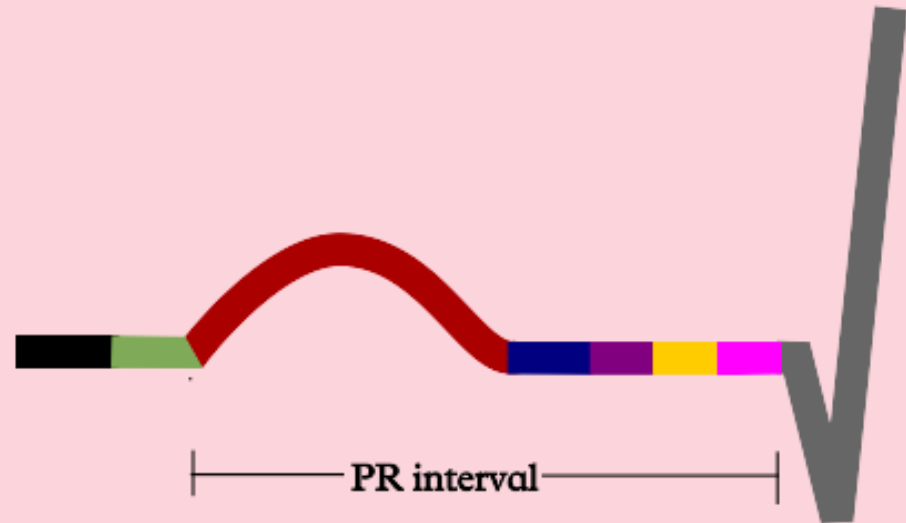


plane. **A.** Normal. **B.** Left axis...



'PR' Interval

- SA node
- Atria
- Atrioventricular (AV) node
- His bundle
- Bundle branches
- Purkinje fibers
- Ventricular myocardium

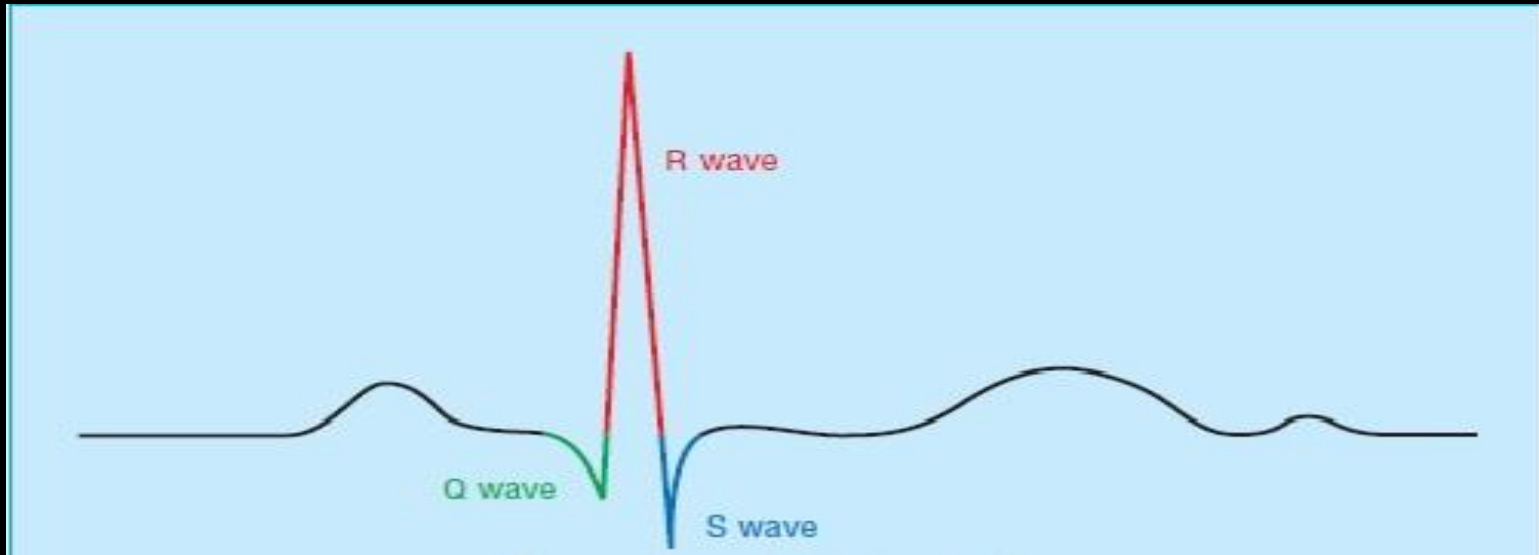


PR interval: Beginning of P to beginning of QRS (PQ or PR interval)

Time taken for the sinus impulse to activate the ventricular myocardium

120 – 200 ms

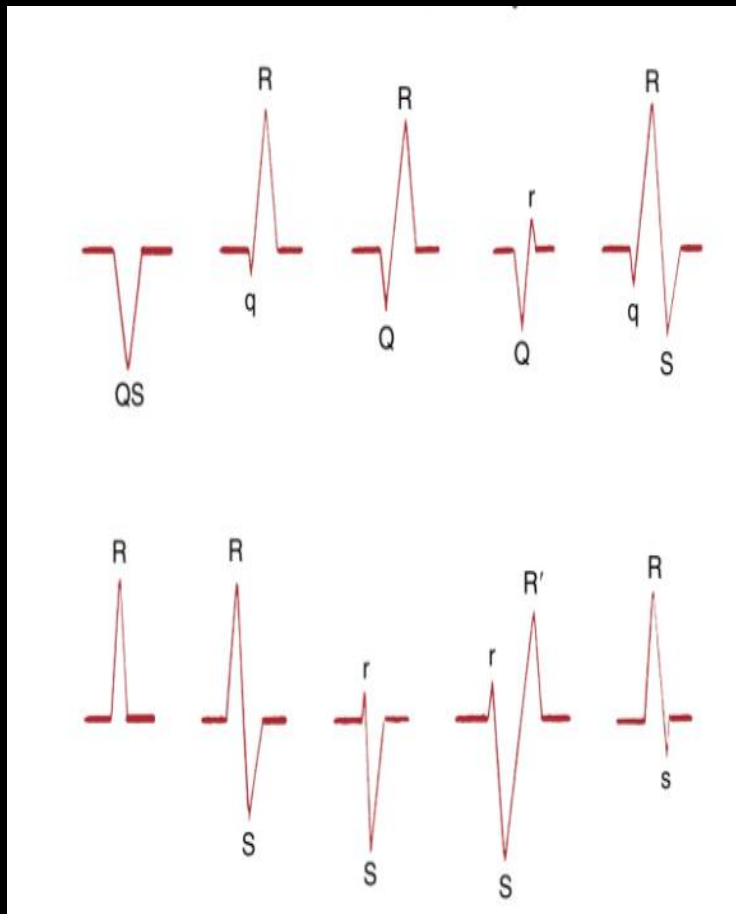
'QRS' Complexes



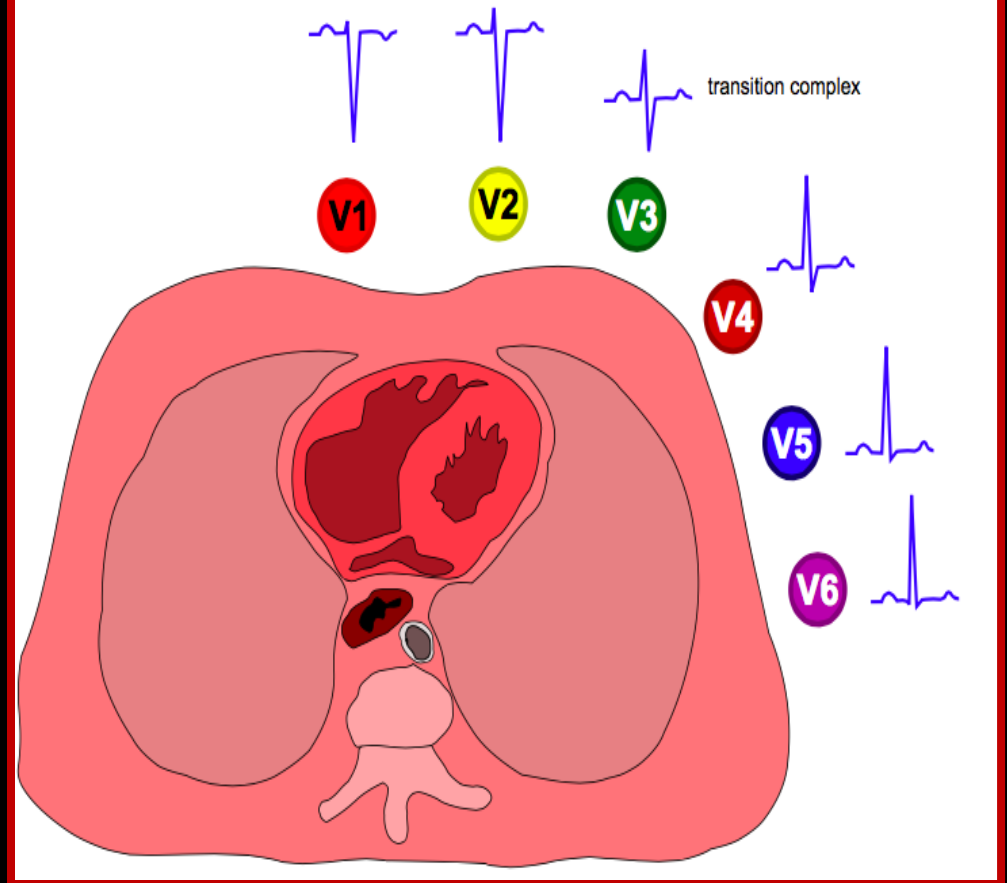
Ventricular Depolarization

80 – 120 ms

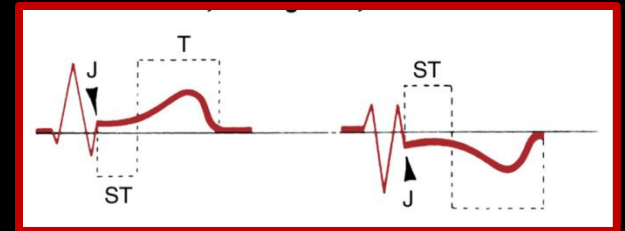
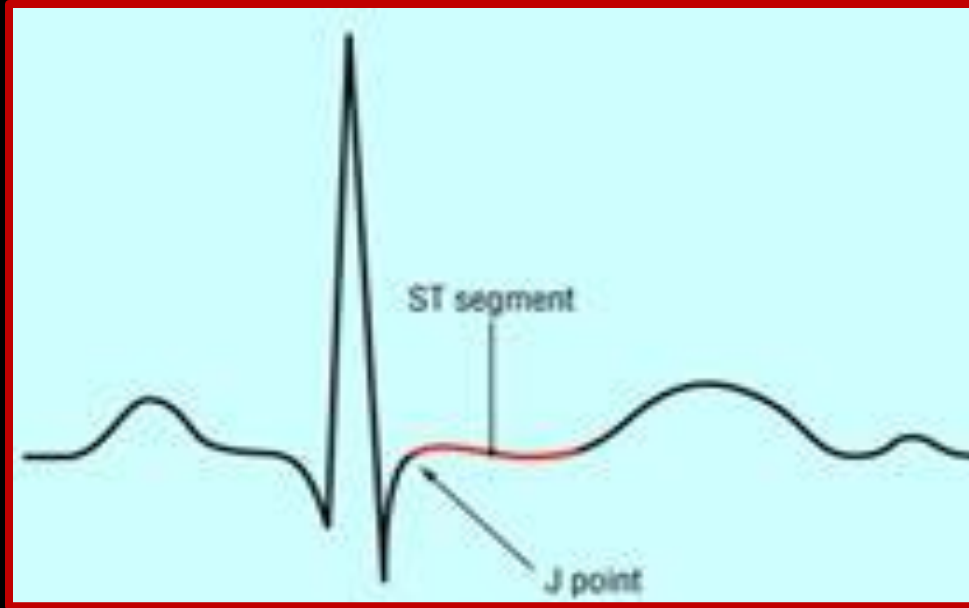
'QRS' Complexes



Normal R wave progression

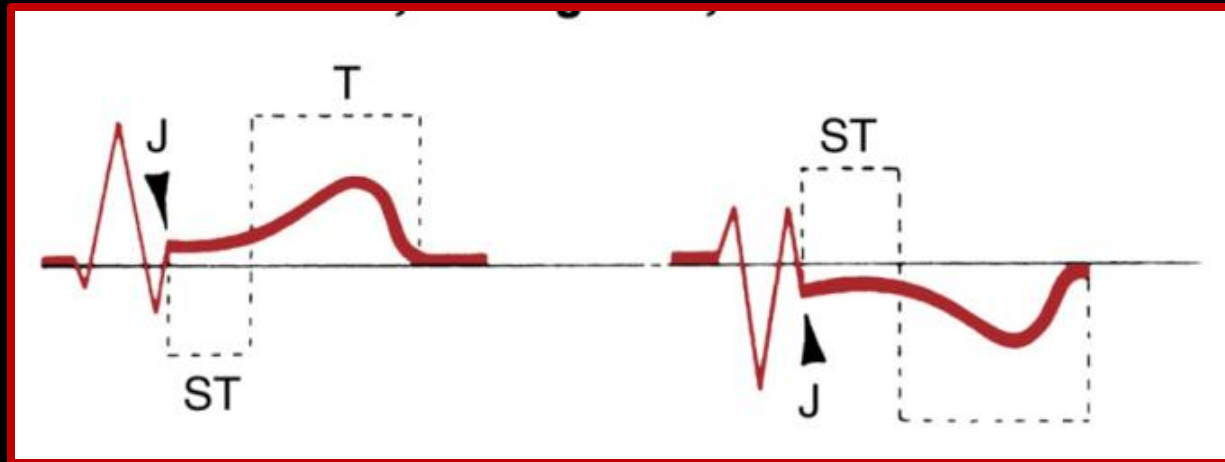


'J' point & 'ST' Segment

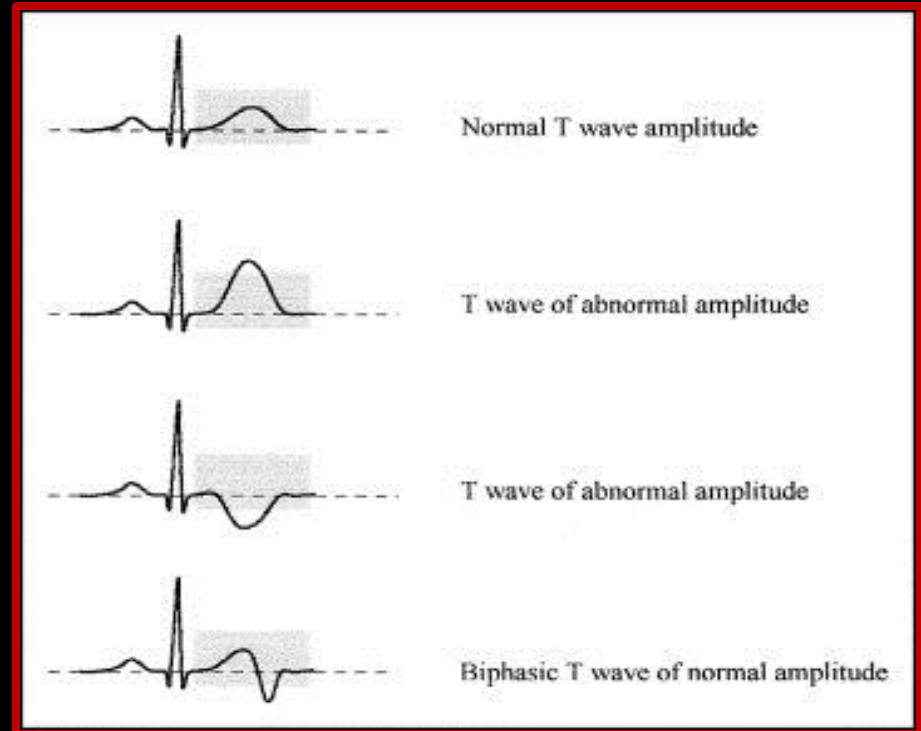
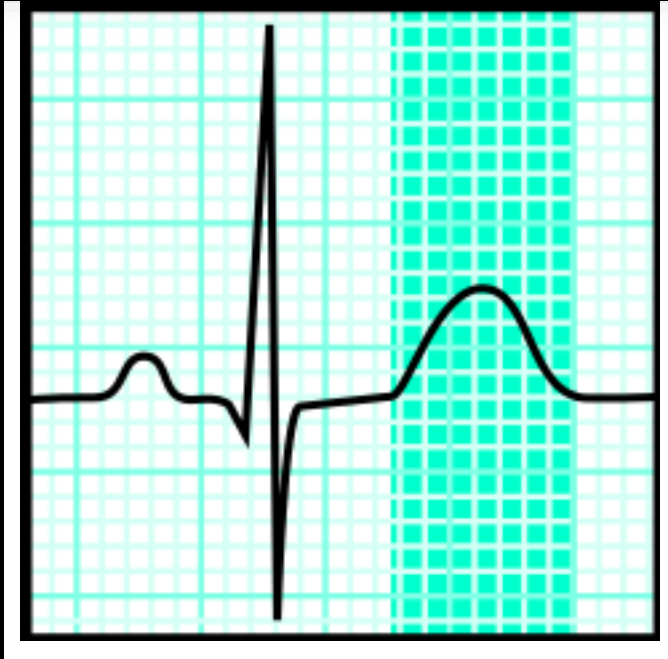


ST SEGMENT: *End of ventricular depolarisation to the beginning of repolarisation fairly flat, may slope upwards slightly before merging with the T wave*

'J' point & 'ST' Segment : *Elevation & Depression*



'T' Waves



T wave – Ventricular repolarization, polarity similar to QRS

2/3rd of amplitude of corresponding R wave

No widely accepted criteria regarding amplitude - rarely exceeds 10 mm



Normal



Biphasic



Bifid / notched



Broad / slow



Flat



Nonspecific ST-T wave abnormalities

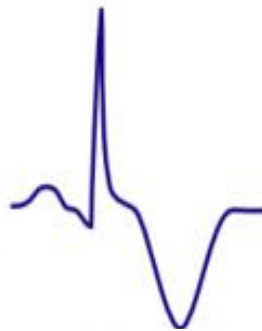
Tall & Peaked



Broad & Tall



**Symmetrical,
deeply inverted**



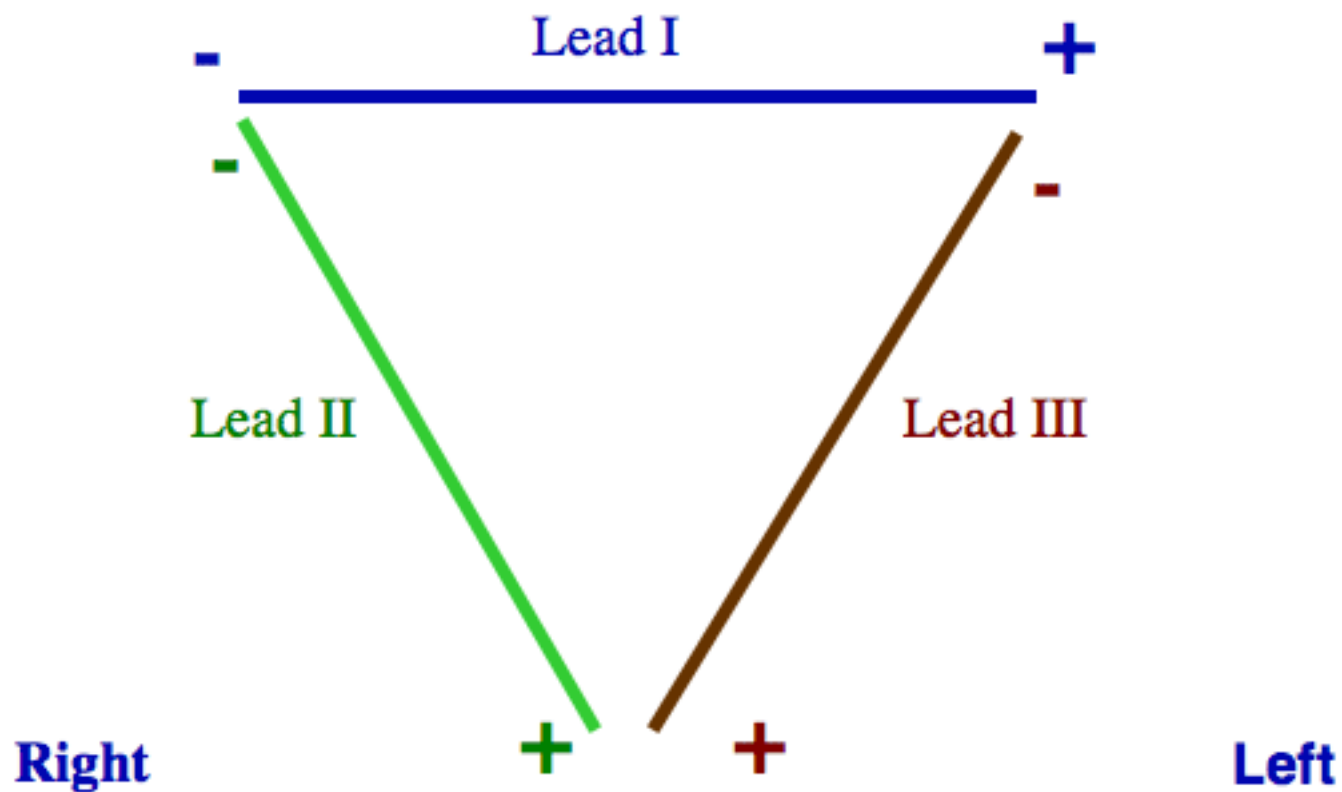
**Upright T wave
with ST depression**

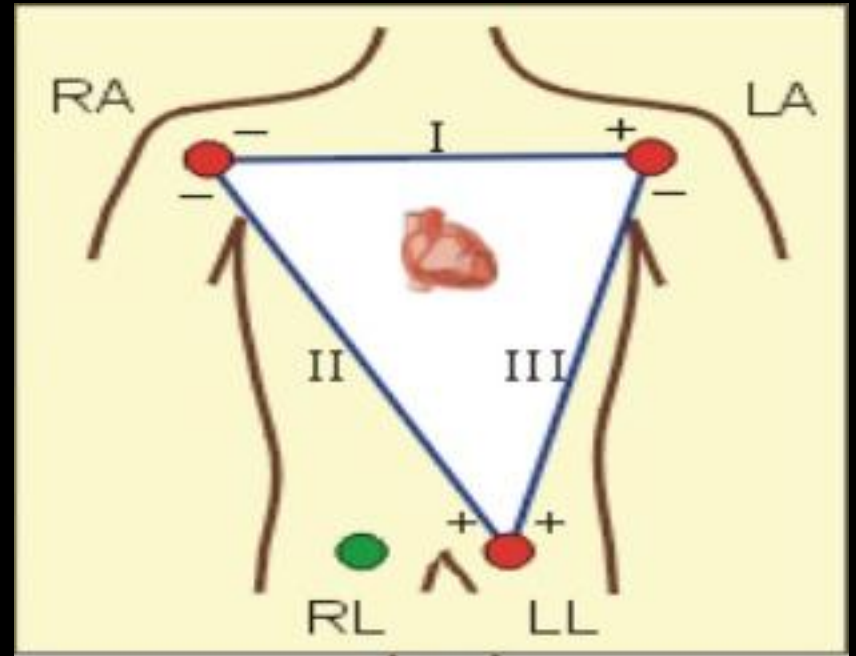


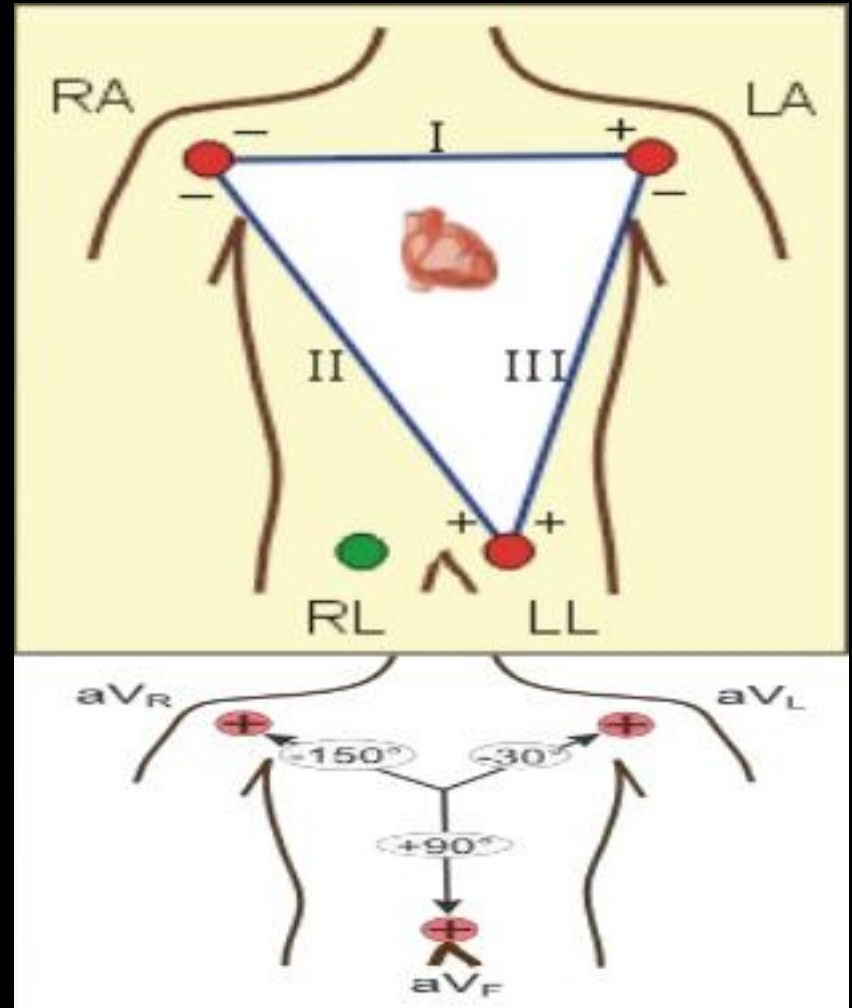
Broad with LQT

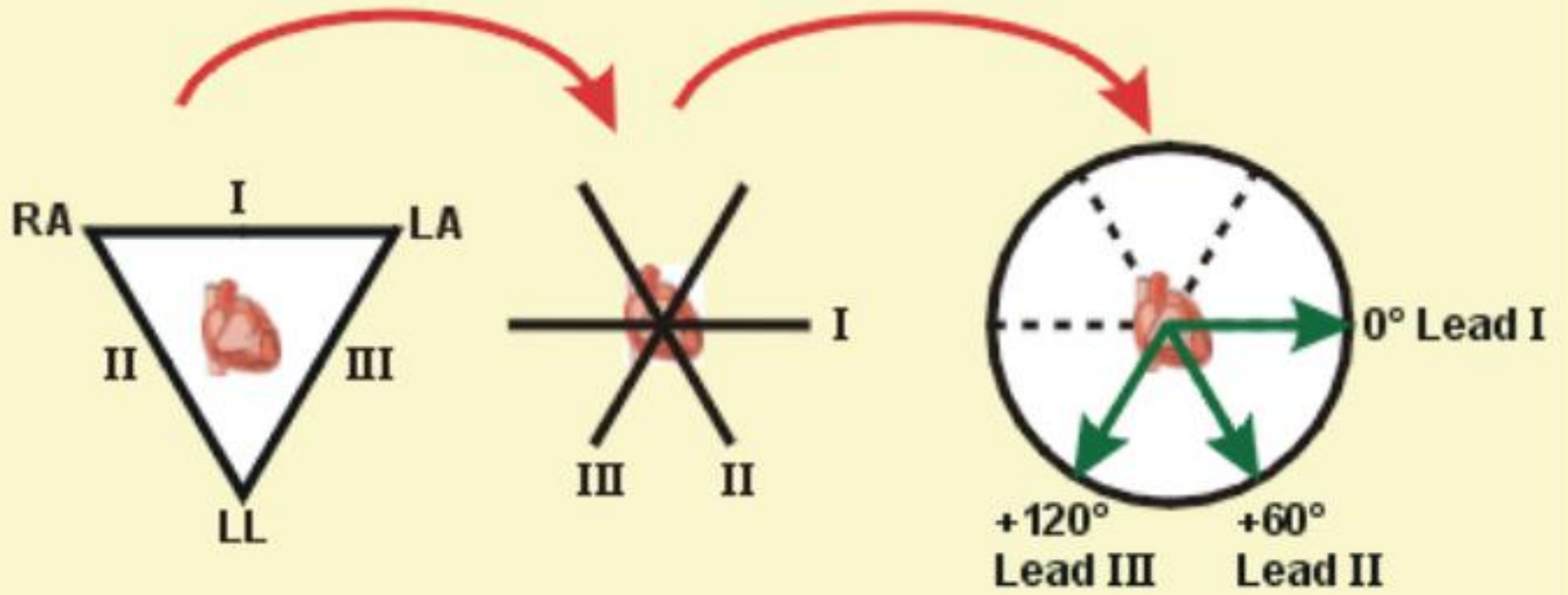


Einthoven's Triangle





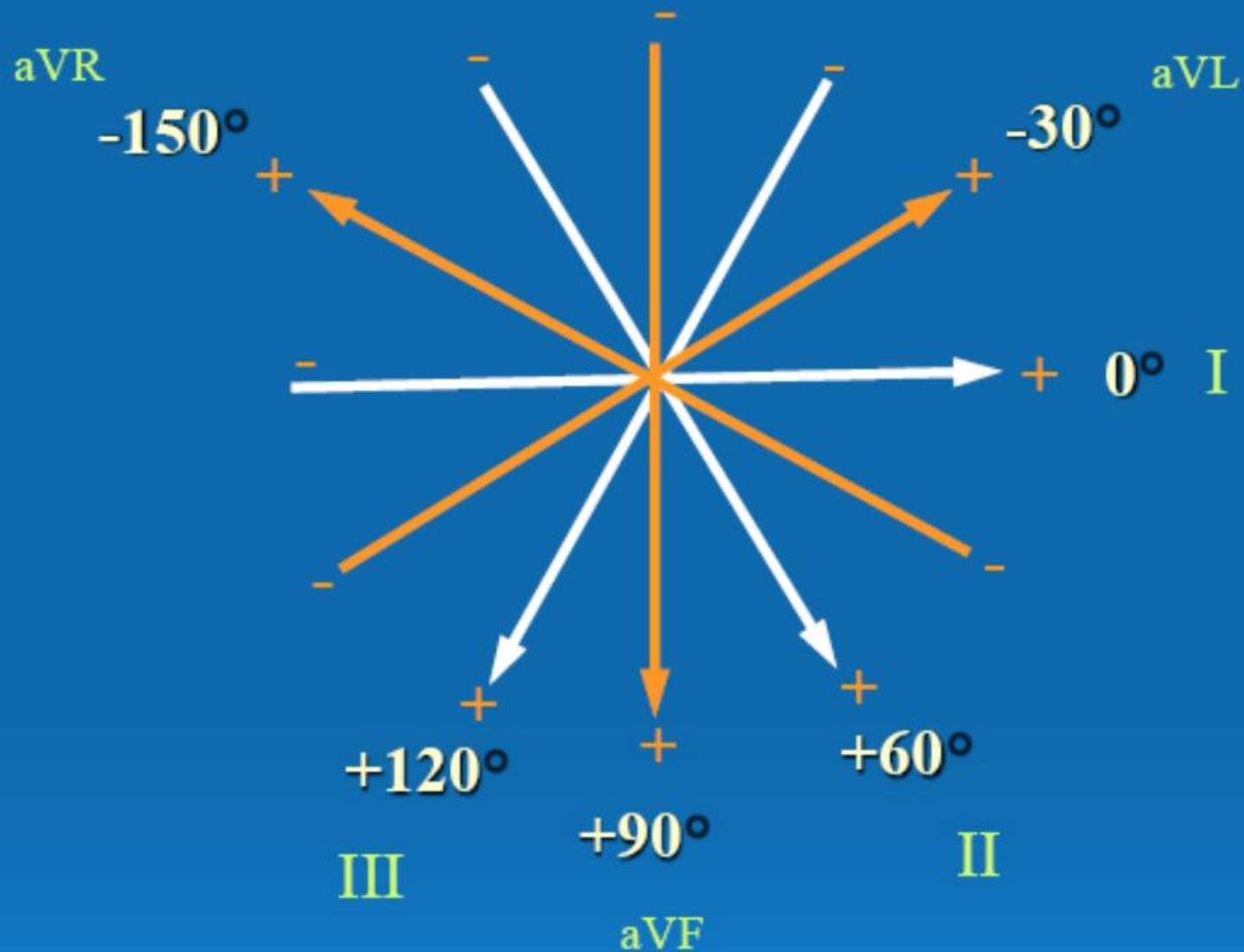




Einthoven's Triangle

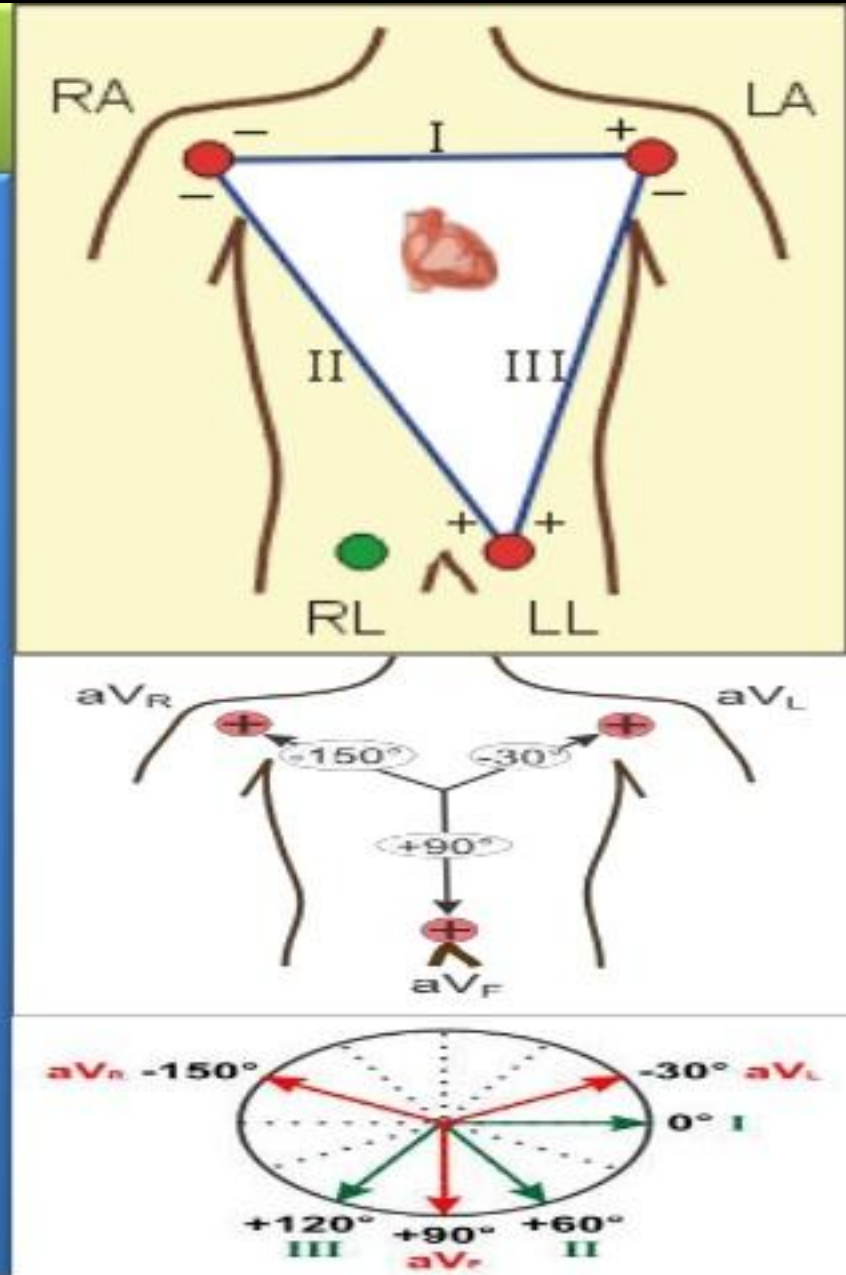
Axial Reference System

Hexagonal reference system



ECG Leads

- The 12 lead consist of:
 - Three Standard limb or bipolar leads (I, II, III) utilize three electrodes; these leads form a triangle known as Einthoven's Triangle.
 - Three Augmented unipolar leads (aV_R , aV_L , aV_F).
 - Six Precordial unipolar leads (V_1 , V_2 , V_3 , V_4 , V_5 , V_6).



Precordial lead placement

V1: 4th intercostal space (IS) adjacent to right sternal border

V2: 4th IS adjacent to left sternal border

V3: Halfway between V2 and V4

V4: 5th IS, midclavicular line

V5: horizontal to V4; anterior axillary line

V6: horizontal to V4-5; midaxillary line

(Note: in women with large breasts, V4-6 leads should be placed ***under the breast surface*** as close to the 5th IS as possible)

P wave: *sequential* depolarization of the right and left atria

QRS complex: right and left ventricular depolarization

ST-T wave: ventricular repolarization

U wave: an electrical-mechanical event at beginning of diastole

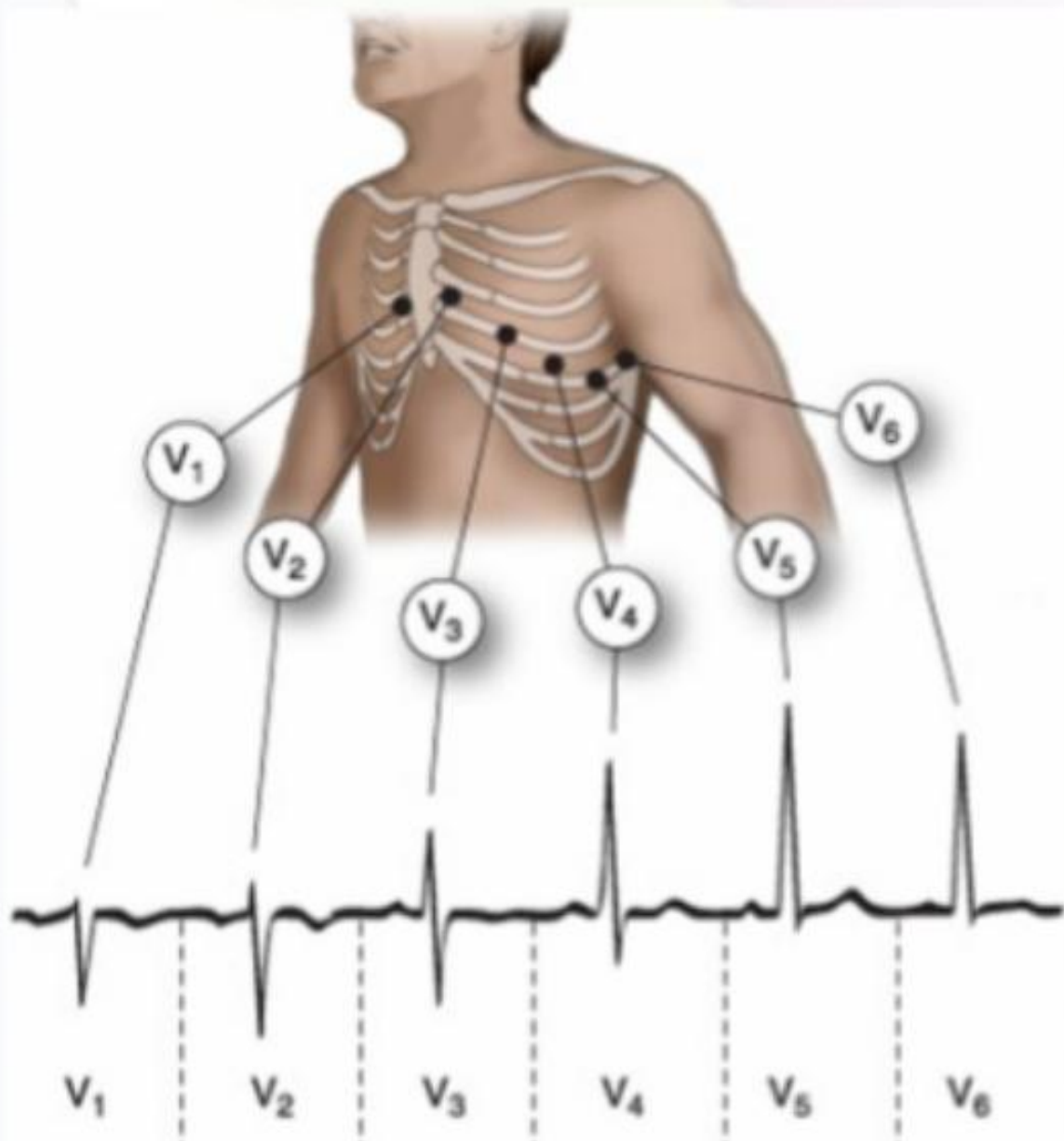
PR interval: time interval from onset of atrial depolarization (P wave) to onset of ventricular muscle depolarization (QRS complex)

QRS duration: duration of ventricular muscle depolarization (width of the QRS complex)

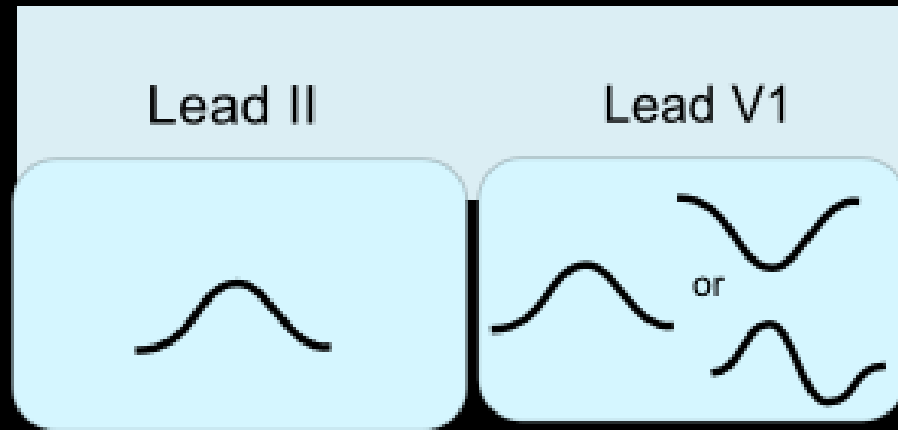
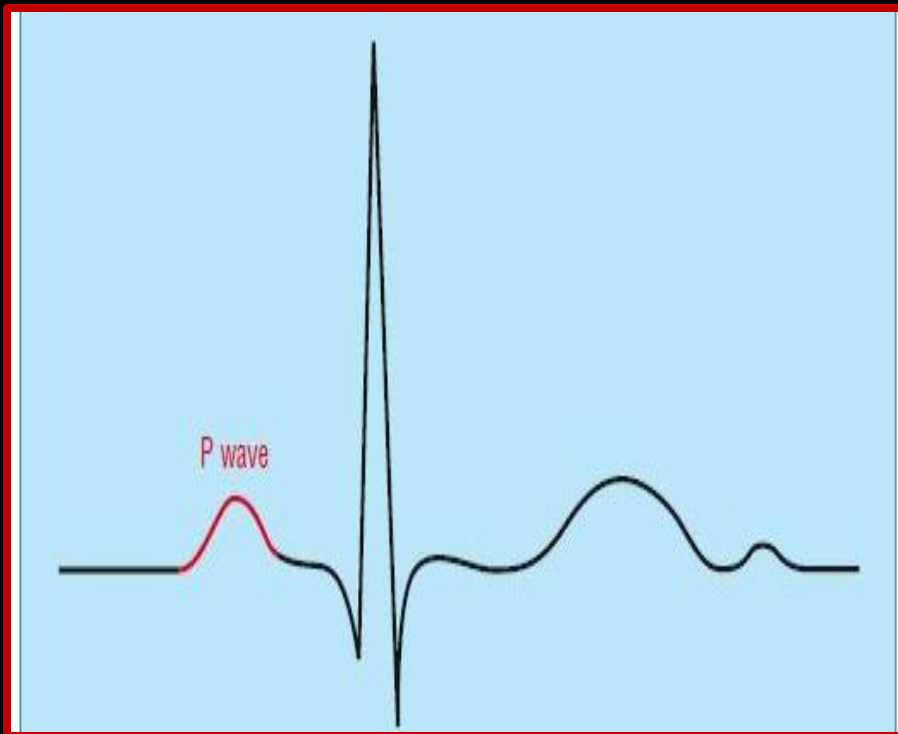
QT interval: duration of ventricular depolarization and repolarization

PP interval: rate of atrial or sinus cycle

RR interval: rate of ventricular cycle



'P' Wave

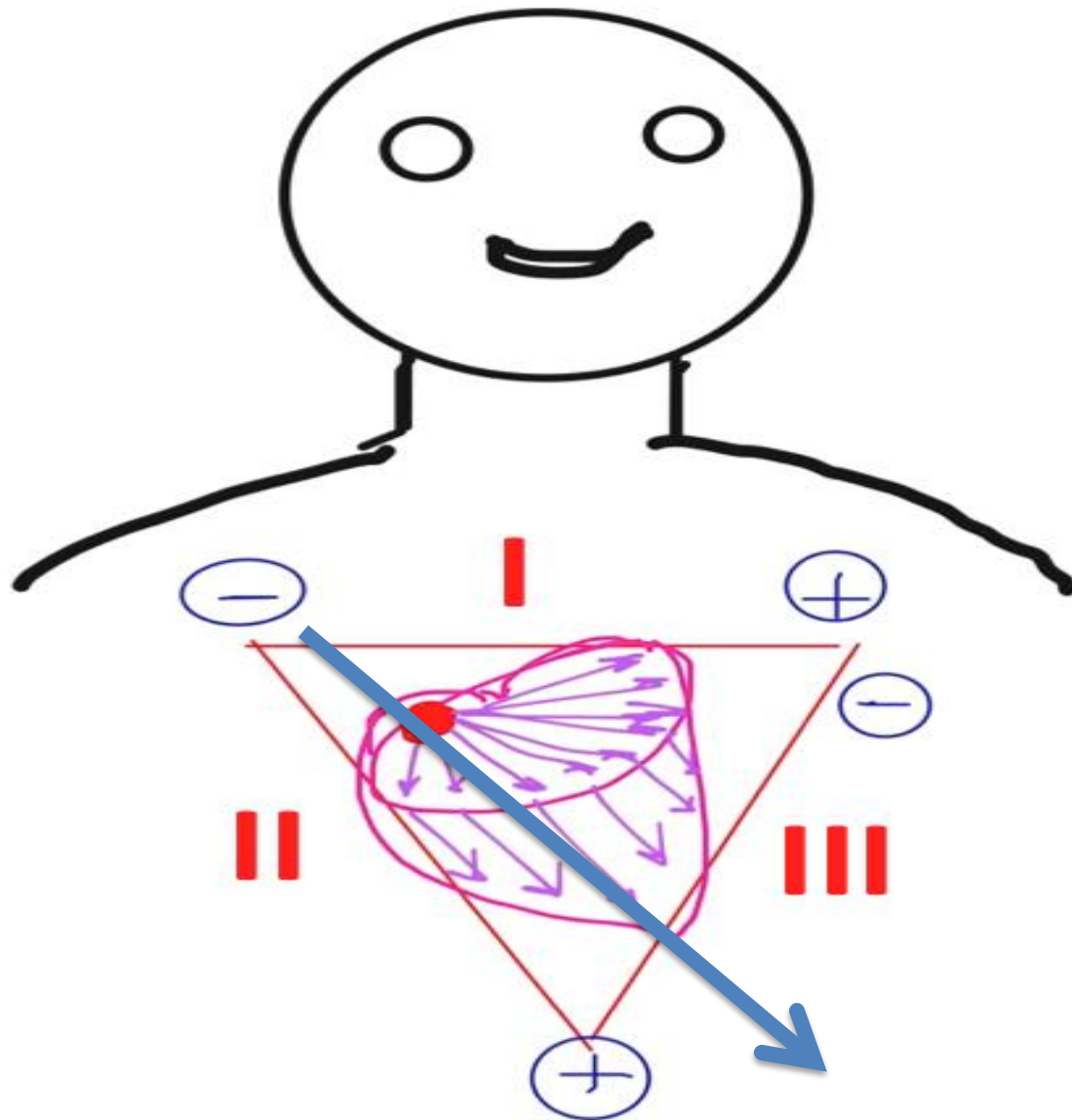


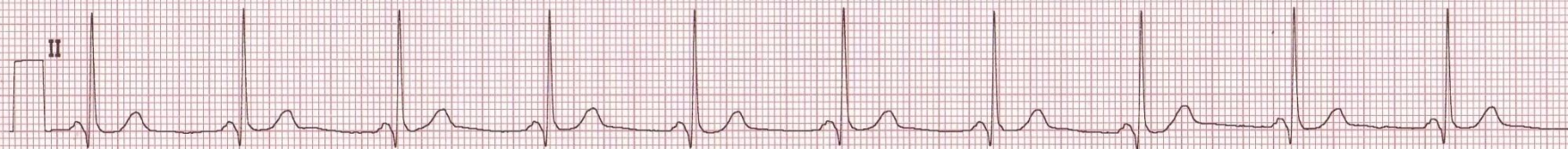
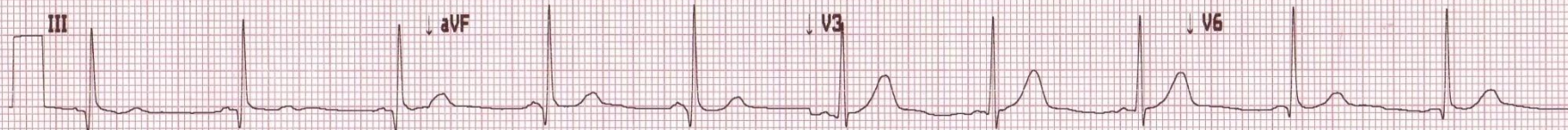
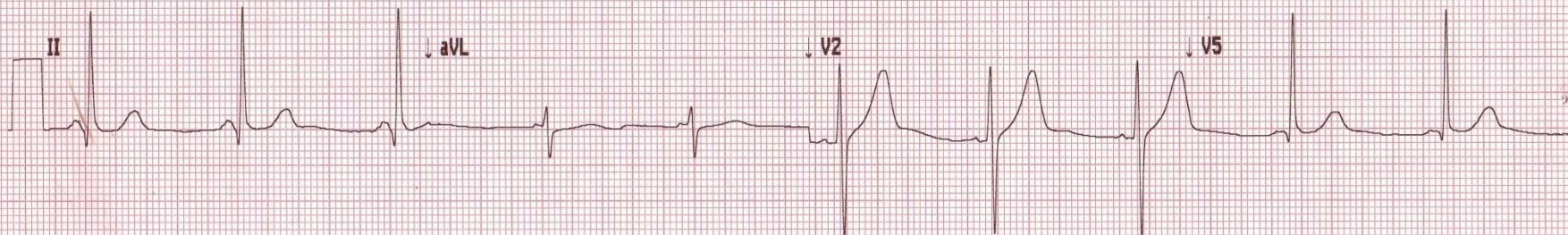
Atrial depolarization

Maximal height = 2.5 mm (leads II /III)

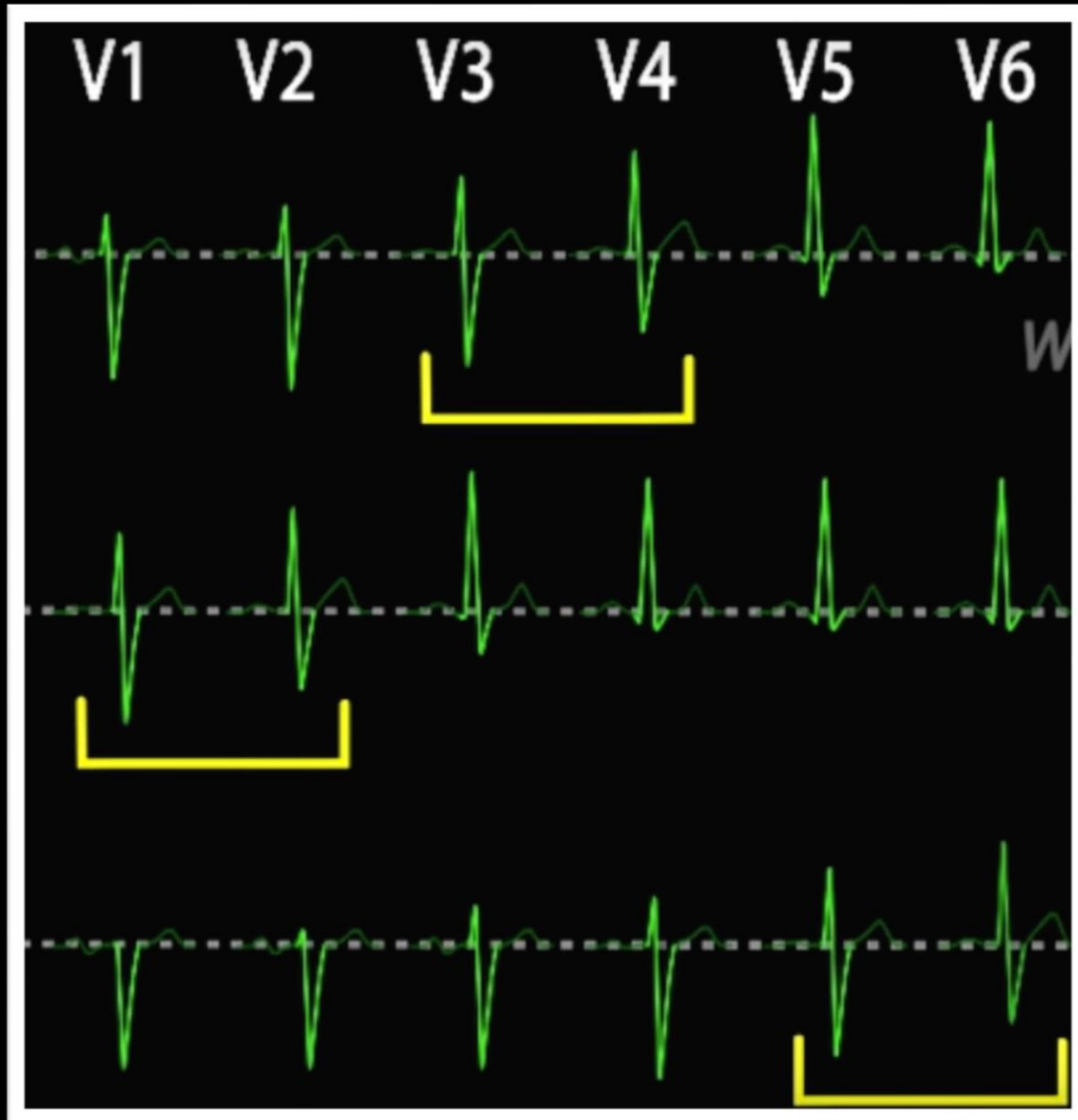
Duration < 0.12 seconds

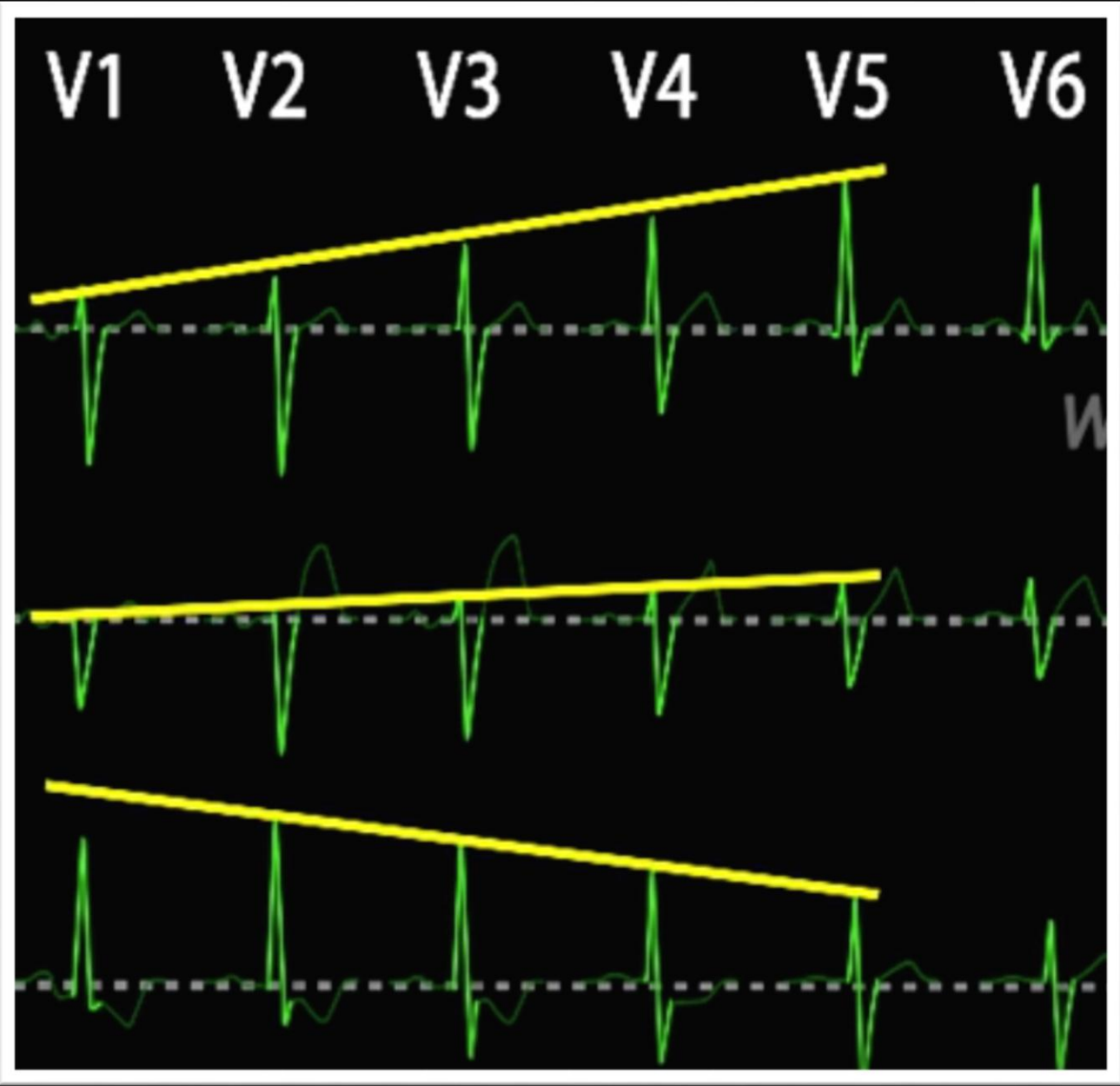
Positive in II and AVF, and biphasic in V1

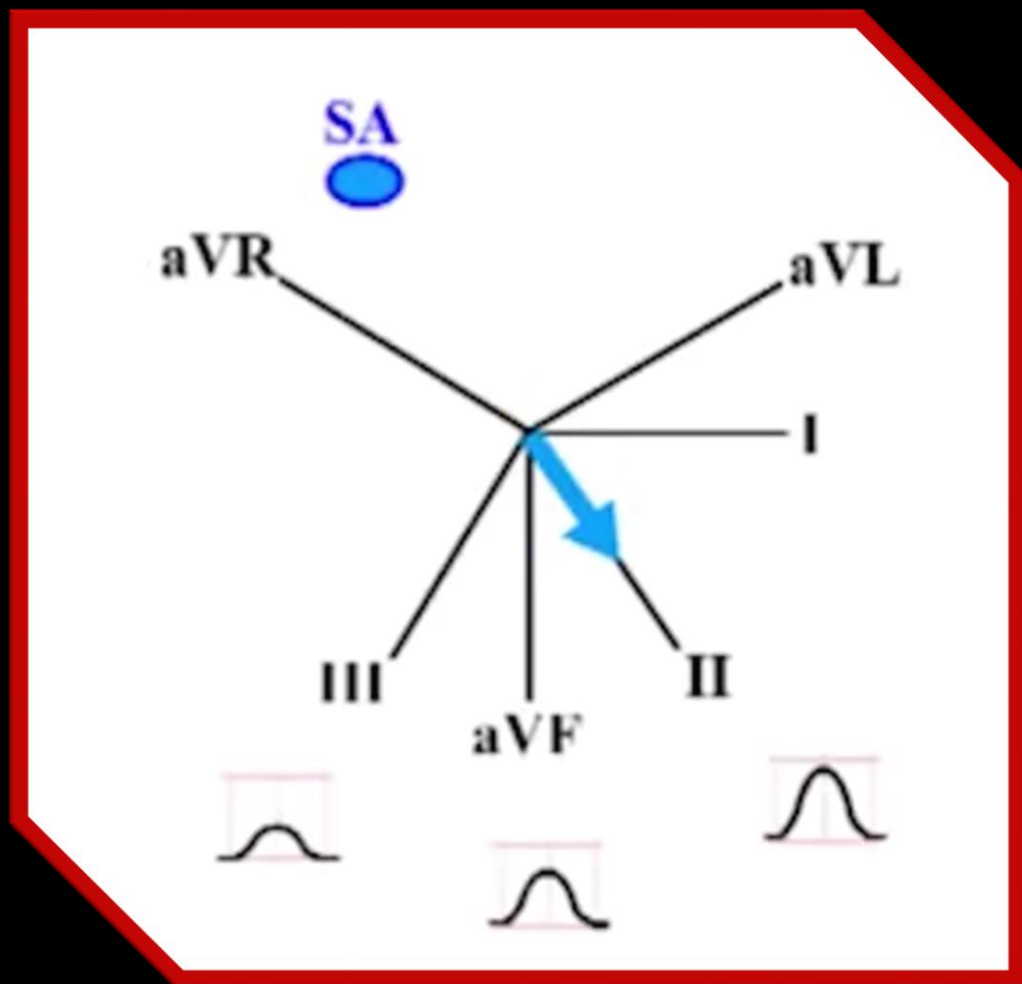




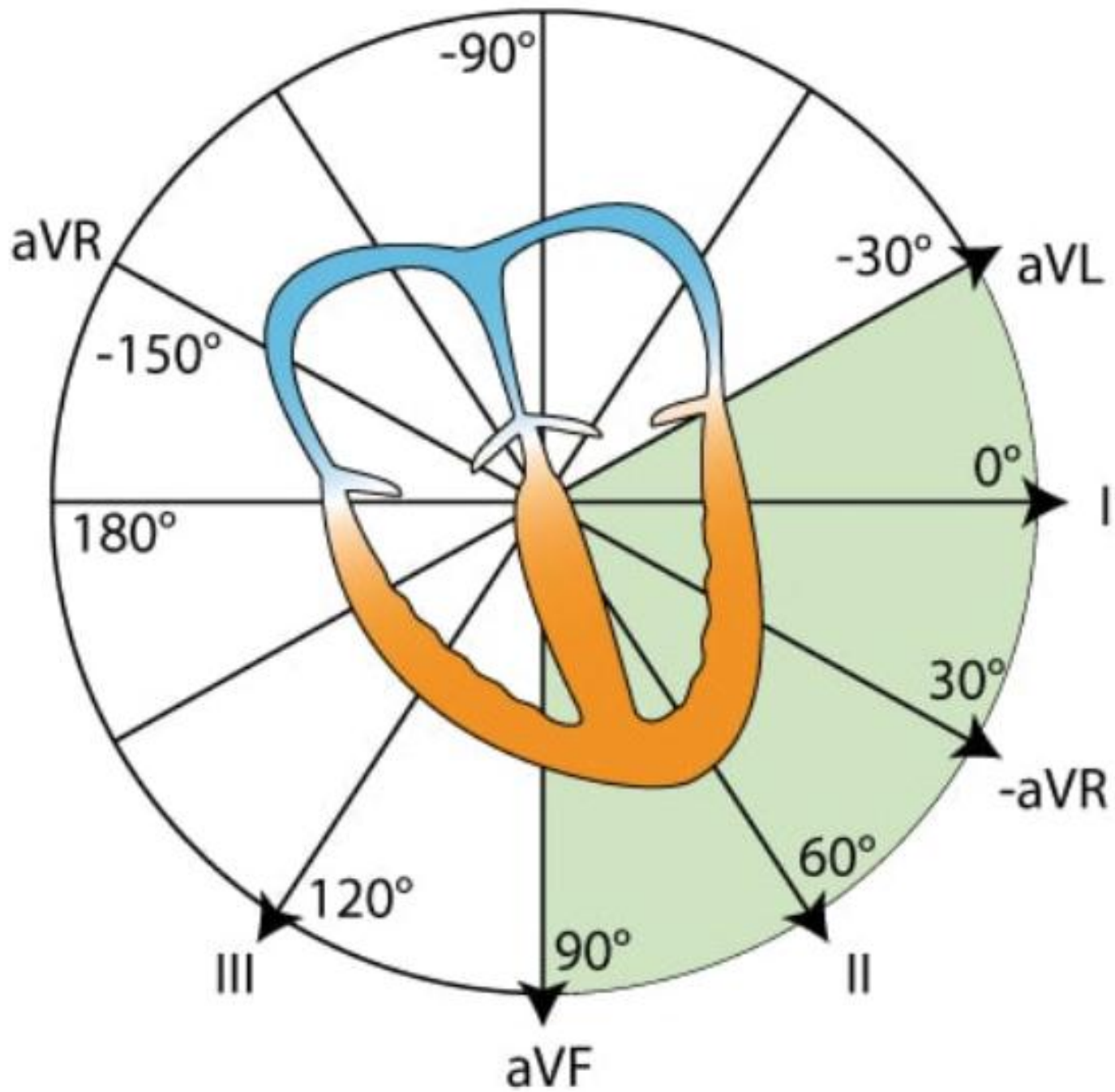
R wave progression : Chest Leads (Transition)

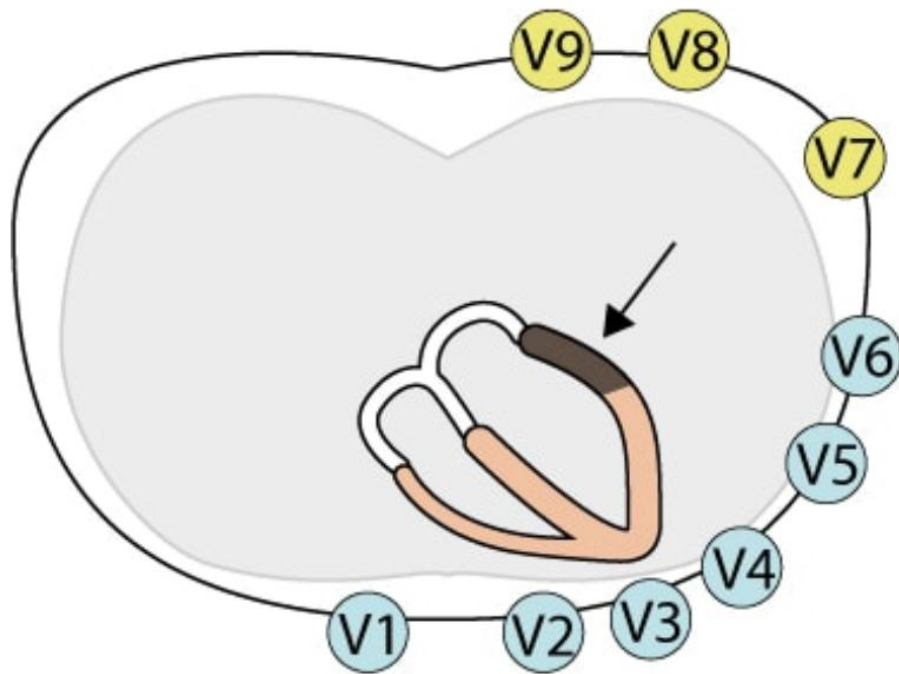




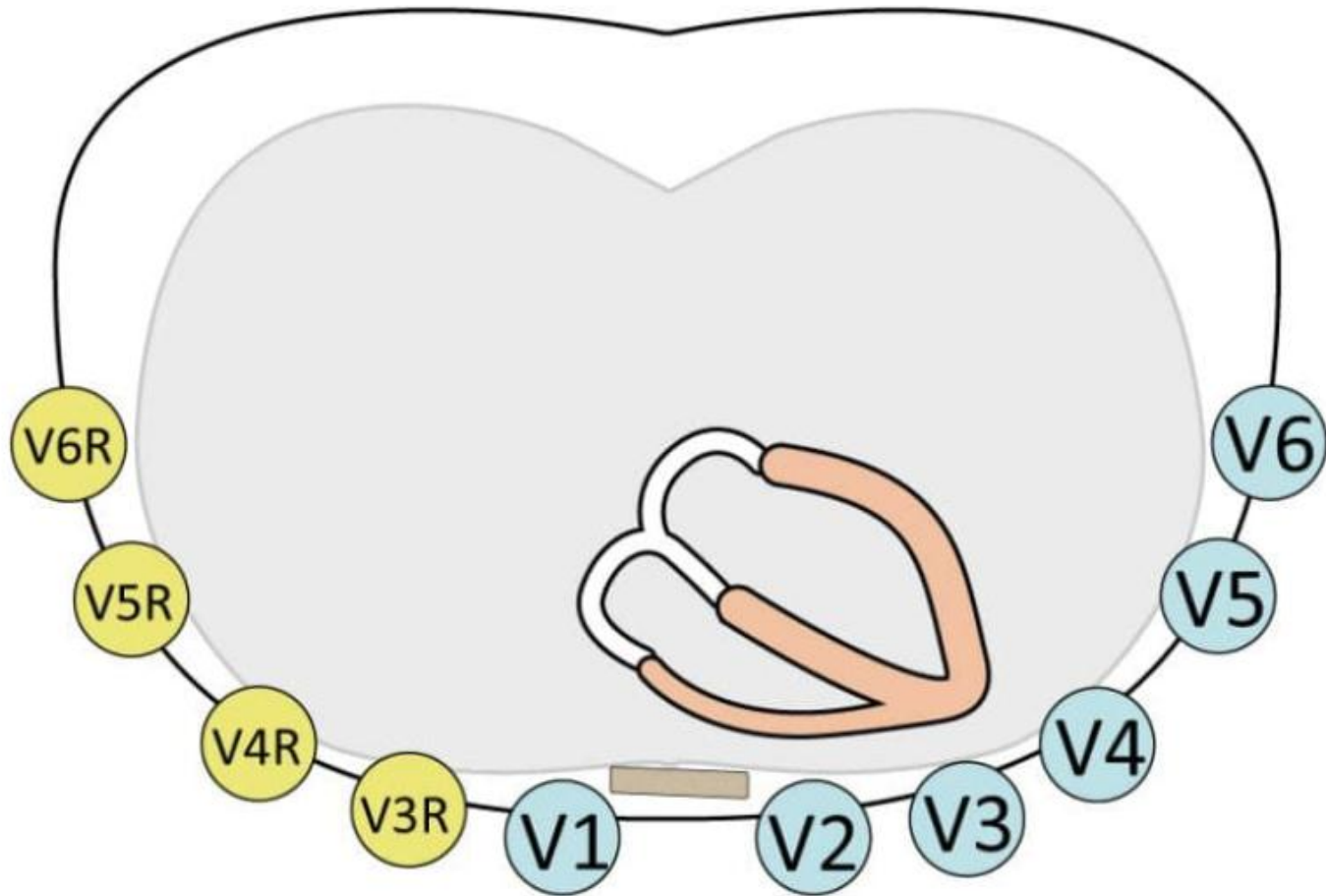




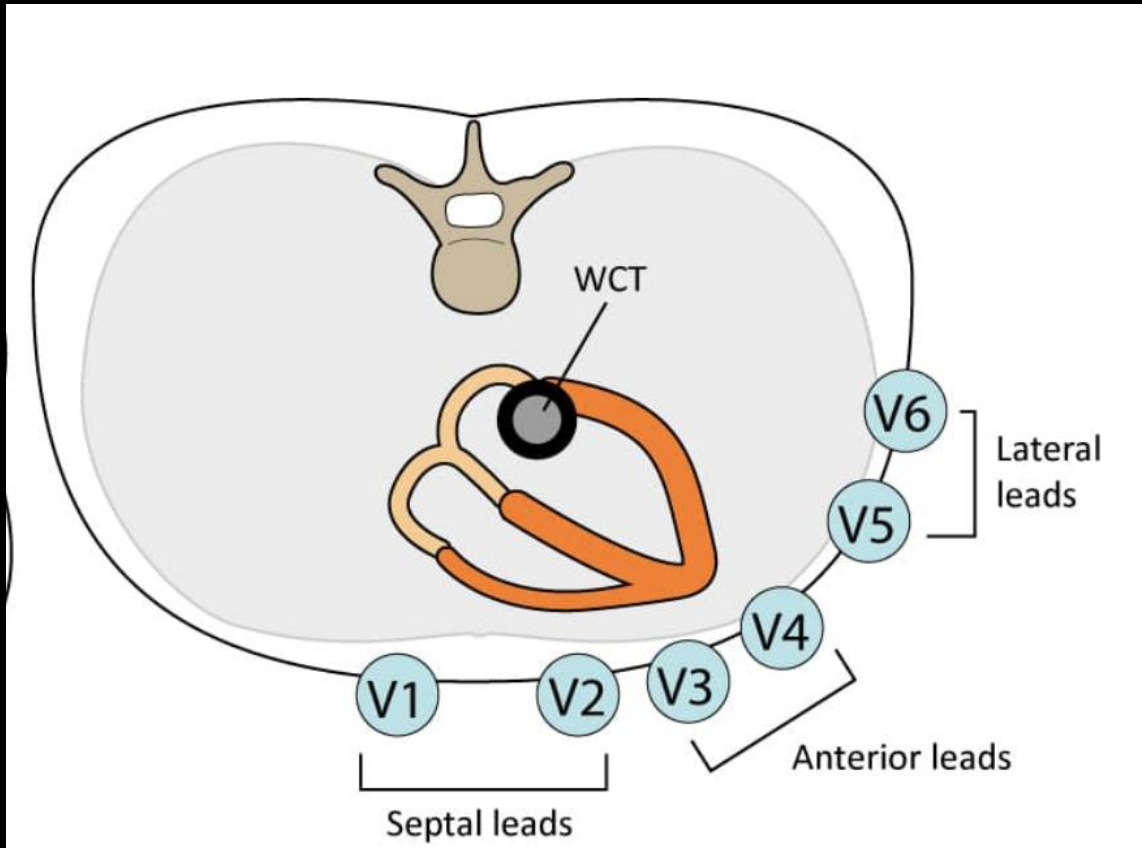




Transmurular ischemia in basal parts of the left ventricle's lateral wall (arrow) is not detected by leads V1–V6, which is why V7–V9 is placed on the back. V7–V9 detects ischemia located there. Note that this part of the left ventricle is also referred to as the *posterolateral wall* or the *inferobasal wall*.



Additional leads are used when suspicion of right ventricular infarction arises. These right sided chest leads (V3R through V6R) are placed on the same locations as their left sided equivalences, but on the right side of the chest.

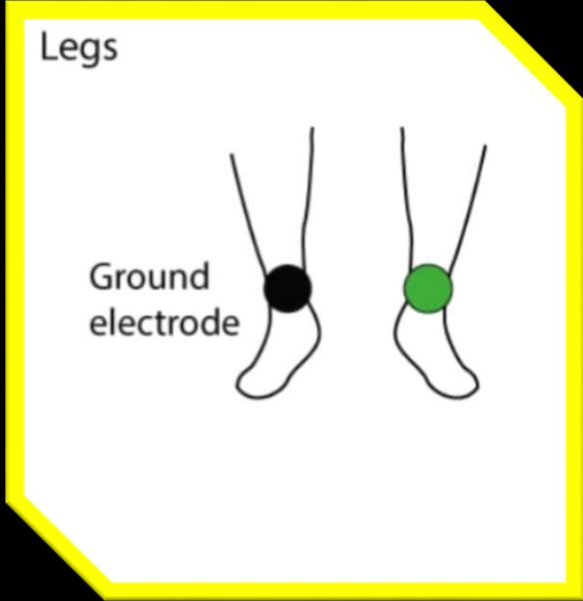
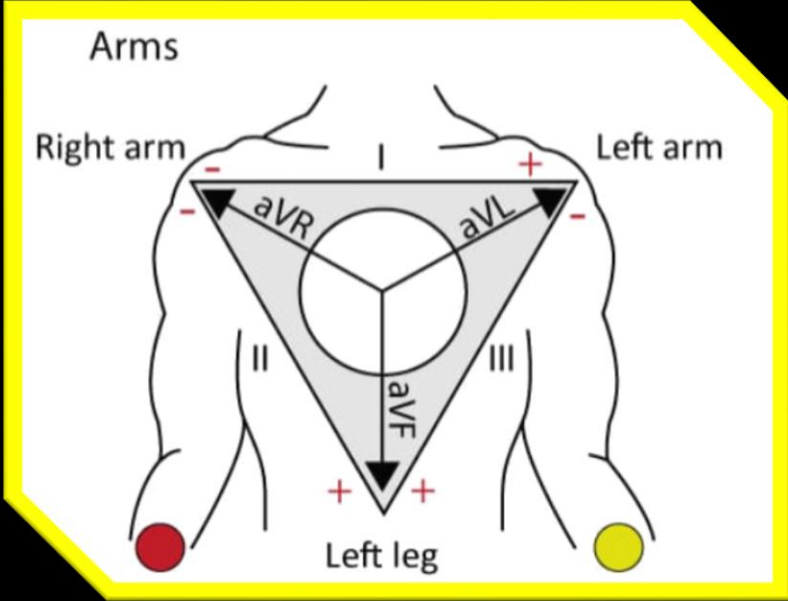


Placement of chest (precordial) electrodes

- V1: fourth intercostal space, to the right of sternum.
- V2: fourth intercostal space, to the left of sternum.
- V3: placed diagonally between V2 and V4.
- V4: between rib 5 and 6 in the midclavicular line.
- V5: placed on the same level as V4, but in the anterior axillary line.
- V6: placed on the same level as V4 and V5, but in the midaxillary line.

Einthoven Triangle

Einthoven Triangle



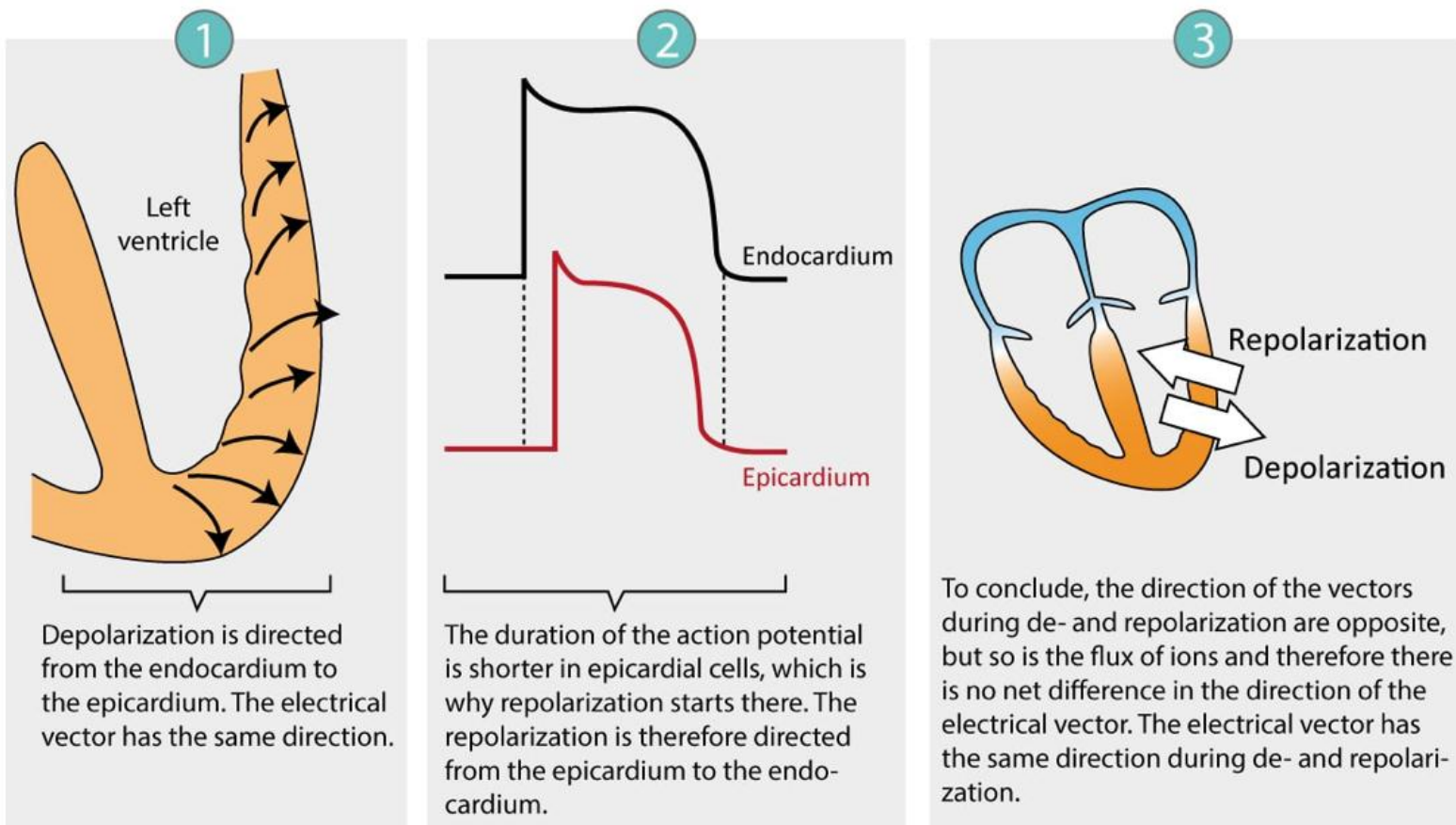
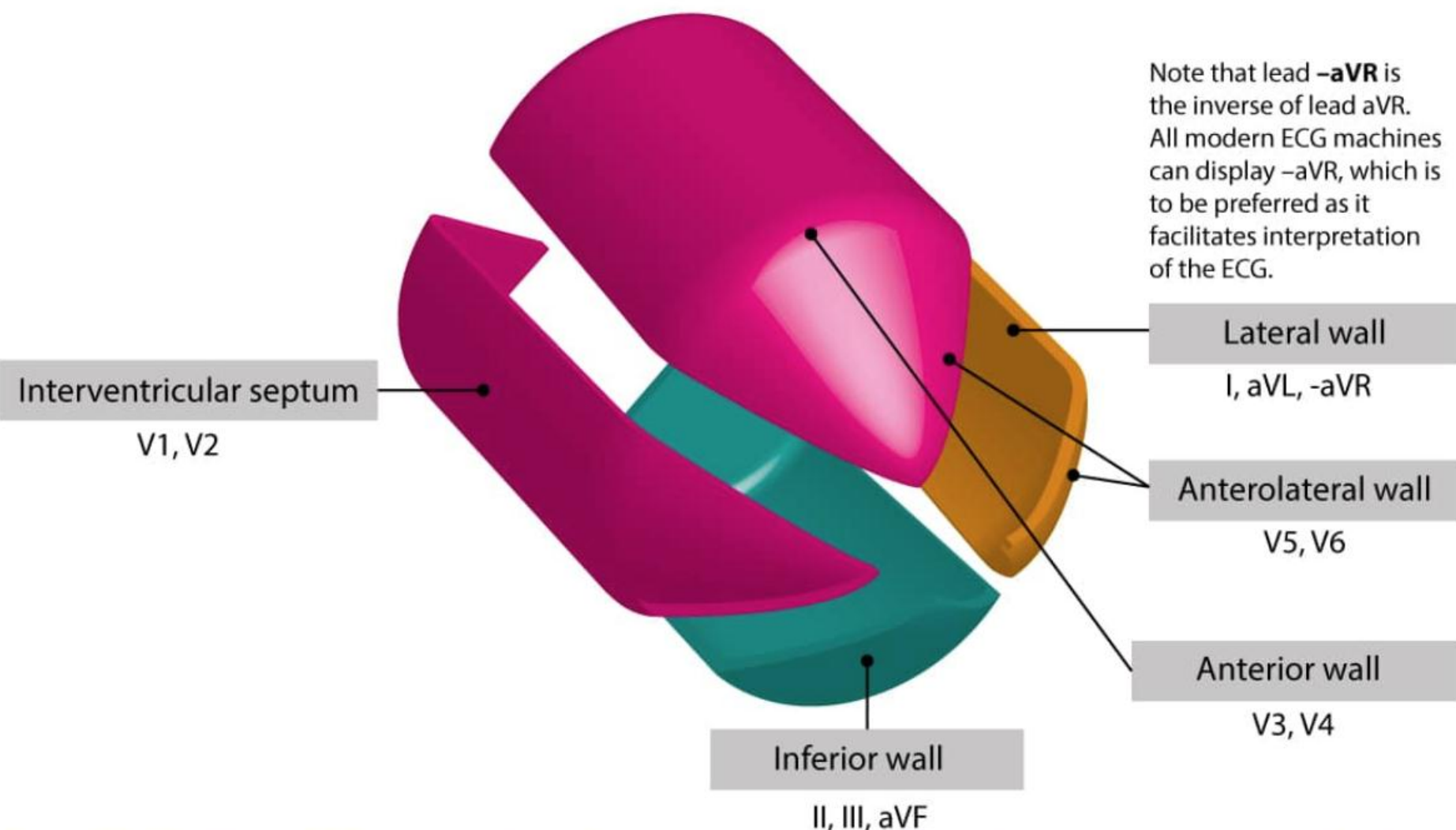


Figure 15. The vector of the T-wave. The reason why the T-wave is concordant with the QRS complex is explained.

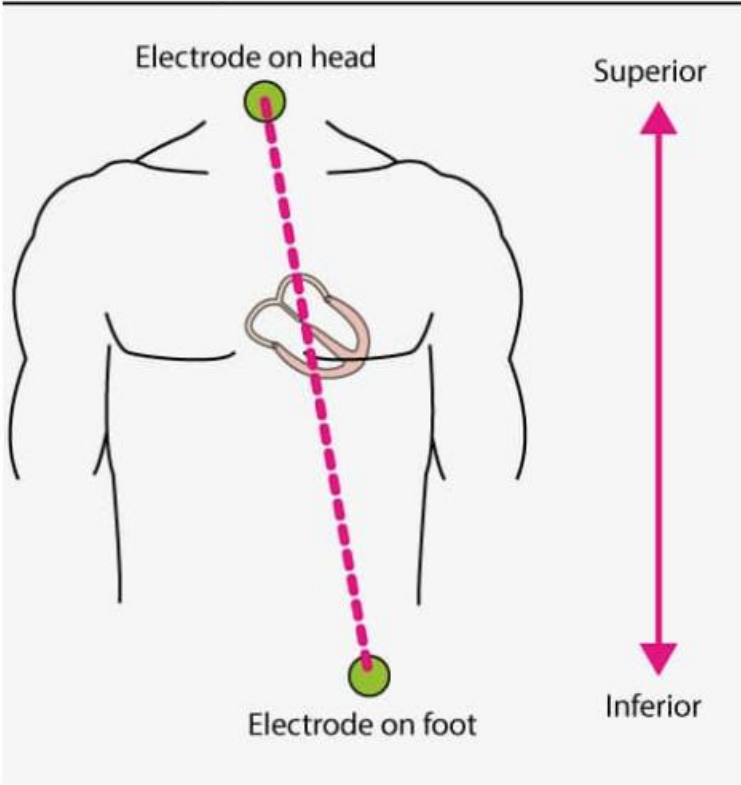
The four walls of the left ventricle and the ECG leads that "view" these walls



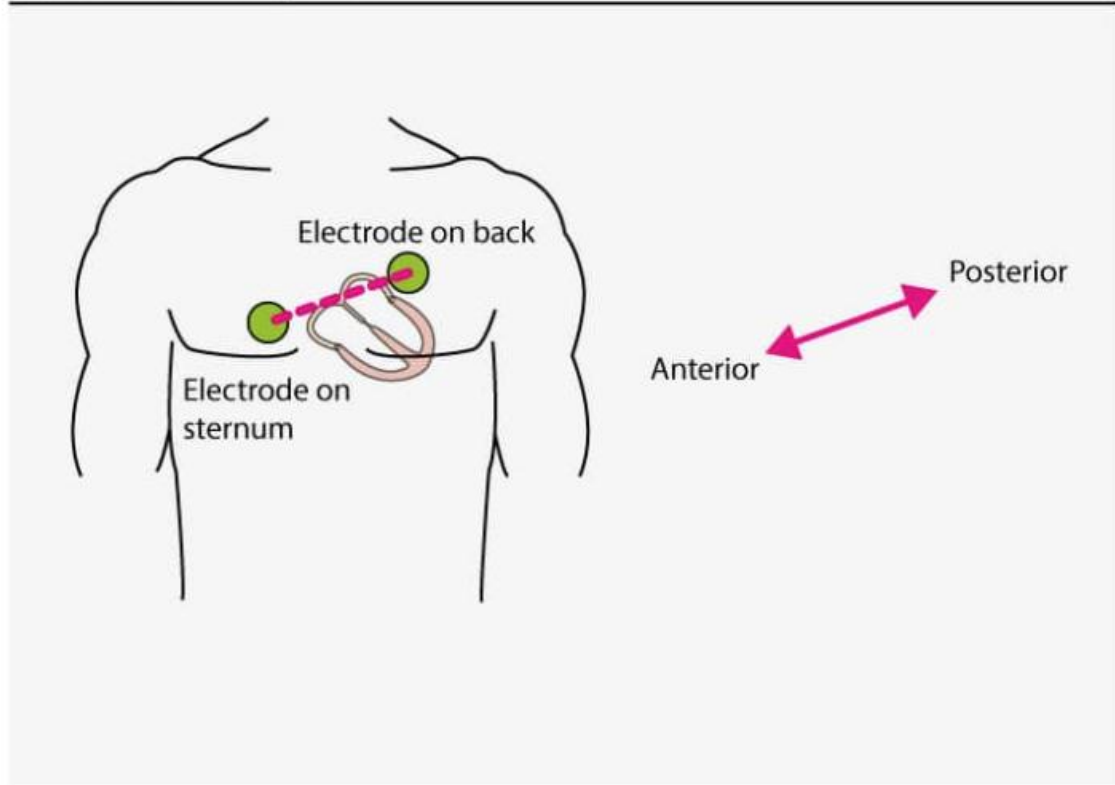
Note that lead **-aVR** is the inverse of lead aVR. All modern ECG machines can display -aVR, which is to be preferred as it facilitates interpretation of the ECG.

Figure 20. The 12-lead ECG records information on electrical activity of the left ventricle (and not so much of the right ventricle). As seen in the figure above the left ventricle has the shape of a bullet. The left ventricle is traditionally divided into four walls, and the figure above shows which leads that best observe electrical activity of each wall.

(A) Frontal plane



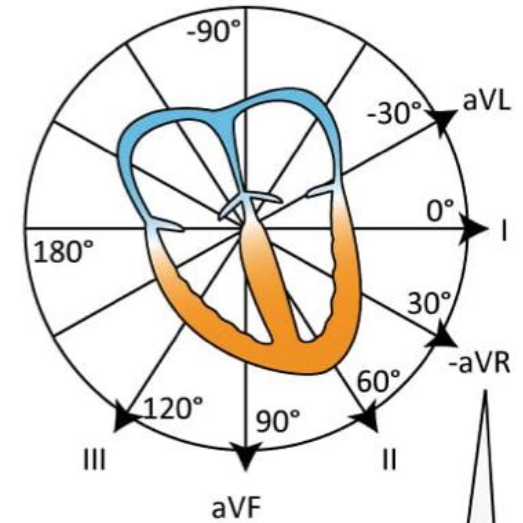
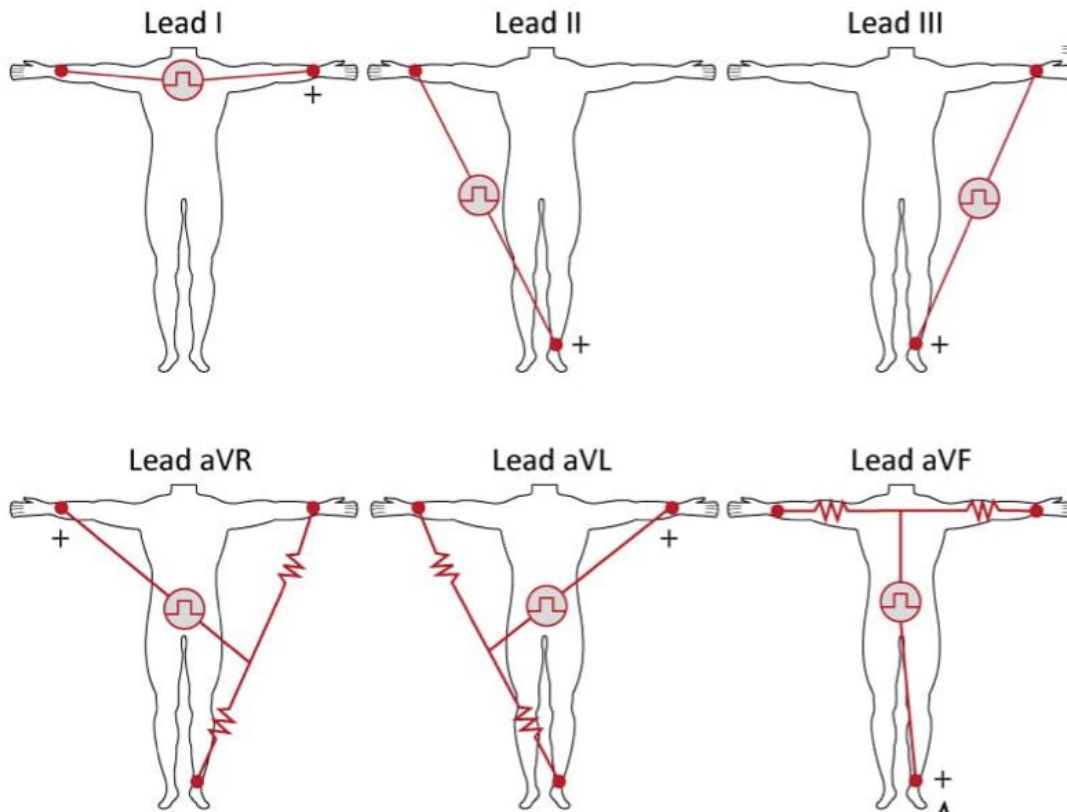
(B) Horizontal plane



The J point and the ST segment

The **ST segment** corresponds to the plateau phase (phase 2) of the action potential. The ST segment must always be studied carefully since it is altered in a wide range of conditions. Many of these conditions cause rather characteristic ST segment changes. The ST segment is of particular interest in the setting of acute myocardial ischemia, because ischemia causes deviation of the ST segment (**ST segment deviation**). There are two types of ST segment deviations. **ST segment depression** implies that the ST segment is displaced, such that it is below the level of the PR segment. **ST segment elevation** implies that the ST segment is displaced, such that it is above the level of the PR segment. The magnitude of depression/elevation is measured as the height difference (in millimeters) between the **J point** and the PR segment. The J point is the point where the ST segment starts. If the baseline (PR segment) is difficult to discern, the **TP interval** may be used as the reference level.

A) The limb leads and their view of the heart's electrical activity

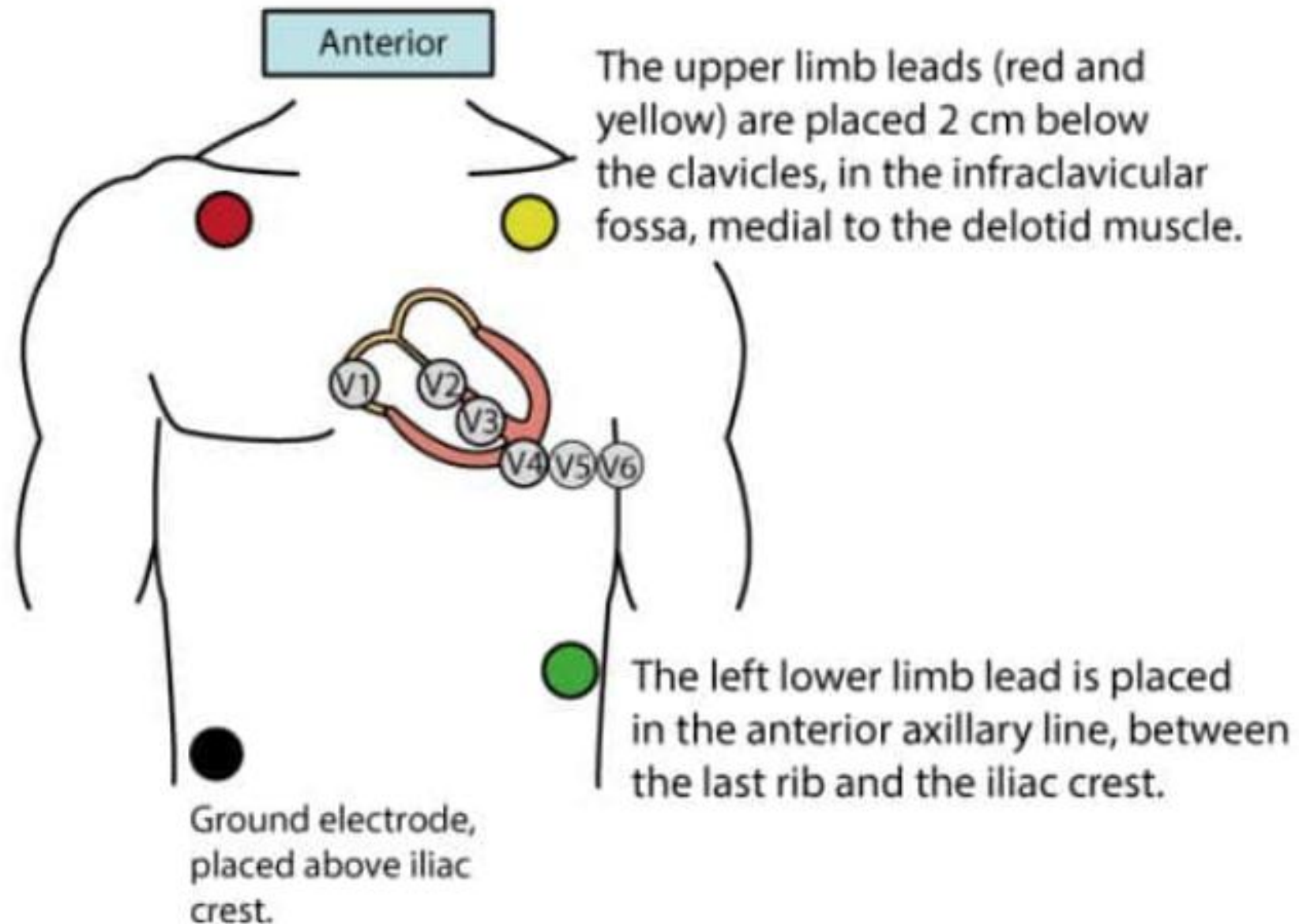


Recall that each lead 'views' the heart from the angle of its positive (exploring) electrode.

The positive electrode is the exploring electrode. This is defined by the ECG machine.

As noted previously, it is recommended that lead aVR be inverted to lead -aVR, as this fills a gap in the coordinate system and thus facilitates interpretation of the ECG.

A) MASON-LIKAR'S LEAD PLACEMENT



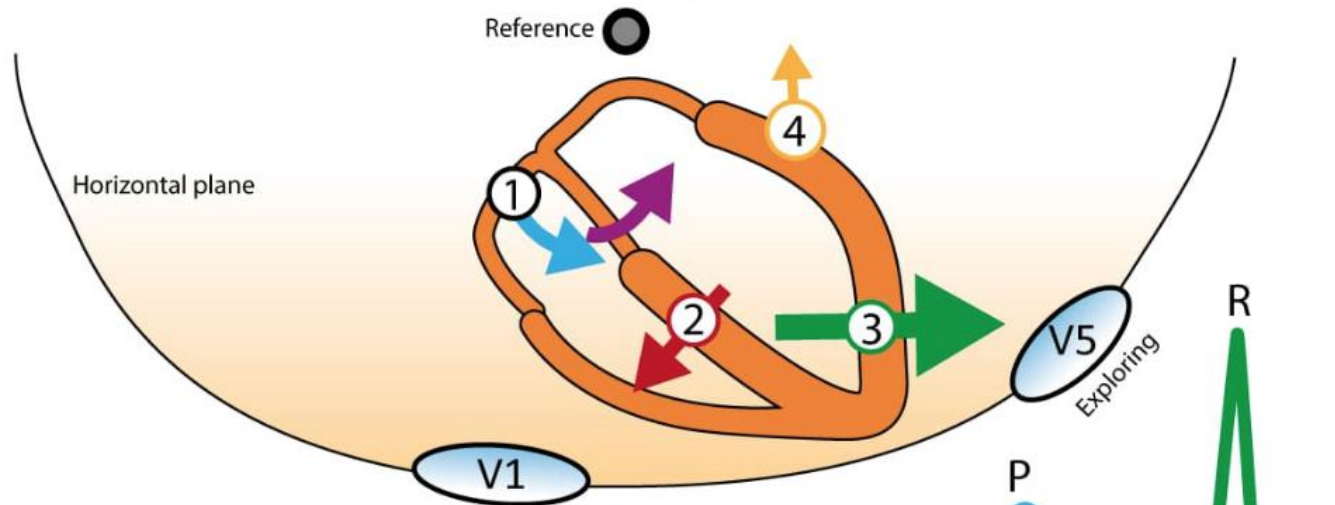
Mason-Likar ECG lead system

Mason-Likar's lead system simply implies that the limb electrodes have been relocated to the trunk. This is used in all types of ECG monitoring (arrhythmias, ischemia *etc*). It is also used for exercise stress testing (as it avoids muscle disturbances from the limbs). As stated above, the initial recording may differ slightly (in amplitudes) so that it is not valid to diagnose ischemia on the initial tracing. For monitoring ischemia over time, however, Mason-Likar is an effective system. Refer to **Figure 24 A**.

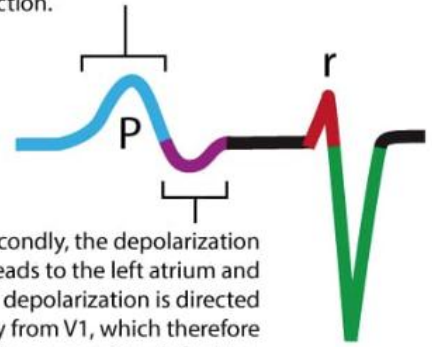
The P-wave, PR interval and PR segment

ECG interpretation traditionally starts with assessment of the P-wave. The **P-wave** reflects atrial depolarization (activation). The **PR interval** is the distance between the onset of the P-wave to the onset of the QRS complex. The PR interval is assessed in order to determine whether impulse conduction from the atria to the ventricles is normal. The flat line between the end of the P-wave and the onset of the QRS complex is called the **PR segment** and it reflects the slow impulse conduction through the atrioventricular node. The PR segment serves as the baseline (also referred to as **reference line** or **isoelectric line**) of the ECG curve. The amplitude of any deflection/wave is measured by using the PR segment as the baseline. Refer to **Figure 1**.

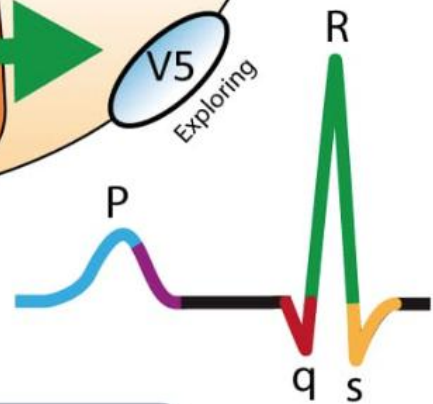
The reference point (Wilson's central terminal) is constructed by taking the average of all three limb electrodes. Taking the average of these yields a reference point located in the centre of Einthoven's triangle.



The right atrium is activated first and the depolarizing wave is directed towards V1, which displays a positive deflection.

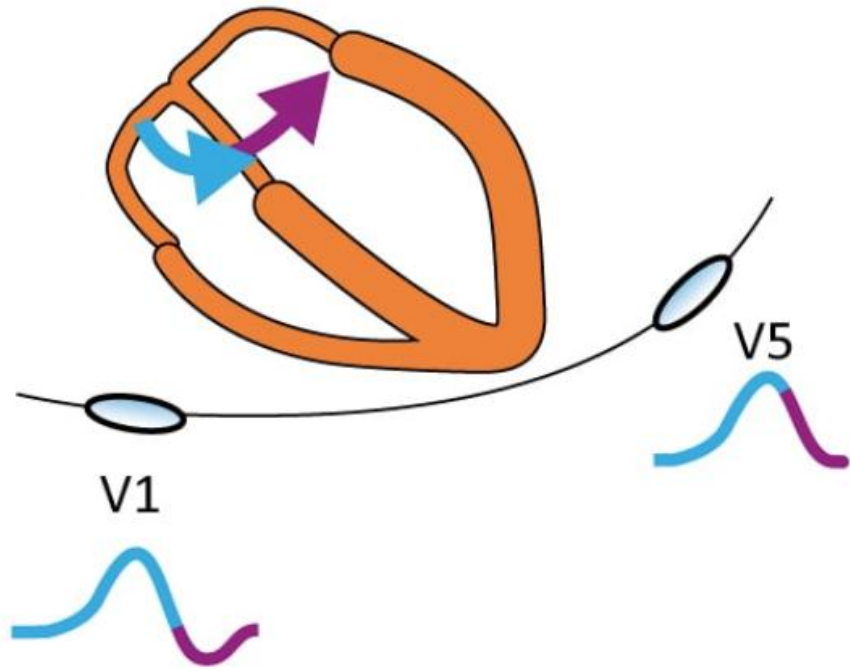


Secondly, the depolarization spreads to the left atrium and the depolarization is directed away from V1, which therefore displays a negative deflection.

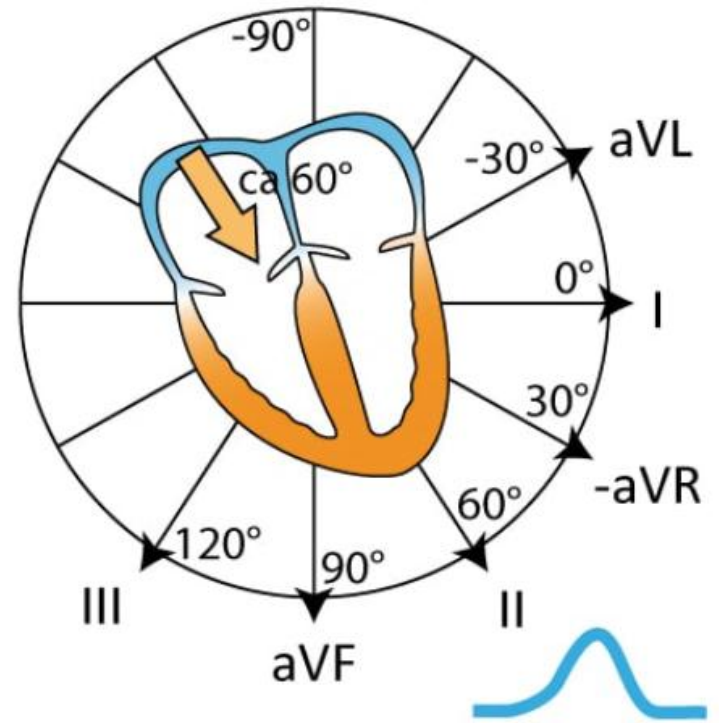


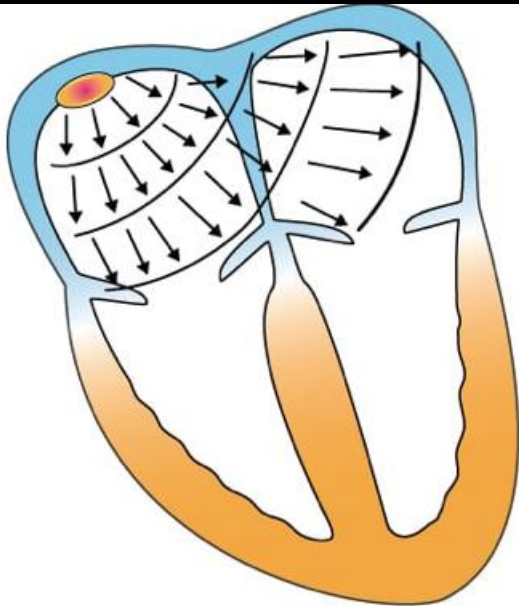
Note the successive transition of the QRS-komplex from V1 to V6.

Horizontal plane - chest leads



Frontal plane - limb leads





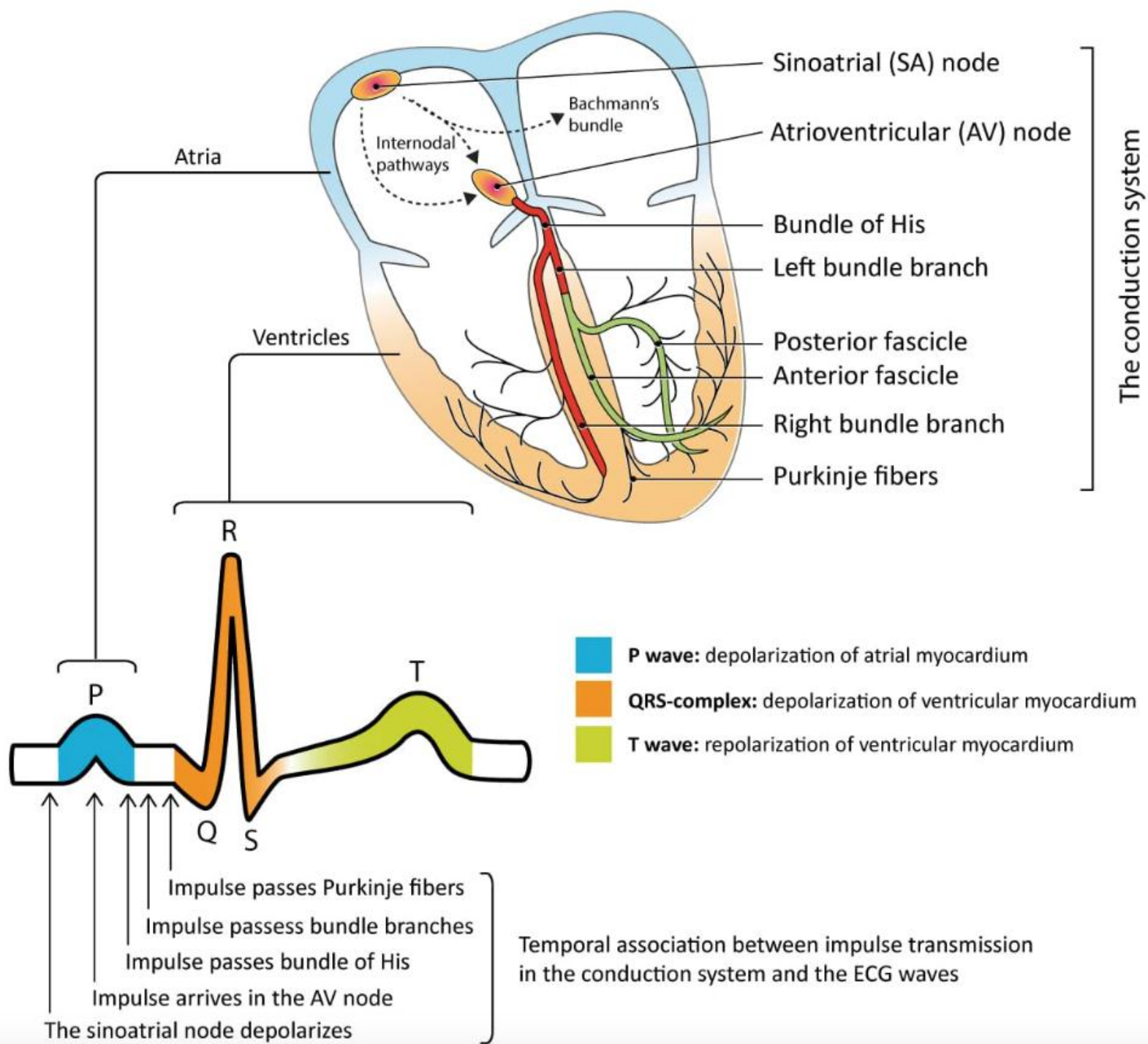
Propagation of the action potential during depolarization of the atria. Each small depolarizing wave front is depicted with an arrow, representing a small electrical vector.



The average of all the instantaneous vectors represents the mean vector, i.e the overall direction of the depolarizing impulse.

P-wave checklist

- The P-wave is always positive in lead II during sinus rhythm.
- The P-wave is virtually always positive in leads aVL, aVF, -aVR, I, V4, V5 and V6. It is negative in lead aVR.
- The P-wave is frequently biphasic in V1 (occasionally in V2). The negative deflection is normally <1 mm.
- P-wave duration should be $\leq 0,12$ seconds.
- P-wave amplitude should be <2,5 mm in the limb leads.
- P-pulmonale implies that the P-wave has abnormally high amplitude in lead II (and in other leads in general).
- P-mitrale implies that the second hump of the P-wave in lead II and the negative deflection of the P-wave in lead V1 are both enhanced.

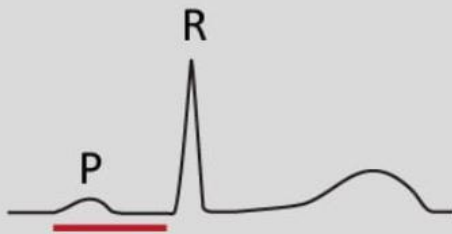
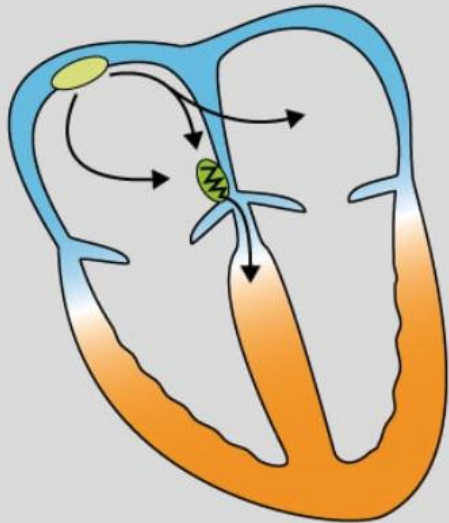


PR interval checklist

- Normal PR interval: 0,12–0,22 seconds. Upper reference limit is 0,20 seconds in young adults.
- A prolonged PR interval (>0.22 s) is consistent with first-degree AV-block.
- A shortened PR interval ($<0,12$ s) indicates pre-excitation (presence of an accessory pathway). This is associated with a delta wave.

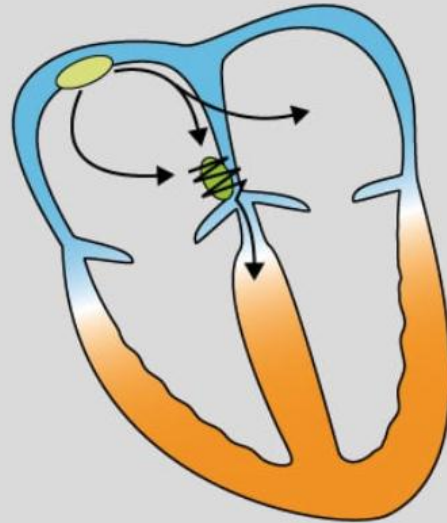
— denotes the PR interval

Normal atrioventricular impulse transmission



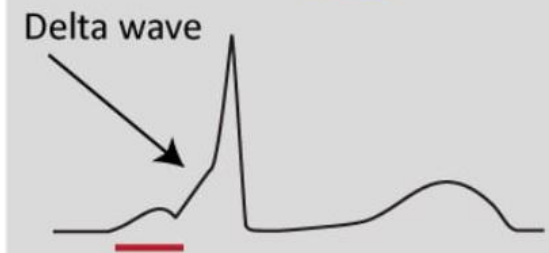
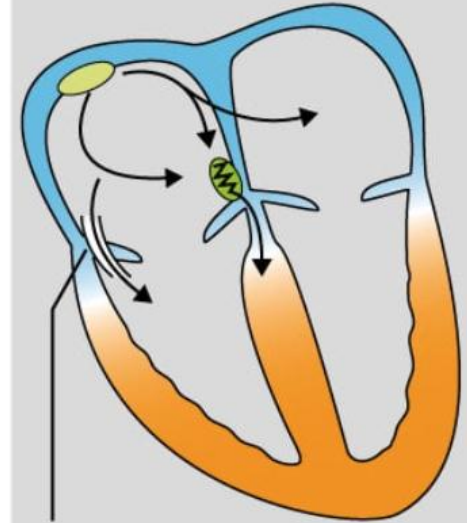
Normal PR interval (0.12–0.22 s)

First-degree AV block



Prolonged PR interval (>0.22 s)

Pre-excitation



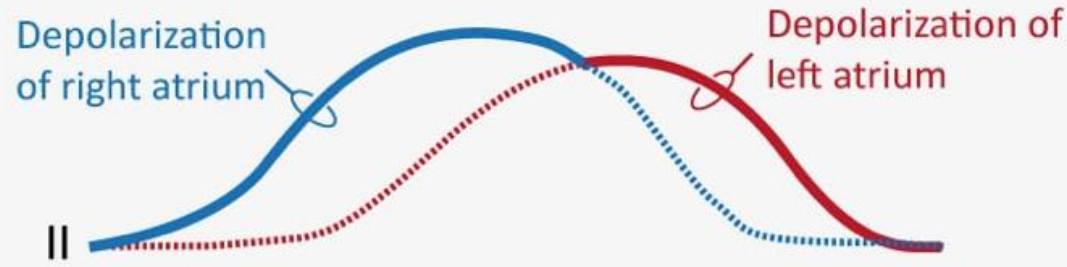
Short PR interval (<0.12 s)

PR interval and PR segment

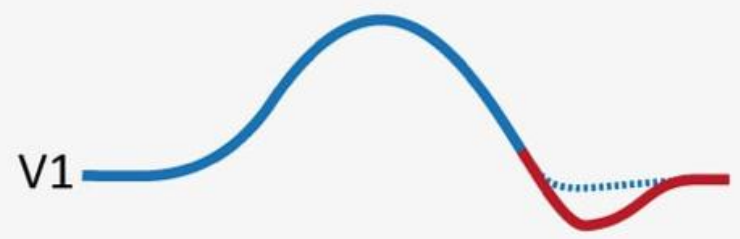
The PR interval starts at the onset of the P-wave and ends at the onset of the QRS complex (**Figure 1**). It reflects the time interval from start of atrial depolarization to start of ventricular depolarization. The PR interval is assessed in order to determine whether impulse conduction from the atria to the ventricles is normal in terms of speed. The PR interval must not be too long nor too short. A normal PR interval ranges between 0.12 seconds to 0.22 seconds.

The flat line between the end of the P-wave and the onset of the QRS complex is called the **PR segment** and it reflects the slow impulse conduction through the atrioventricular node. The PR segment serves as the baseline (also referred to as **reference line** or **isoelectric line**) of the ECG curve. The amplitude of any deflection/wave is measured by using the PR segment as the baseline.

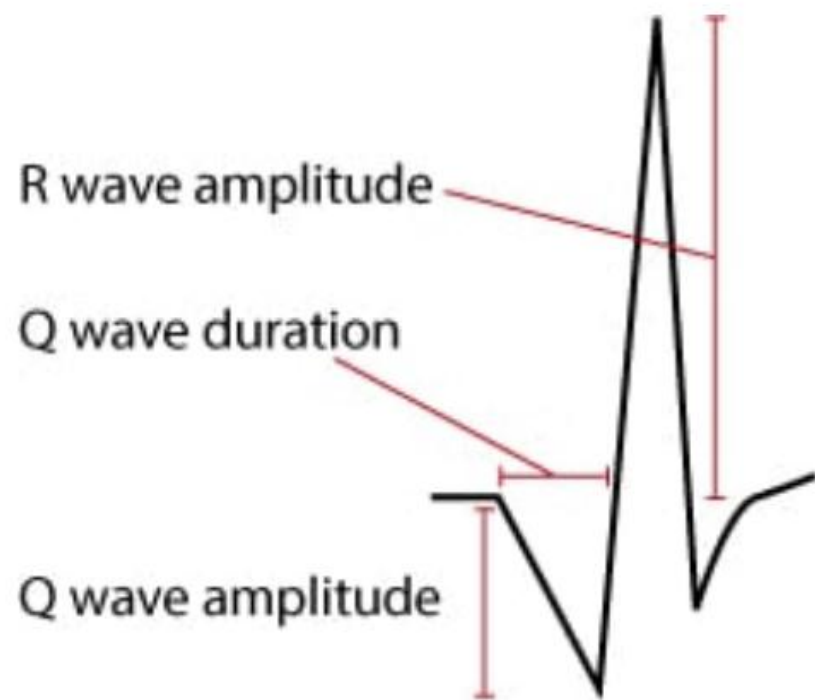
Contour of the normal P wave



The P-wave is always positive in lead II if the rhythm is sinus rhythm. The P-wave may, however, display two humps, as shown here. This is due to the fact that the atria are not depolarized (activated) simultaneously.



The P-wave in lead V1 may be biphasic, due to the negative deflection caused by depolarization of the left atrium (the electrical vector is directed away from V1).



Definition of pathological Q wave

- Duration >0.03 seconds and/or
- Amplitude $>25\%$ of R wave amplitude

Hence, the Q wave visible here does fulfill criteria for pathological Q waves.

The amplitude (depth) and the duration (width) of the Q-wave dictates whether it is abnormal or not. Pathological Q-waves have duration $\geq 0,03$ sec and/or amplitude $\geq 25\%$ of the R-wave amplitude. Pathological Q-waves must exist in at least two anatomically contiguous leads (i.e neighbouring leads, such as aVF and III, or V4 and V5) in order to reflect an actual morphological abnormality. The existence of pathological Q-waves in two contiguous leads is sufficient for a diagnosis of Q-wave infarction. This is illustrated in **Figure 11**.

The QRS complex (ventricular complex)

A complete QRS complex consists of a Q-, R- and S-wave. However, all three waves may not be visible and there is always variation between the leads. Some leads may display all waves, whereas others might only display one of the waves. Regardless of which waves are visible, the wave(s) that reflect ventricular depolarization is always referred to as the *QRS complex*.

The QRS complex

The **QRS complex** represents the depolarization (activation) of the ventricles. It is always referred to as the “QRS complex” although it may not always display all three waves. Since the electrical vector generated by the left ventricle is many times larger than the vector generated by the right ventricle, the QRS complex is actually a reflection of left ventricular depolarization. **QRS duration** is the time interval from the onset to the end of the QRS complex. A short QRS complex is desirable as it proves that the ventricles are depolarized rapidly, which in turn implies that the conduction system functions properly. Wide (also referred to as *broad*) QRS complexes indicate that ventricular depolarization is slow, which may be due to dysfunction in the conduction system.



The first (and only) wave is positive and thus an R wave.



The first wave is large and positive (R), followed by a small negative wave (s).



Initially a small positive wave (r), followed by a large negative wave (S).



The first wave is negative and small (q), followed by a large positive wave (R), and finally a small negative wave (s).



Initially a large negative (Q), then a large positive wave (R).



A single negative wave is called a QS-complex.



A large negative wave (Q), followed by a small positive wave (r).



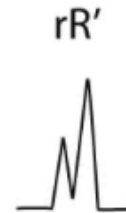
The negative wave manages to pass the baseline, and is therefore qualified as an S wave.



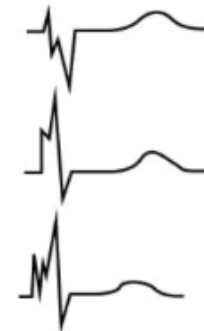
Initially a small negative wave (q), followed by a large positive wave (R).



Notching on the upstroke of the R wave.



The negative deflection does not manage to pass the baseline and can therefore qualify as an s wave.



Examples of fragmented QRS-complexes.

Naming of the waves in the QRS complex:

Naming of the waves in the QRS complex is easy but frequently misunderstood. The following rules apply when naming the waves:

- A deflection is only referred to as a *wave* if it passes the baseline.
- If the first wave is negative then it is referred to as Q-wave. If the first wave is not negative, then the QRS complex does not possess a Q-wave, regardless of the appearance of the QRS complex.
- All positive waves are referred to as R-waves. The first positive wave is simply an “R-wave” (R). The second positive wave is called “R-prime wave” (R’). If a third positive wave occurs (rare) it is referred to as “R-bis wave” (R”).
- Any negative wave occurring after a positive wave is an S-wave.
- Large waves are referred to by their capital letters (Q, R, S), and small waves are referred to by their lower-case letters (q, r, s).

QT duration and QTc duration

QT duration reflects the total duration of ventricular depolarization and repolarization. It is measured from the onset of the QRS complex to the end of the T-wave. The QT duration is inversely related to heart rate; i.e the QT interval increases at slower heart rates and decreases at higher heart rates. Therefore to determine whether the QT interval is within normal limits, it is necessary to adjust for the heart rate. The heart rate adjusted QT interval is referred to as the **corrected QT interval (QTc interval)**. A long QTc interval increases the risk of ventricular arrhythmias.

R-wave amplitude

It is important to assess the amplitude of the R-waves. High amplitudes may be due to ventricular enlargement or hypertrophy. To determine whether the amplitudes are enlarged, the following references are at hand:

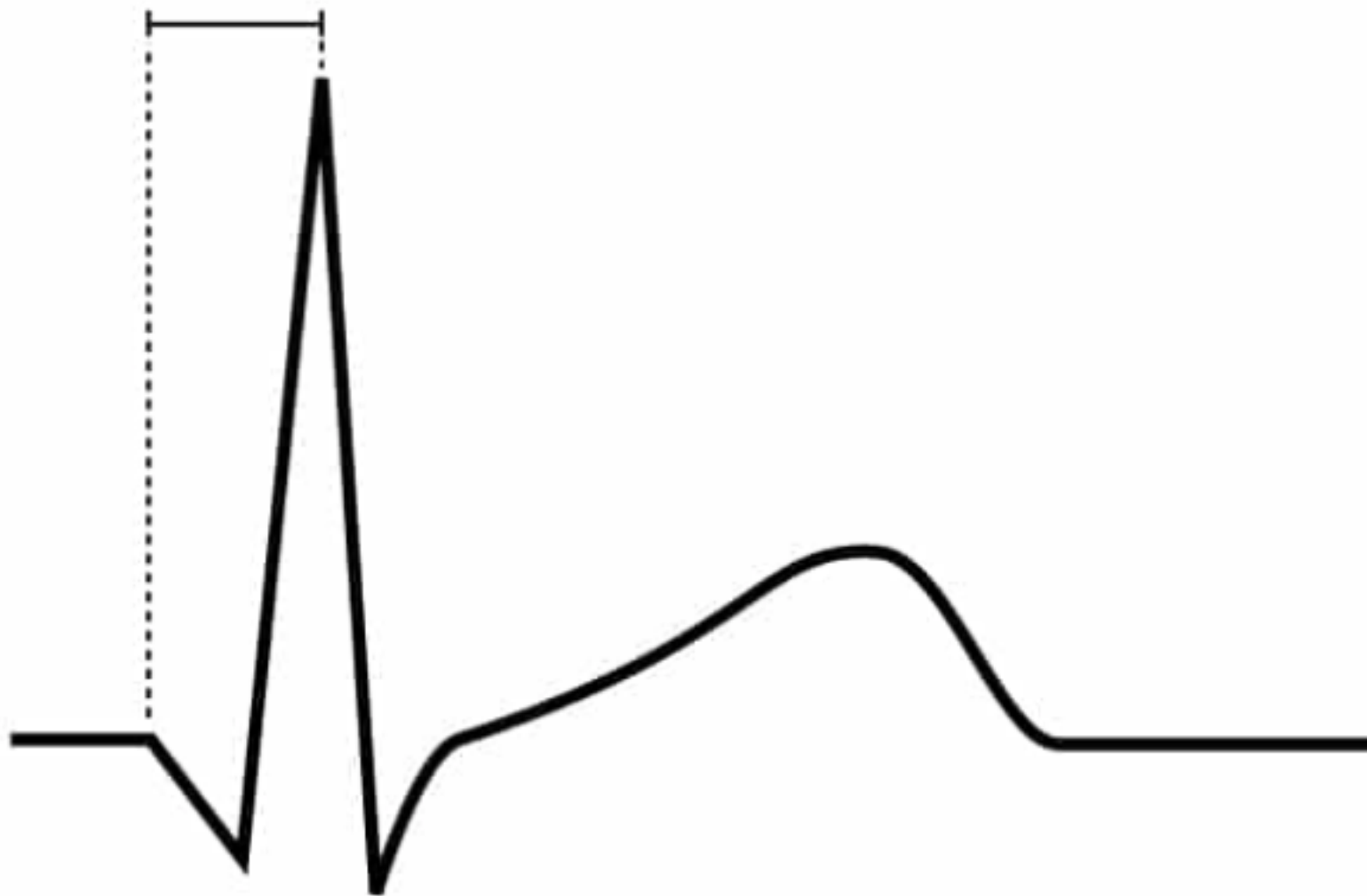
- R-wave should be < 26 mm in V5 and V6.
- R-wave amplitude in V5 + S-wave amplitude in V1 should be < 35 mm.
- R-wave amplitude in V6 + S-wave amplitude in V1 should be < 35 mm.
- R-wave amplitude in aVL should be ≤ 12 mm.
- R-wave amplitude in leads I, II and III should all be ≤ 20 mm.
- If R-wave in V1 is larger than S-wave in V1, the R-wave should be < 5 mm.

R-wave peak time (**Figure 9**) is the interval from the beginning of the QRS-complex to the apex of the R-wave. This interval reflects the time elapsed for the depolarization to spread from the endocardium to the epicardium. R-wave peak time is prolonged in hypertrophy and conduction disturbances.

Normal values for R-wave peak time follow:

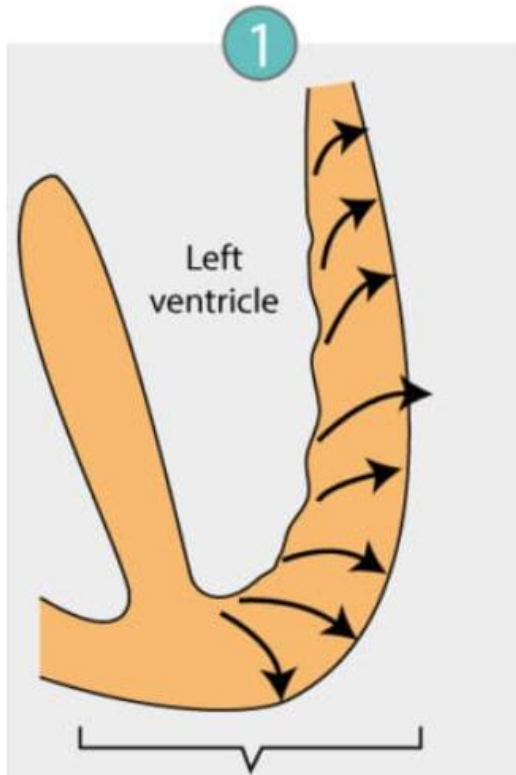
- Leads V1-V2 (right ventricle) <0,035 seconds
- Leads V5-V6 (left ventricle) <0,045 seconds

R wave peak time

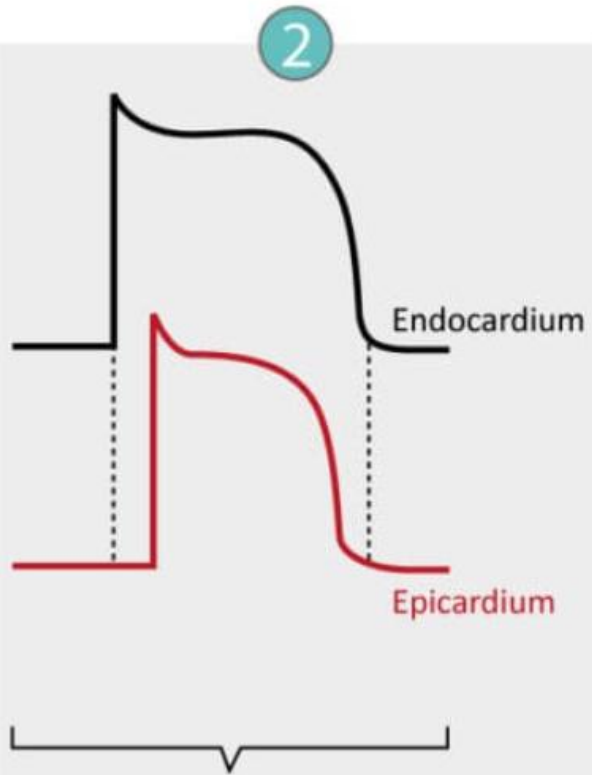


The T-wave

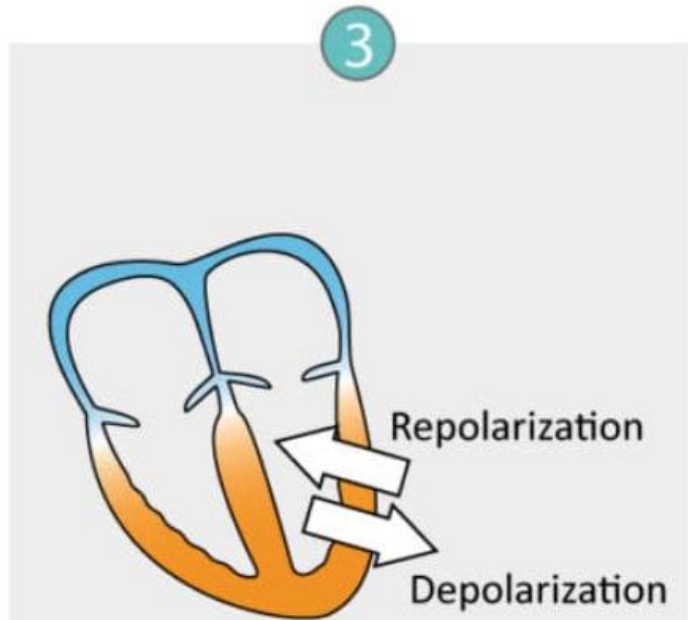
The T-wave reflects the rapid repolarization of contractile cells (phase 3) and T-wave changes occur in a wide range of conditions. T-wave changes are frequently misunderstood in clinical practice, which the discussion below will attempt to cure. The transition from the ST segment to the T-wave should be smooth (and not abrupt). The normal T-wave is slightly asymmetric, with a steeper downward slope.



Depolarization is directed from the endocardium to the epicardium. The electrical vector has the same direction.



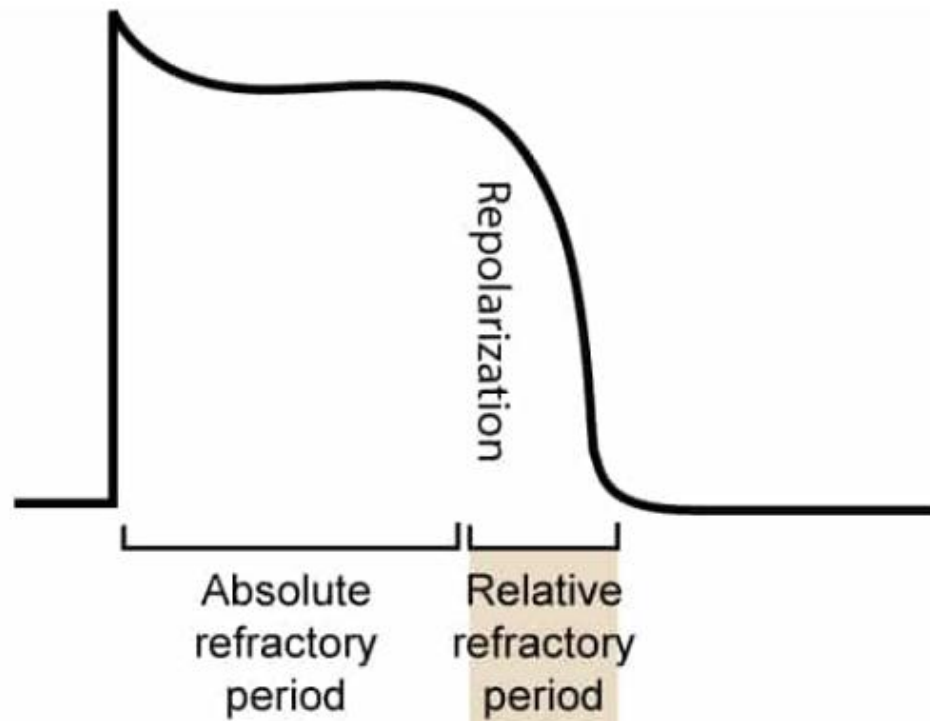
The duration of the action potential is shorter in epicardial cells, which is why repolarization starts there. The repolarization is therefore directed from the epicardium to the endocardium.



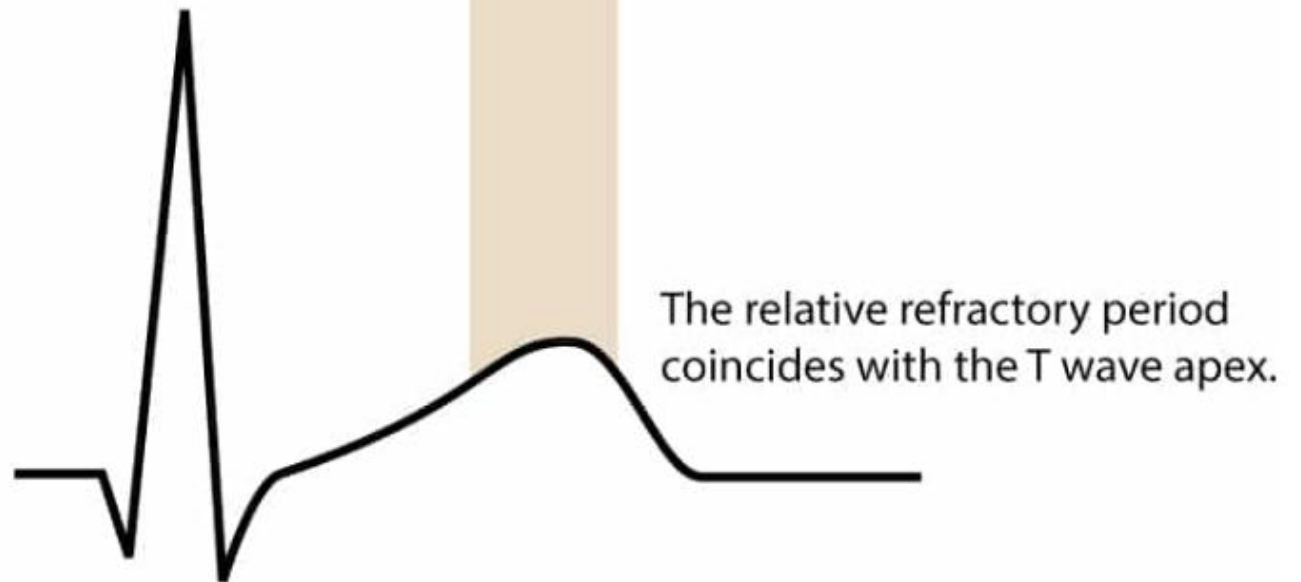
To conclude, the direction of the vectors during de- and repolarization are opposite, but so is the flux of ions and therefore there is no net difference in the direction of the electrical vector. The electrical vector has the same direction during de- and repolarization.

Figure 15. The direction of the electrical vector during the QRS complex is determined by the direction of the electrical vector during the QRS complex.

Action potential of myocardial cells

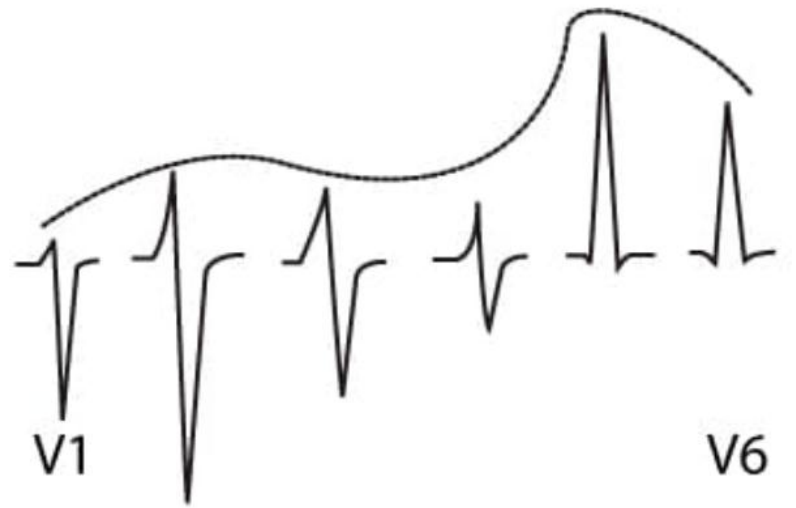


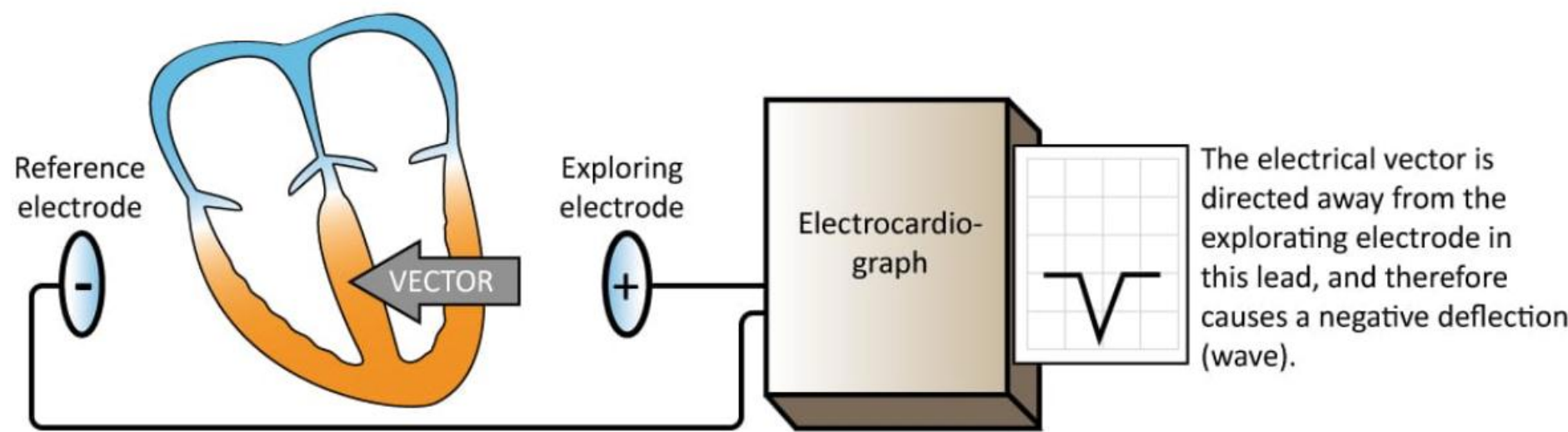
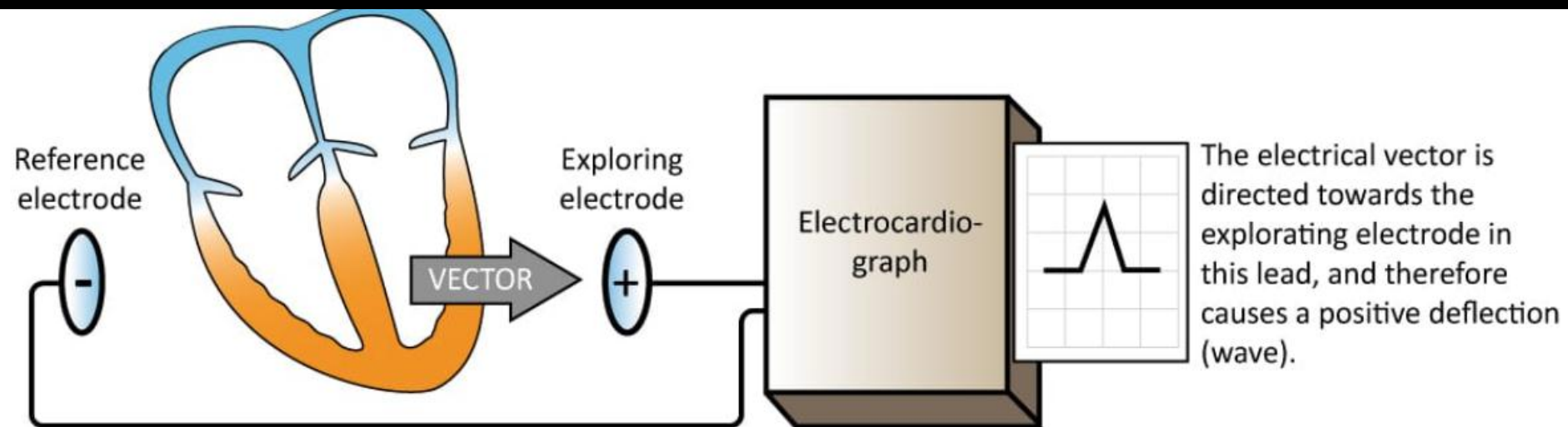
ECG recorded on body surface



The U-wave

The U-wave is seen occasionally. It is a positive wave occurring after the T-wave. Its amplitude is generally one fourth of the T-wave's amplitude. The U-wave is most frequently seen in leads V2–V4. Individuals with prominent T-waves, as well as those with slow heart rates, display U-waves more often. The genesis of the U-wave remain elusive.





The reference point (Wilson's central terminal) is constructed by taking the average of all three limb electrodes. Taking the average of these yields a reference point located in the centre of Einthoven's triangle.

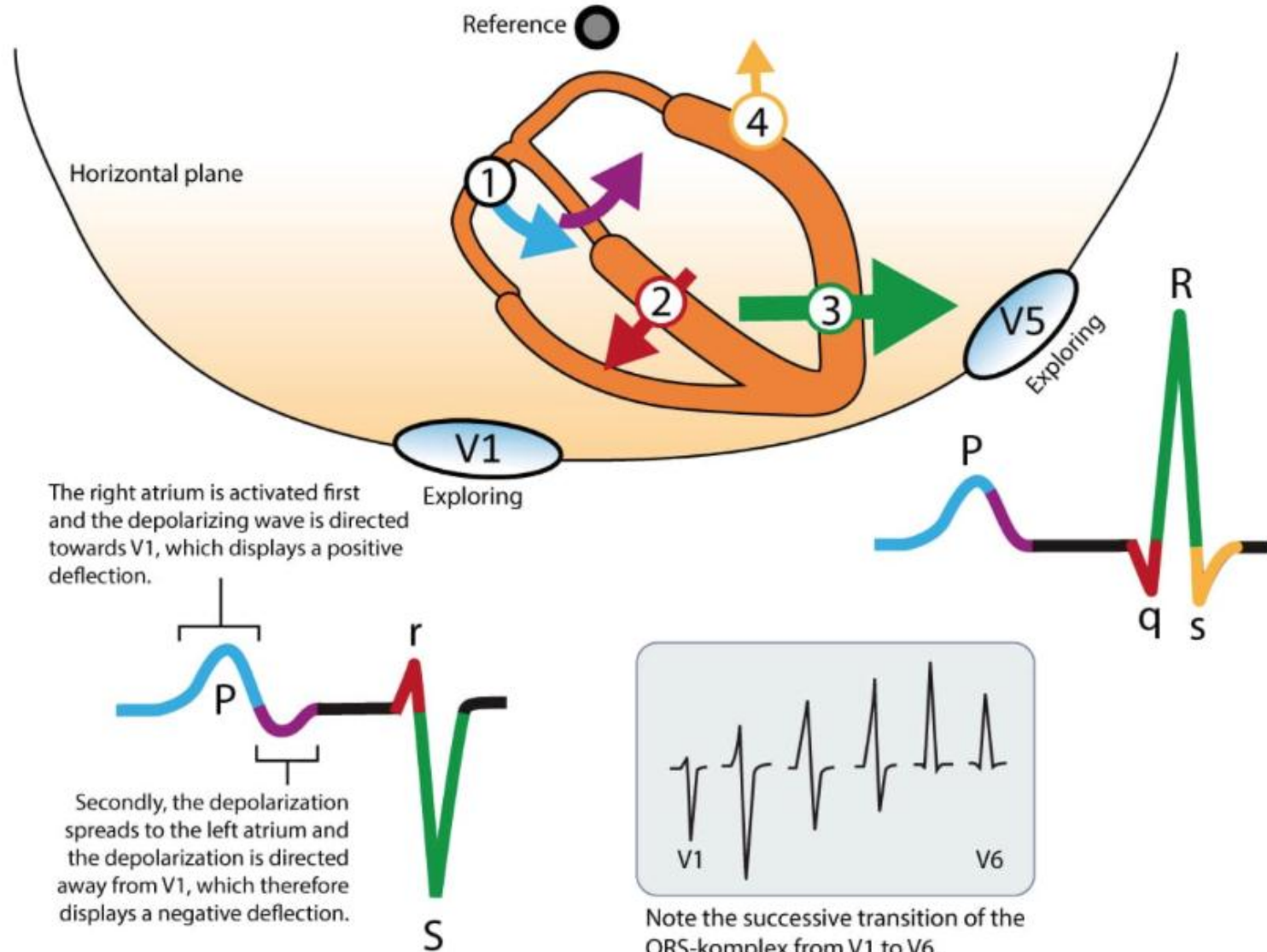
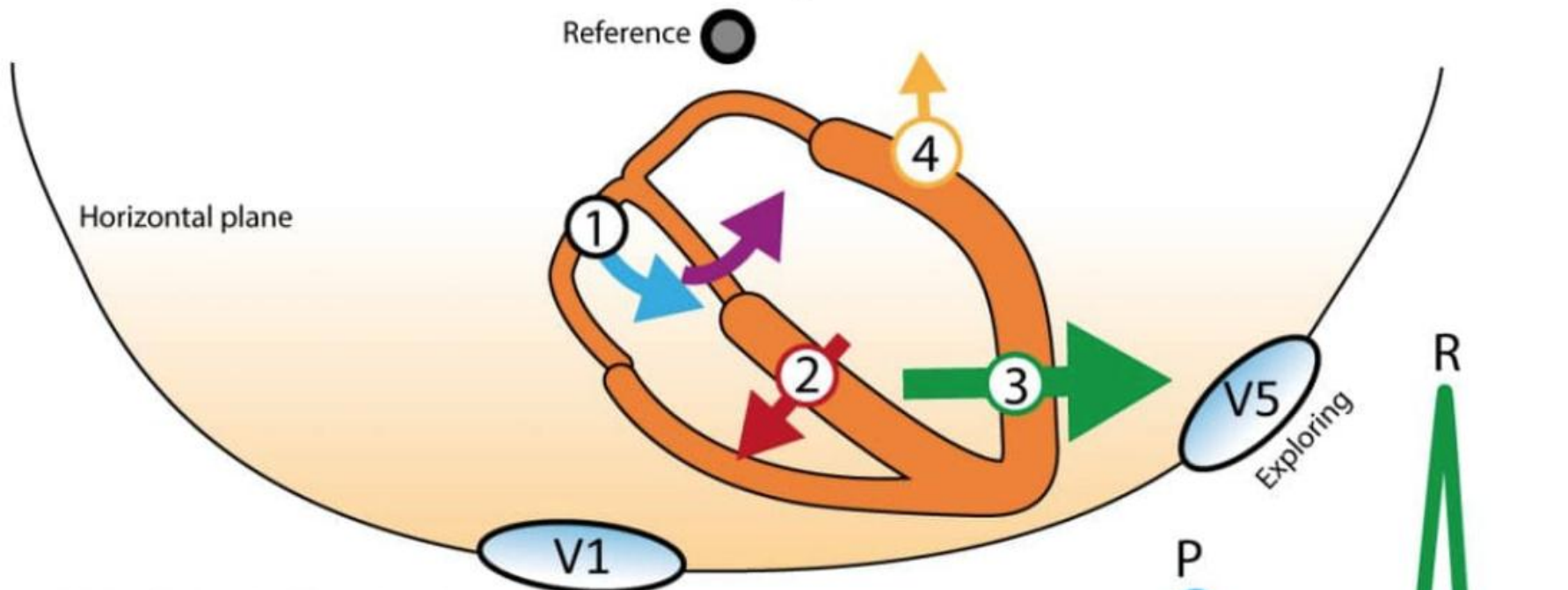
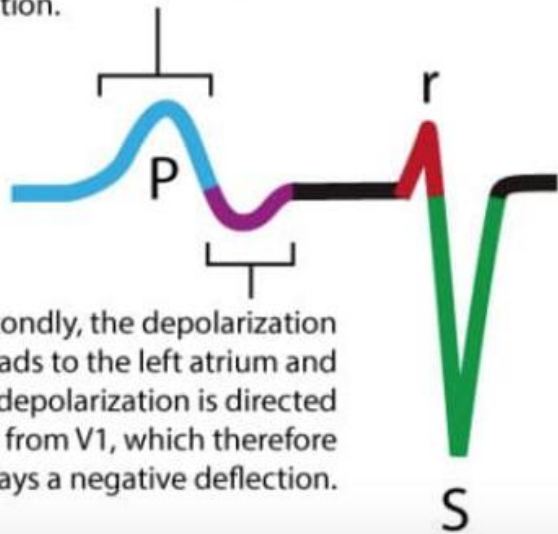


Figure 13. The main electrical vectors in the horizontal plane. V1 and V5 are exploring electrodes and the reference point is composed of the average of the electrodes placed on the limbs (this reference is called Wilson's central terminal).



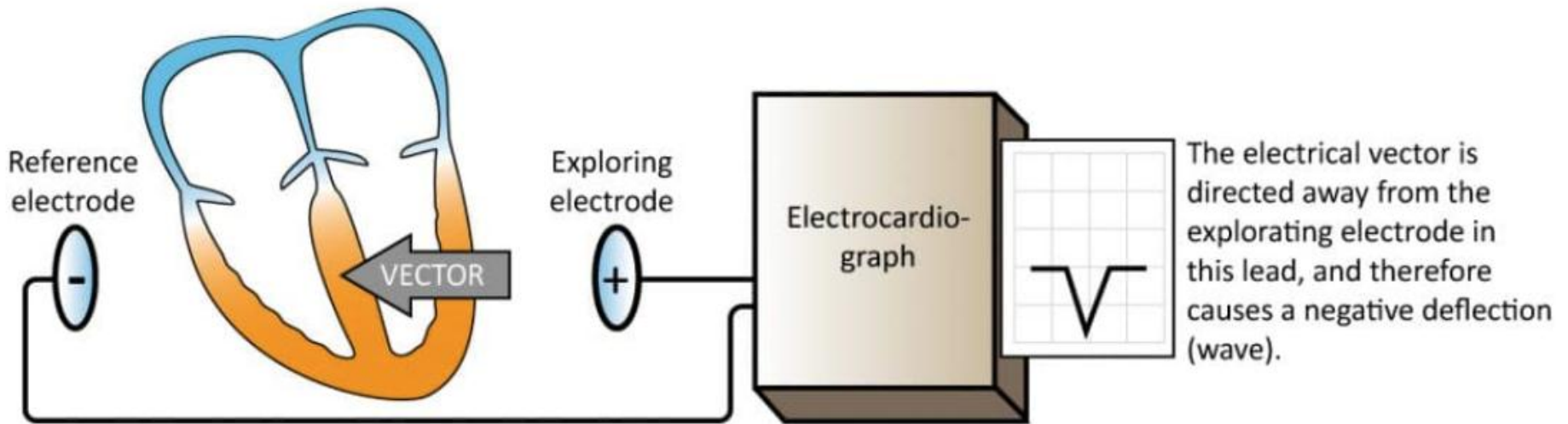
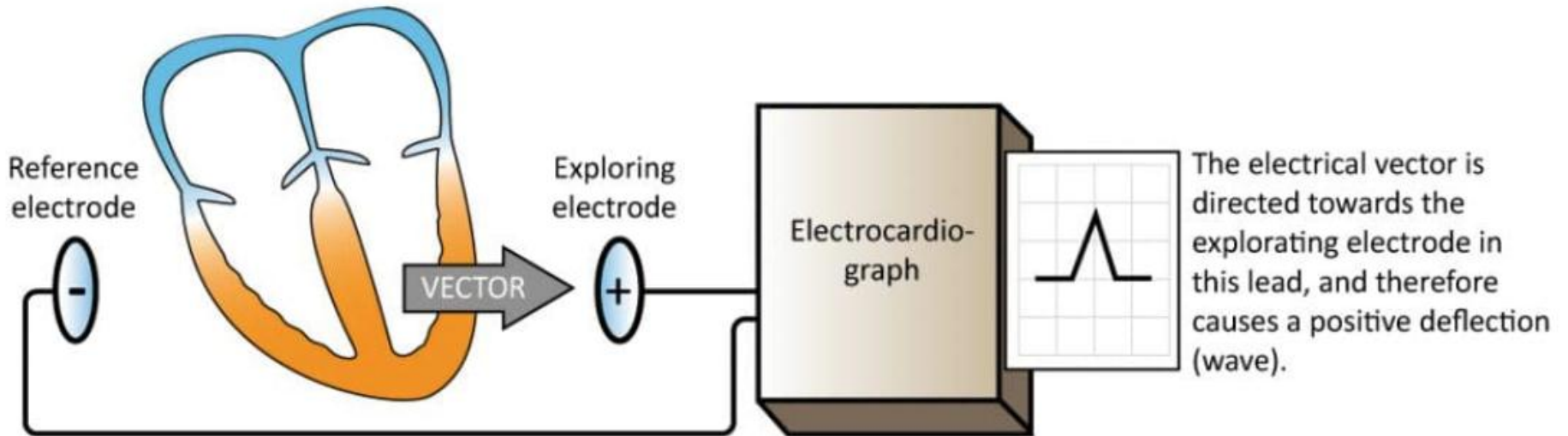
The right atrium is activated first and the depolarizing wave is directed towards V1, which displays a positive deflection.

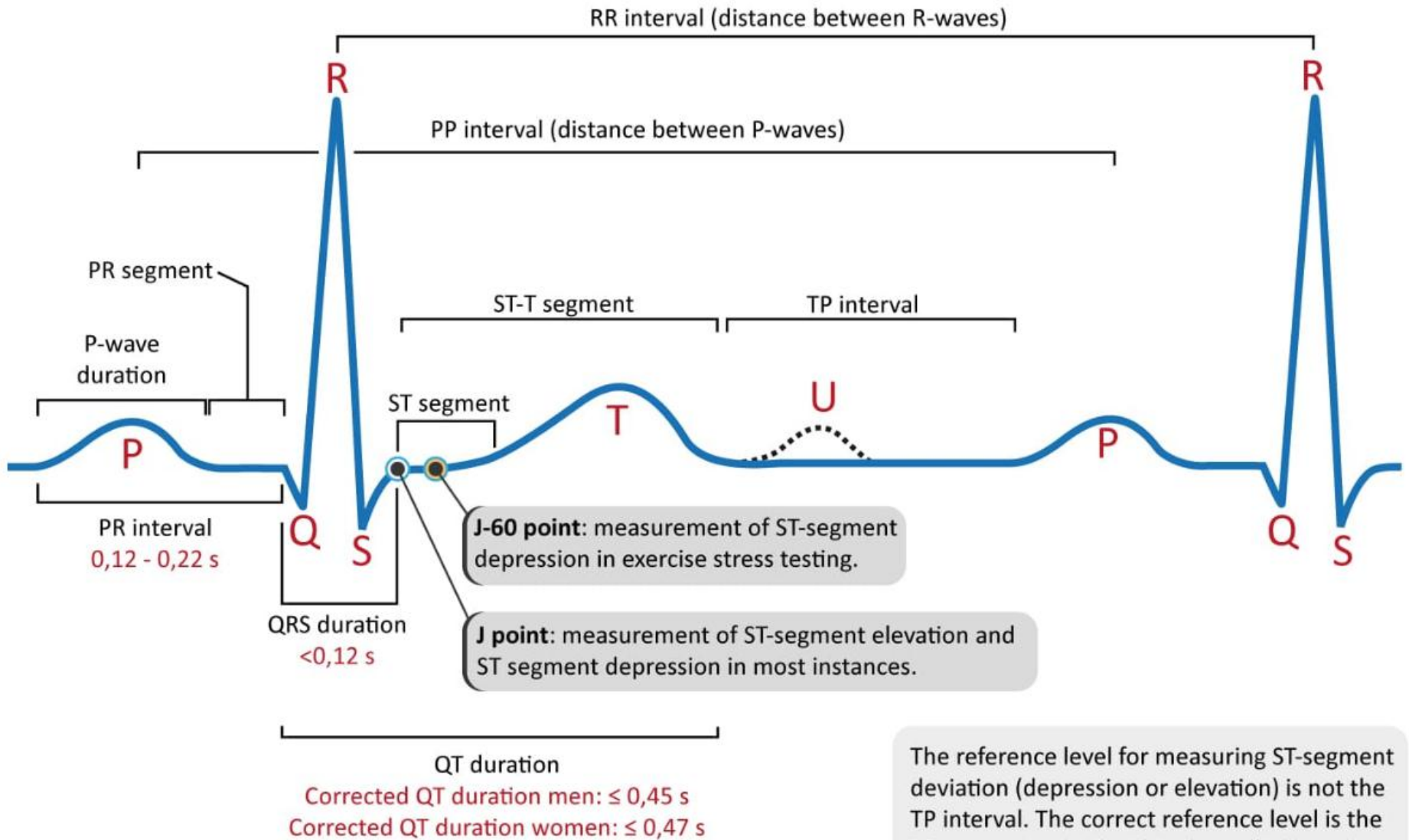


Secondly, the depolarization spreads to the left atrium and the depolarization is directed away from V1, which therefore displays a negative deflection.



Note the successive transition of the QRS-komplex from V1 to V6.





The reference level for measuring ST-segment deviation (depression or elevation) is not the TP interval. The correct reference level is the **PR segment**. This level is also called **baseline level** or **isoelectric level**.

Frank Wilson and colleagues constructed the central terminal, later termed **Wilson's central terminal (WCT)**. This terminal is a theoretical reference point located approximately in the center of thorax, or more precisely in the centre of Einthoven's triangle. WCT is computed by connecting all three limb electrodes (via electrical resistance) to one terminal. This terminal will represent the average of the electrical potentials recorded in the limb electrodes. Under ideal circumstances, the sum of these potentials is zero (Kirchoff's law). WCT serves as the reference point for each of the six electrodes which are placed anteriorly on the chest wall. The chest leads are derived by comparing the electrical potentials in WCT to the potentials recorded by each of the electrodes placed on the chest wall. There are six electrodes on the chest wall and thus six chest leads (**Figure 19**). Each chest lead offers unique information that cannot be derived mathematically from other leads. Since the exploring electrode and the reference is placed in the horizontal plane, these leads primarily observe vectors moving in that plane.