

RECORDING OF ECG ON 12-LEAD SYSTEM - A FUNDAMENTAL APPROACH

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OUTLINE

Introduction

The recording of an ECG is a technical phenomenon in which the electrical potential difference between two electrodes of a lead detects the cardiac electrical activity, with the direction of the electrical wavefront determining whether the recorded deflection is positive or negative, and the resulting electrical activity is expressed graphically through the language of P–QRS–T.

ECG recording on 12-lead system

- ☐ **Hexaxial lead system :**
 - A six pointed electrical vertical system – the three bipolar arms lead I , II , III and the augmented unipolar leads aVR , aVL , aVF constitute hexaxial lead system
 - The basic facts leading to the formation of hexaxial lead system
- ☐ **Precordial lead system :**
 - Horizontal electrical field consisting of chest leads V1-V6
 - How does it help in recording the electrical changes

Some pertinent points while placing the 12-leads over the body

A broader canvas of 12-lead system to gain insight the electrical changes in toto at a glance

- ☐ The combined mental picture of 12-lead system
- ☐ The graphing of electrical axis

Take-Home Message

References

Recording of ECG on 12-lead system - A fundamental approach

A Narrative Review

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Electrical science has provided us with innumerable appliances and instruments of precision, and has thereby vastly added to the exactness of our knowledge. An electrocardiogram (ECG) is a graphic recording of the heart's electrical potentials changing over time.

- **Hexaxial lead system for recording the electrical activity in the frontal plane through the arrangement of augmented unipolar leads (aVR, aVL and aVF) and bipolar limb leads (I, II, III).**
- **Precordial lead system is spread over through six leads (V1–V6) placed over the chest at specific anatomical locations, providing views of the heart in the horizontal plane.**

The 12-lead system is a boon in recording the electrical activity of the heart.

1. Introduction (Keypoints)

- Each cardiac impulse innovates and dissipates an electric field which wraps the heart from within and out. The physical principle states that every electrical field is coupled with a magnetic field as well and this association creates an electromagnetic force around the heart. The heart is having the largest rhythmic electromagnetic field which is widespread over the body with its expanding flame even outside its sphere.
- An electrocardiogram (ECG) is a graphic recording of the heart's electrical potentials changing over time. It is heavily dependent on precise bioelectric signal acquisition, amplification, standardized lead placement, and rigorous digital filtering to translate microvolt-level myocardial changes into a readable clinical tracing.
- By 12-lead ECG, this cardiac electrical activity is picked up across both the vertical and horizontal planes. The limb leads are used to detect the electrical current over the vertical plane and the chest leads are used to detect the electrical changes over the horizontal plane.

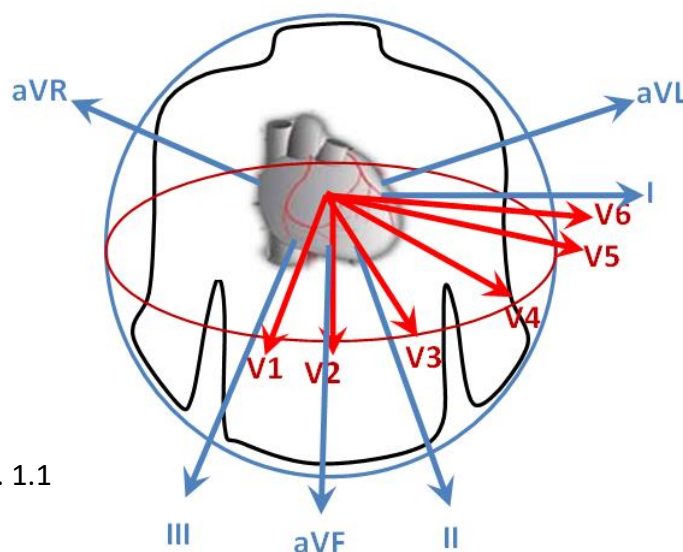


Fig. 1.1

2. ECG recording on 12-lead system

- ☐ Hexaxial lead system
- ☐ Precordial lead system

Hexaxial lead system

The hexaxial lead system assesses the overview of the heart's electrical field over the vertical plane, creating a six pointed perspective system which captures the electrical signals from different angles, transforming the complex current into measurable waves. It makes easier to understand at which direction the cardiac vector is projected.

The basic facts leading to the formation of 'Hexaxial lead system' :

- **Einthoven's triangle** is the "Soul-essential" for the purpose.
Einthoven Triangle is an imaginary geometry based three limb leads triangle, being formed by the two shoulders (left and right) and the left leg.
This is an inverted electrical triangle with the heart lying at the centre.
- **Augmented Unipolar Limb leads : Dr. Emanuel Goldberger**
Unipolar limb leads were named as augmented unipolar limb leads – aVL, aVR, aVF (aV denotes augmented vector and L, R, F used for different concerned limbs).
- **The concept of the central terminal : Goldberger's indifferent electrode**
Since the recorded signals from the unipolar leads were small, Goldberger devised a special central terminal to augment these leads by 50% - by averaging only two of the limb electrodes and excluding the one being measured. **This is used as an indifferent electrode (negative electrode) to record the potential difference in respect to unipolar limb leads.**

The understanding of stepwise construction of hexaxial lead system :

STEP 1 Leads I, II, III represent bipolar limb system, while aVL, aVR, aVF represent augmented unipolar limb lead system

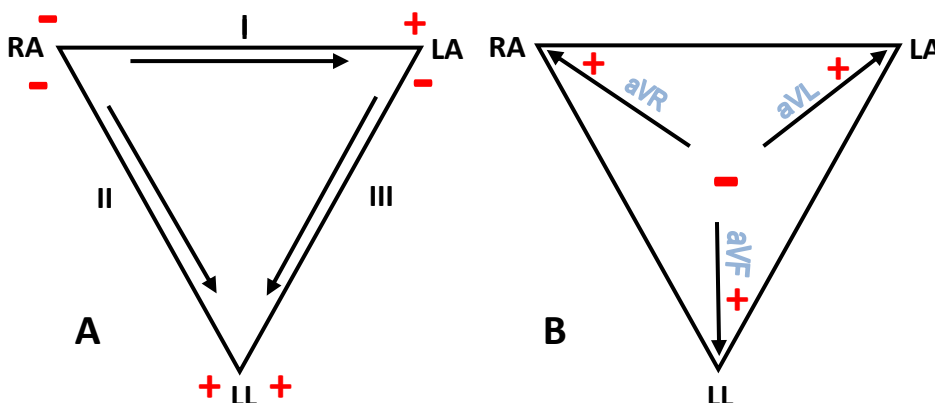
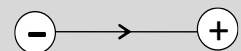


Fig. 1.2

The flow of cardiac current on the vertical plane is picked up through the negative electrode to be directed towards the positive electrode due to the potential difference in between these two poles, as illustrated in the preceding sketches.



Lead aVR

Being placed at its extreme opposite end, the lead aVR usually records all the waves as negative (P-QRS-T).

STEP 2

By rearranging the augmented unipolar leads (aVR, aVL, aVF) with those of limb leads of Einthoven's triangle (I, II, III), the following sketch is obtained :

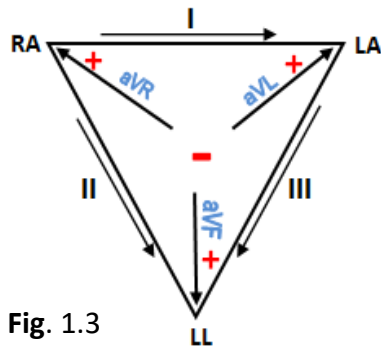


Fig. 1.3

Leads	Negative Electrode	Positive Electrode
Bipolar I II III	Right Arm Right Arm Left Leg Einthoven's system	Left Arm Left Leg Left Leg
Unipolar aVR aVL aVF	Goldberger's terminal	Right Arm Left Arm Left Leg

STEP 3

The three bipolar arms leads I, II, III are imagined to pass parallel through the centre of the triangle and the augmented unipolar leads aVR, aVL, aVF are remaining as such, being projected from the centre to the respective corners of the triangle – thus, the 'Hexaxial Lead System' came into existence (the heart is conceptually considered to lie at the centre)

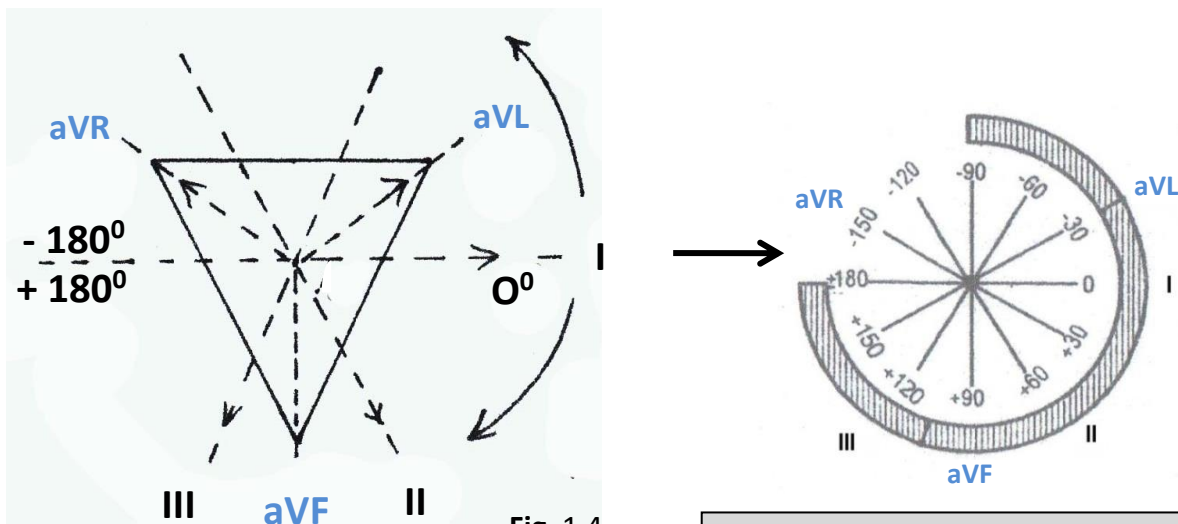


Fig. 1.4

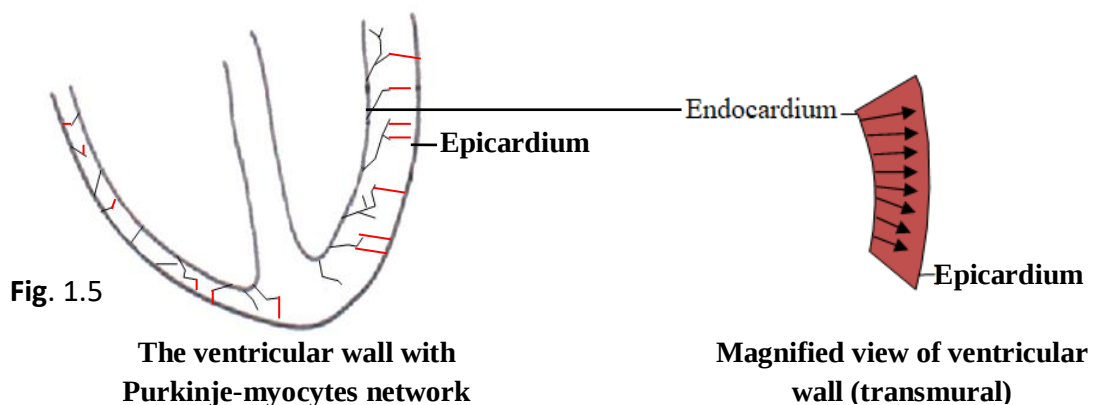
Hexaxial Lead System

By convention the leads are arranged degreewise around a circle as shown above. Lead I is located at 0° being used as the reference lead. Positive designation gets increased by 30° increments in a clockwise direction to $+180^\circ$ and negative designation gets increased by the same increment (30°) in a counterclockwise direction to -180° (please see the above diagram). Thus, so oriented negative and positive nomenclature of the various leads are used by convention for the mathematical determination of the electrical axis. The positive and negative degrees are nothing to do with the positive or negative pole of the leads. This is to be mentioned here that this system came into existence because of its conventional and

constant usage in clinical practice. This inscription of 'Hexaxial lead system' is very much helpful in the determination of electrical axis.

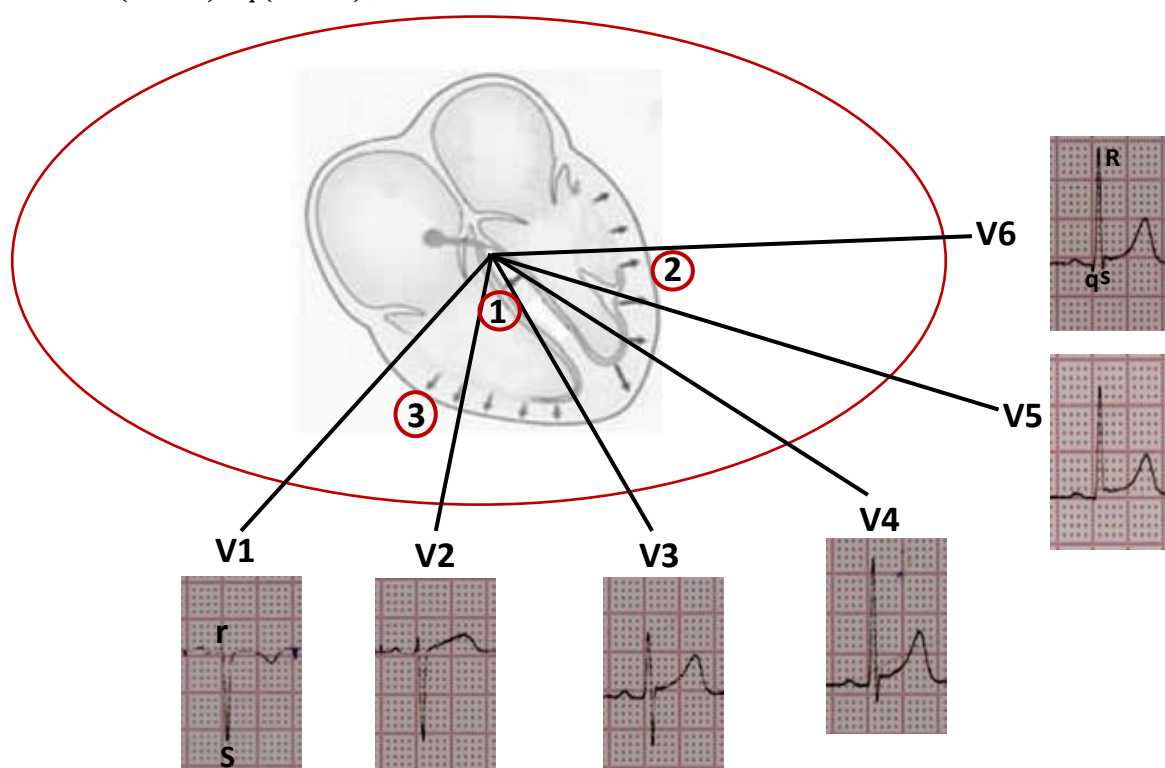
Precordial lead system

The precordial lead system assesses the overview of the heart's electrical field over the horizontal plane, it records all the net electrical events from the selected site, as per the placement of the precordial leads V1 to V6. This system records electrical potential from the underneath myocardium, as such illustrated below:

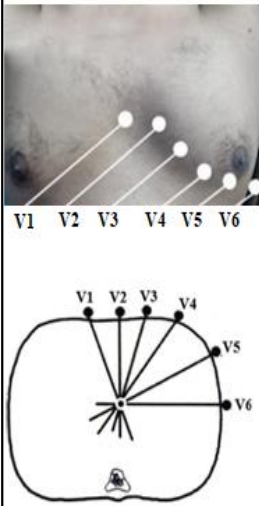


How does it help in recording the electrical changes

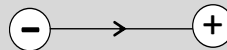
- Waves morphology as per sequential activation of the Ventricles from V1 to V6
- The left ventricle is thicker than that of right ventricle, therefore the net flow is towards the left ventricle.
- Positive deflection towards the flow of current, equiphase or no deflection at transitional zone and -ve deflection when away from the flow of current.
- Septal wave - the normal left-to-right depolarization of the interventricular septum (V1-V2) / q (V5-V6); +ve R-wave over V5-V6 / -ve S-wave over V1-V2.



Placement of precordial leads over the chest

Precordial			
	V1	*Wilson central terminal (This is different from that of Goldberger's central terminal)	4 th Right intercostal space parasternal
	V2		4 th left intercostal space parasternal
	V3		Midway between V2 and V4
	V4		5 th intercostal space at left midclavicular line
	V5		Level with V4 at left anterior axillary line
	V6		Level with V5 at left mid axillary line
(V stands for Voltage)			

*** Wilson central terminal** is created by adjoining the potential from the right arm (RA) , left arm (LA) , and left leg (LL) electrodes. This terminal represents the average of the unipolar limbs potential near about 0 (zero). This indifferent terminal with negative potential records the potential difference in respect to individual precordial lead.



3. Some pertinent points while placing the 12- leads over the body

Hexaxial Lead system

- The individual limb electrode as guided by its printed colour is placed over the distal part of the corresponding right arm and left arm , just proximal to the wrist joint and over the right leg and left leg , just proximal to the ankle joint –taking special care to place the electrode over the bony prominence , not over the muscular part to have the smooth recording of ECG tracings.

IEC(International Electrotechnical Commission)

Inscription	Colour
RA (Right arm)	 Red
LA (Left arm)	 Yellow
RL (Right leg)	 Black
LL (Left leg)	 Green

- In case of any difficulty in placing the limb electrode over any limb, say in case of amputated or short arm, the exploring electrode may be placed over any point of the corresponding limb.

It would be worthwhile to mention here that :

As per *LeoSchamroth – An Introduction to ELECTROCARDIOGRAPHY - EIGHTH ADAPTED EDITION : P-6 (‘ With distances greater than 15 cm from the heart, the decrement in the intensity of the electrical field is hardly noticeable. Consequently, all electrodes placed at a distance greater than 15 cm from the heart may, in an electrical sense, be considered to be equidistant from the heart ’).

- Right leg electrode works as neutral electrode, as this electrode does not directly contribute to the ECG waveforms tracings – it works as a neutral lead just to complete the electrical circuit.
 - Grounding and thus minimizing noise interference from the environment
 - Enhancing the quality and stability of the ECG tracings by allowing uninterrupted electrical flow through the exploring electrodes.

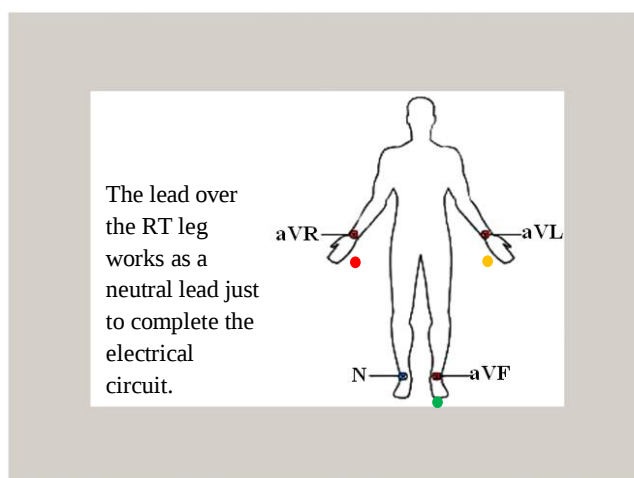


Fig. 1.7

The internal arrangement of bipolar leads I, II, III is facilitated through the internal adjustment within the ECG machine – one should not bother about this, it is automatically adjusted to record the ECG tracings through these bipolar leads. Only is needed to place the corresponding electrodes over the limbs as discussed with.

Precordial Lead system

- The correct placement of the precordial leads needs the correct counting of intercostal spaces – the fingers are moved downward across the upper part of the manubrium till the horizontal bony ridge (Angle of Louis) is felt, the intercostal space just below is 2nd one and accordingly 4th and 5th intercostal spaces are counted.

Just follow the followings points for the purpose :

- Start at the second intercostal space
- Run your finger downward across the next ribs till the needed intercostal space is felt.

Common mistake in ECG precordial lead placement is placing V1 and V2 too high and placing V5 and V6 too medially.

- ☐ The placing of the individual precordial electrode is also guided by its printed colour over V1 , V2 and so on.

IEC(International Electrotechnical Commission)

Inscription	Colour
Lead V1	 Red
Lead V2	 Yellow
Lead V3	 Green
Lead V4	 Brown
Lead V5	 Black
Lead V6	 Purple

Please refer to P-5 for placing of precordial leads over the chest

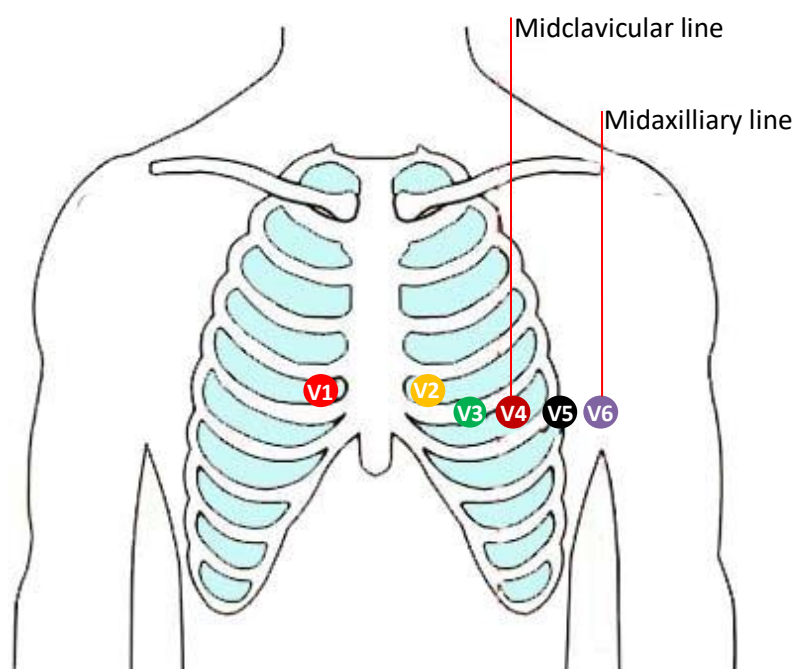
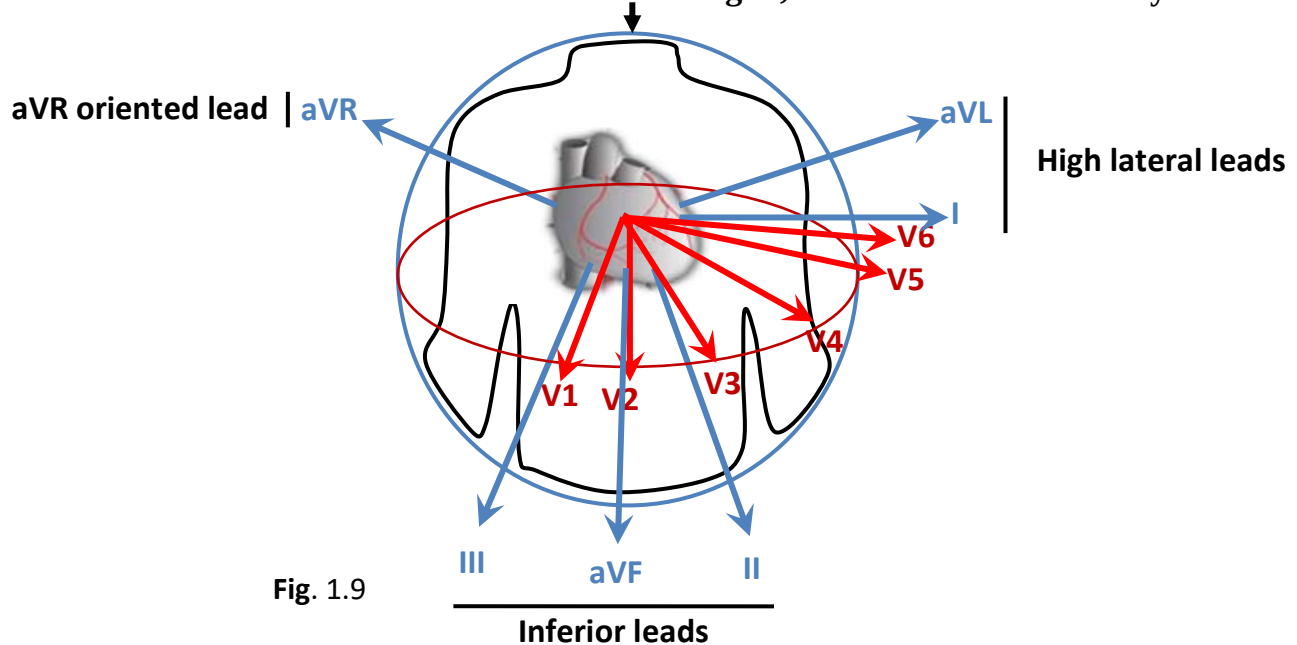


Fig. 1.8

4. A broader canvas of 12-lead system to gain insight the electrical changes in toto at a glance

□ It would be beneficial here to have the combined mental picture of 12-lead system

Classification of ECG based electrical changes , as reflected on 12-lead system



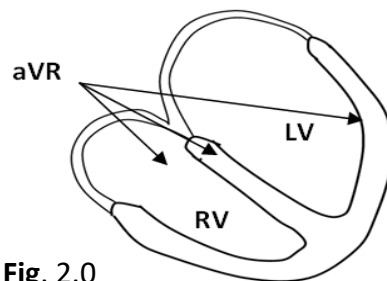
Right ventricular epicardial complex - V1/V2

Transistional zone - V3 / V4

Left ventricular epicardial complex - V5, V6, aVL, I

aVR oriented lead

This is possible to record the electrical activity from the right arm – a lead (aVR) looking opposite to the direction of electrical vector – a very useful discovery.



This aVR lead gives a useful information viewing the right upper side of the heart such as outflow tract of the right ventricle and the basal part of the septum. This lead also gives reciprocal information from the lateral side of the left ventricle.

- ☐ The entire frontal hexaxial system is divided into four quadrants for the purpose of graphing the electrical axis.

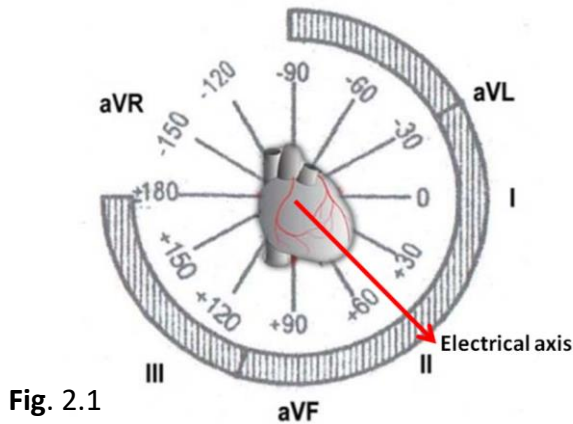


Fig. 2.1

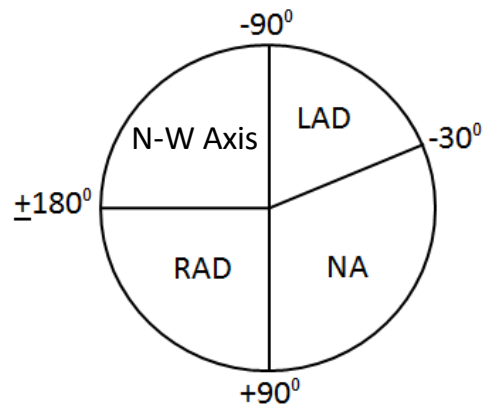


Fig. 2.2

QUADRANT DETERMINATION

Look at QRS complex in lead I and II

QRS Positive in leads I and II	Normal Axis	-30° to +90°
QRS complex is positive in lead I but negative in lead II	Left Axis Deviation	- 30° to -90°
QRS Negative in lead I but positive in lead II	Right Axis Deviation	+90° to +180°

A predominantly positive QRS complex in aVR associated with a predominantly or wholly negative deflection in lead I and aVF- **North -west Axis** - 90° to -180°

Indeterminate QRS axis is not equivalent to north-west axis. This terminology is used if QRS complex is equiphaseic almost in all limb leads , then QRS axis cannot be truly plotted.

- ☐ **The basic principle of electrical axis determination**

The axis of the ECG is the major direction of the overall electrical activity of the heart. The following concept would be very useful while calculating the electrical axis of the heart.

- ✓ Any exploring lead placed within a range of 90° in respect to cardiac vector records positive deflection , at 90° equiphaseic deflection or no deflection and beyond 90° negative deflection (with reference to hexaxial lead system)

- ☐ **The accurate localization of electrical axis**

- One can reach to the nearest multiple of 30 degree as per hexagonal lead system, the electrical axis would be in midway of both the positive deflections. And if one deflection is having more net positivity , the axis should be considered to be tilted towards that lead by the range of 10° or so.

- Then it becomes easier to graph the mean electrical axis of any particular deflection with reasonable accuracy with an error of approximately 10^0 (within a few seconds by the process of inspection, but it comes by gradual practice while interpreting the ECGs).

✓ **And for this purpose, the hexaxial lead system must be kept always either in mind or on the working table, as illustrated below :**

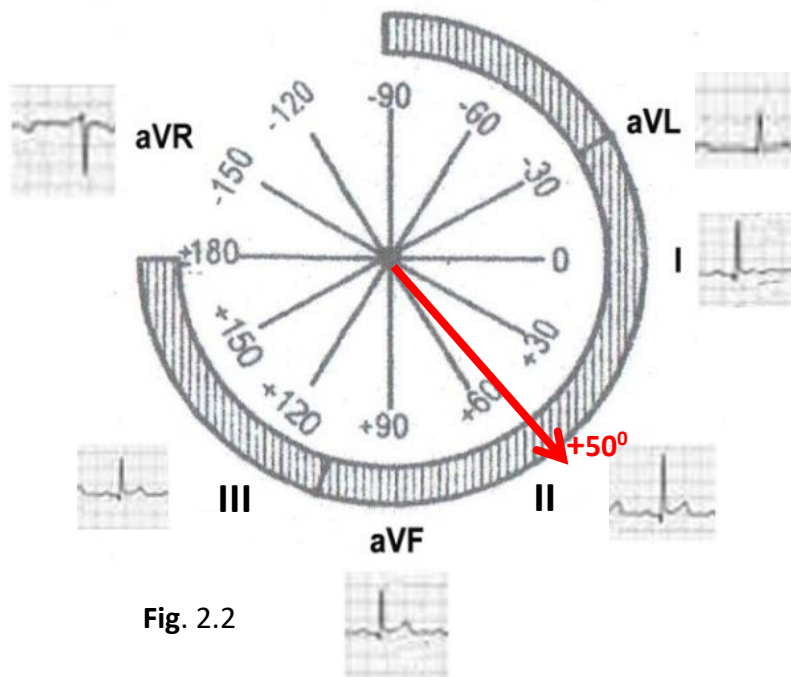


Fig. 2.2

If all the limb leads (except aVR) are showing predominantly positive waves as in this ECG, the axis lies in between $+30^0$ to $+60^0$. For the purpose the negative wave over aVR is plotted against the opposite pole at $+30^0$ as a presumptive positive deflection. The R in lead II is taller as compared to plotted positive wave of aVR at $+30^0$ and so the QRS axis is approximately at $+50^0$.

NB : The normal frontal QRS axis is at -30^0 to $+90^0$

The atrial axis P and the T wave axis can also be determined by following the same principle (P axis : 0^0 to $+75^0$). The axis of the T wave should be accessed in relation to that of the QRS complex (the angle between QRS axis and T wave axis, QRS-T angle usually does not exceed 45^0 - 60^0 on the frontal plane) .

5. Take-Home Message

- The recording of ECG is a technical phenomenon by which the flow of current from the negative pole towards the positive pole is picked up due to the prevailing potential difference in between two poles of a lead system with a bright reply onto the graph through the language of P-QRS-T.
- ECG recording on 12-lead system
 - Hexaxial lead system
 - Precordial lead system
- The hexaxial lead system assesses the overview of the heart's electrical field over the vertical plane, creating a six pointed perspective system which captures the electrical signals from different angles, transforming the complex current into

measurable waves. It makes easier to understand at which direction the cardiac vector is projected.

The three bipolar arm leads I, II, III and the augmented unipolar leads aVR, aVL, aVF constitute the hexaxial lead system

- The precordial lead system assesses the overview of the heart's electrical field over the horizontal plane, it records all the net electrical events from the selected site, as per the placement of the precordial leads V1 to V6. This system records electrical potential from the underneath myocardium.
- Consideration to record the potential difference :
 - Bipolar lead system (I, II, III) since this lead system records the potential in between two limbs, there needs no special terminal to record the changes, it is known as Einthoven system
 - Goldberger's Central terminal : Since the recorded signals from the unipolar leads were small, Goldberger devised a special central terminal to augment these leads by 50% - by averaging only two of the limb electrodes and excluding the one being measured. **This is used as an indifferent electrode (negative electrode) to record the potential difference in respect to unipolar limb leads.**
 - Wilson Central terminal : It is created by adjoining the potential from the right arm (RA), left arm (LA) and the left leg (LL) electrodes to record potential difference in respect to chest leads.
- Right leg electrode works as neutral electrode, while this electrode does not directly contribute to the ECG waveforms tracings – it works as a neutral lead just to complete the electrical circuit.
 - Grounding and thus minimizing noise interference from the environment
 - Enhancing the quality and stability of the ECG tracings by allowing uninterrupted electrical flow through the exploring electrodes.
- It would be beneficial here to have the combined mental picture of 12-lead system.
- The axis of the ECG is the major direction of the overall electrical activity of the heart. The following concept would be very useful while calculating the electrical axis of the heart.

Any exploring lead placed within a range of 90° in respect to cardiac vector records positive deflection, at 90° equiphasic deflection or no deflection and beyond 90° negative deflection (with reference to hexaxial lead system)

□ Normal Electrical Axis

The normal frontal QRS axis is at -30° to $+90^{\circ}$

The atrial axis P and the T wave axis can also be determined by following the same principle (P axis : 0° to $+75^{\circ}$). The axis of the T wave should be assessed in relation to that of the QRS complex (the angle between QRS axis and T wave axis, QRS-T angle usually does not exceed 45° - 60° on the frontal plane).

- With precordial lead system
 - Waves morphology as per sequential activation of the Ventricles from V1 to V6
 - The left ventricle is thicker than that of right ventricle , therefore the net flow is towards the left ventricle.
 - Positive deflection towards the flow of current , equiphasic or no deflection at transitional zone and –ve deflection when away from the flow of current.
- Though this part as below is dealt here at the end but it should be rather touched in the beginning :
 - Voltage standardization is 1 mV = 10 mm (10 small squares deflection vertically on applying 1 mV current)
 Deviations from standardization by 1 mV = 5 mm (half standard) or 1 mV = 20 mm (double standard) may be used in cases where waveforms are unusually large or small.
 - Speed of recording
 The standard paper runs at 25 mm / second.
 Speed with 50 mm / second is used to ‘stretch out’ the ECG for detailed analysis of rapid arrhythmias or closely spaced waveforms.

6. References

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https://www.google.com/search?q=Recording+of+ECG+on+12-lead+system&oq=Recording+of+ECG+on+12-lead+system&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigATIHCAIQIRigATIHCAIQIRigAdIBCjI1MTE2ajBqMTWoAgCwAgA&sourceid=chrome&ie=UTF-8
