https://africanjournalofbiomedicalresearch.com/index.php/AJBR
Afr. J. Biomed. Res. Vol. 27(4s) (December 2024); 6320-6328
Research Article

Determination Of Cardiac Vector Magnitude And Angle In The 4 Quadrant Graph Using Cardiac Vector Theory

Dr.T.Rajini Samuel[1*]

[1*]Professor, Department of Biochemistry, Shri Sathya Sai Medical College and Research Institute, SBV Chennai Campus, Sri Balaji Vidyapeeth Deemed to be University, Shri Sathya Sai Nagar, Ammapettai, Thiruporur, Chengalpet District, Tamil Nadu, 603108, Phone number: 7305971317 & 9884971317, Email address: samuel.biochemistry@gmail.com & samuel.rajini@gmail.com

***Corresponding Author:** Dr.T.Rajini Samuel
*Professor, Department of Biochemistry, Shri Sathya Sai Medical College and Research Institute, SBV Chennai Campus, Sri Balaji Vidyapeeth Deemed to be University, Shri Sathya Sai Nagar, Ammapettai, Thiruporur, Chengalpet District, Tamil Nadu, 603108, Phone number: 7305971317 & 9884971317, Email address: samuel.biochemistry@gmail.com & samuel.rajini@gmail.com

ABSTRACT
INTRODUCTION: The angle determination in ECG is done using the hex-axial reference system with the changes observed in two leads namely Lead I and aVF or using three leads namely Lead I, Lead II and aVF. The angle determination is very difficult in certain conditions. Cardiac vector theory helps in the understanding and determination of cardiac vector magnitude and angle in ECG interpretation.
AIM: To derive and calculate the cardiac vector magnitude and cardiac vector angle and to correlate with the lead vector in all the 4 quadrants of the hex-axial reference system.
MATERIALS AND METHODS: The cardiac vector theory derived using the projection of heart vector onto the lead vector is applied in detail in different quadrants of the 4 quadrant graph to derive the cardiac vector angle and magnitude.
RESULTS: The determination of magnitude and angle(axis) of Cardiac vector was cited with 11 examples. Cardiac vector magnitude and angle determination in each of the 4 quadrant was clearly depicted using graphical figures.
CONCLUSION: The cardiac axis calculation remains an arduous and challenging task. Therefore, this detailed approach using vector principles will serve as an important guide to the medical students to understand and analyze the cardiac axis in various clinical conditions.

KEY WORDS: ECG, Axis, Angle, Magnitude, Cardiac Vector Theory

***Author for correspondence: Email:** samuel.biochemistry@gmail.com & samuel.rajini@gmail.com*

Received:30/11/2024 Accepted: 02/12/2024

DOI: https://doi.org/10.53555/AJBR.v27i4S.4776

INTRODUCTION:

The **angle determination** in **ECG** is done using the changes observed in **two leads** namely Lead I and aVF or using **three lead** analysis (Lead I, Lead II and aVF). The angle can be determined using **grant method** by observing and identifying the **iso-electric lead** with the help of vector principles (Leo Shamroth 2010, Atul Luthra 2004,Hurst JW 2002). The **cardiac vector**

theory can be easily applied to explain these concepts. If the **heart vector** is **perpendicular** to a particular lead, then the net voltage recorded in that particular lead will be **zero**. If the heart vector is **parallel** to a particular lead, then the net voltage recorded in that particular lead will be **maximum** (Rajini Samuel T 2012, Rajini Samuel T 2018). If the heart vector is perpendicular to aVF or parallel to Lead I, then the angle will be zero degree. If the heart vector is parallel to aVF or perpendicular to Lead I, then the angle will be 90º (Rajini Samuel T 2018, Rajini Samuel T 2021). Using the **hex-axial reference system**, the **angle** can be **analyzed** but it requires thorough knowledge of the lead orientation system of ECG and also difficult to analyze angle in all cases. But the **trigonometric formula** is very easy to apply and accurately calculate the cardiac vector angle in various conditions(Rajini Samuel T 2018, Rajini Samuel T 2023). The cardiac vector theory derived using the projection of heart vector onto the lead vector helps to clearly understand the derivation of cardiac vector angle and to correlate the changes in cardiac vector angle in different quadrants.

Cardiac Vector theory states that voltage recorded in a particular lead is the result of dot product between Cardiac Vector (electrical field vector in volt/metre) and Lead Vector (measured in metre). Hence voltage(measured in volt) is a scalar quantity (Rajini Samuel T 2018, Rajini Samuel T 2023).The voltage recorded in a particular lead depends on both the magnitude and direction of cardiac vector and only on the direction of the lead vector.In ECG graph paper, **each small square** is **1 mm** and **each large square** is **5 small squares**. **1 millivolt signal** from the standardized ECG machine produces **10 millimetre vertical** deflection.Each **small square** on the vertical axis represents **0.1 mV** and each **large square** represents **0.5 mV** (Leo Shamroth 2010, Atul Luthra 2004).

This research study discuss in detail the derivation and calculation of cardiac vector magnitude and angle and its correlation with the lead vector in all the 4 quadrants of the hex-axial reference system.

MATERIALS AND METHODS:

Right angled triangle:

In a right angled triangle (one of the angle of the triangle is 90º), the side **opposite** to **90º** is **hypotenuse (shown in figure 1)**. The side adjacent to the angle α is called **adjacent side** and the side opposite to the **angle** α is called **opposite side** (Rajini Samuel T 2018). According to **Pythagoras theorem**, the **square** on the **hypotenuse** is equal to the sum of the squares on the other two sides (adjacent and opposite side).

In trigonometry,

Sin α = opposite side / hypotenuse

Cos α =adjacent side / hypotenuse

Tan α = sin α / cos α

Tan α = opposite side / adjacent side

[where 0° < A < 90°]

The values of Sin,Cos and Tan angle are clearly shown in **table 1.** Sin angle value is positive in 1st and 2nd quadrant. Cos angle value is positive in 1st and 4th quadrant. Cos angle value is negative for obtuse angle (**90° < θ < 180°**). Tan angle value is positive in 1st and 3rd quadrant and negative in 2nd and 4th quadrant.

Figure 1: Trigonometry in Right angled Triangle

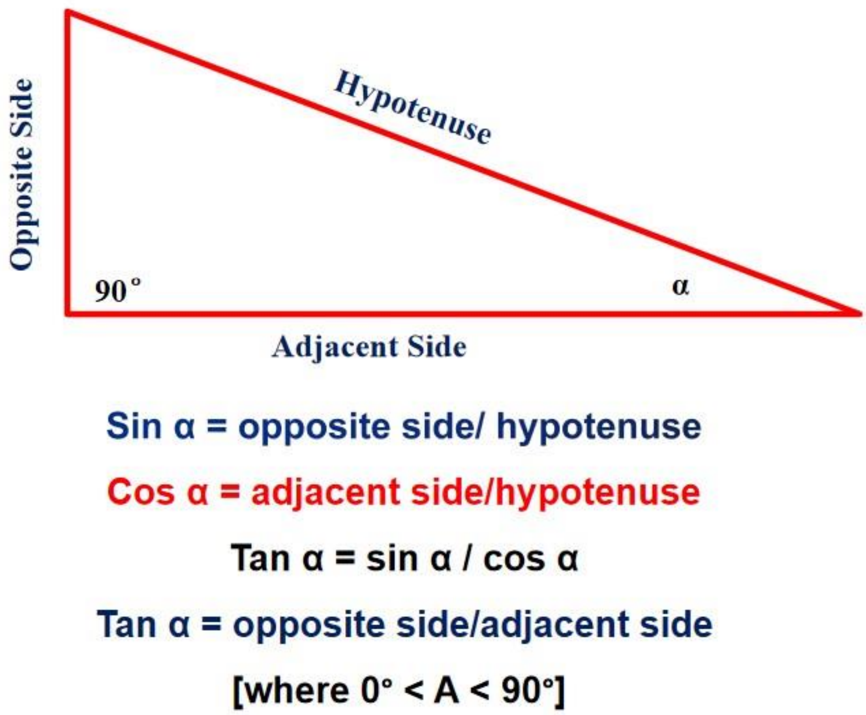
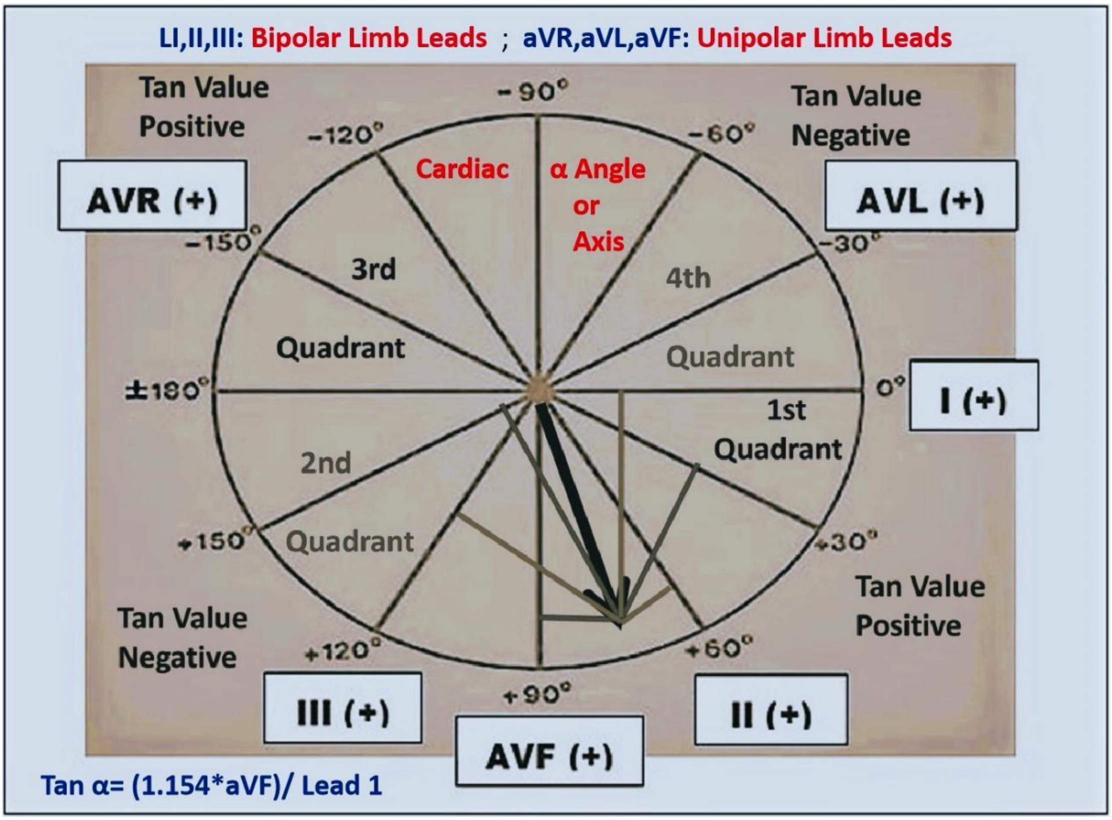


Table 1: The values of Sin,Cos and Tan angle

Angle Values	**0⁰**	**30⁰**	**45⁰**	**60⁰**	**90⁰**
Sin angle Values	0	0.5 or [1/2]	0.707 or [1/√**2**]	0.866 or [√**3**/2]	1
Cos angle Values	1	0.866 or [√**3**/2]	0.707 or [1/√**2**]	0.5 or [1/2]	0
Tan angle Values	0	1/√**3** (0.577)	1	√3 (1.732)	Infinity (undefined)

The hex-axial reference system is constructed by the combination of the bipolar limb leads (LI, LII & LIII) and unipolar limb leads(aVR, aVL & aVF) which is clearly shown in **figure 2**. The **bipolar limb leads** LI(0⁰), LII(60⁰), LIII(120⁰) and **unipolar limb leads** aVR(-150⁰), aVL(-30⁰), aVF(90⁰) are forming **two electrical equilateral triangles** in the hex-axial reference system. The heart in zero potential is located at the centre of the hex-axial reference system (Rajini Samuel T 2012, Rajini Samuel T 2018).

Figure 2: Hex-axial Reference System using Bipolar & Unipolar Limb Leads



Triangle OHV is a right angled triangle. The point O denotes the origin (zero point).**Heart vector OH → is projected on** to the **lead vector (O L→).** A perpendicular line drawn from the point H meets the **point V** on the **lead vector (**shown in **figure 3** and **4).** The lead vector denotes the orientation of the electrode. The **magnitude** of the **heart vector**[**OH]** can be determined using the application of pythagoras theorem.The cardiac angle(axis) is the angle between the cardiac vector and the lead I vector(oriented at **0⁰**). The cardiac angle can be calculated using the values of Sinα, Cos α and Tan α values (Rajini Samuel T 2012, Rajini Samuel T 2018, Rajini Samuel T 2021, Rajini Samuel T 2023).

Figure 3: Four Quadrant Graph for Determination of Cardiac Vector Angle and Magnitude

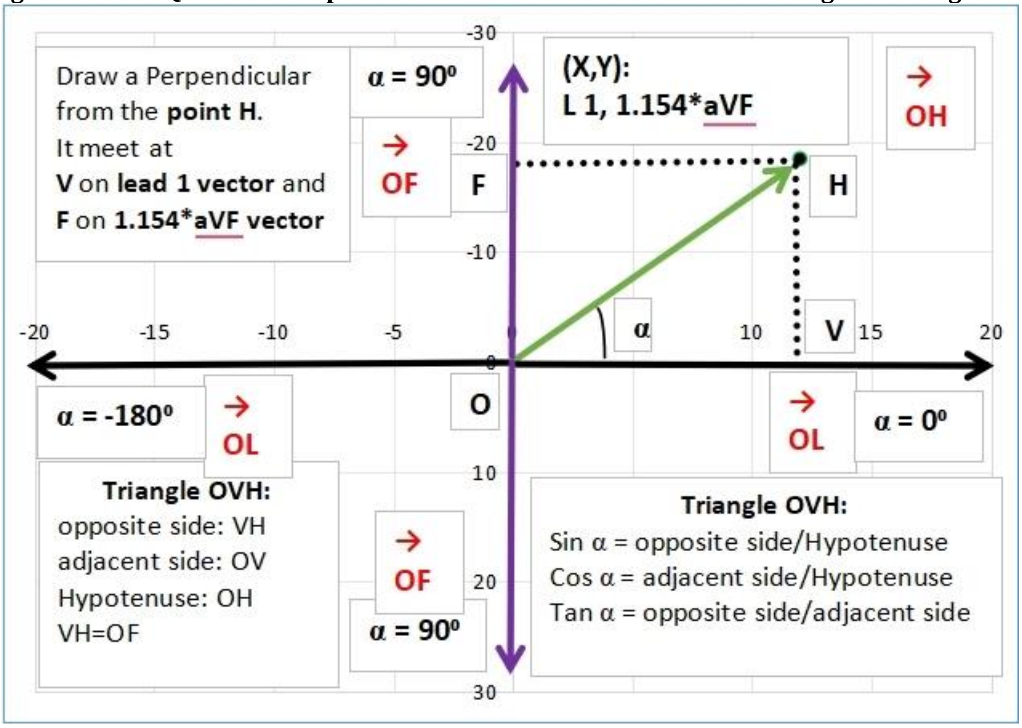
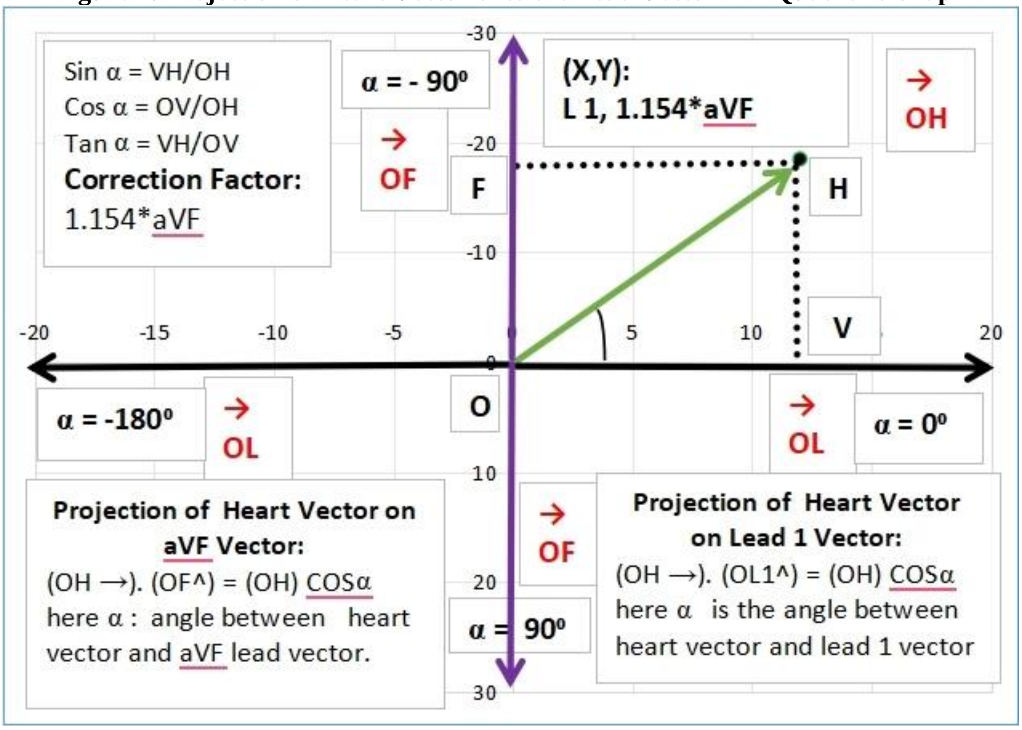


Figure 4: Projection of Heart Vector onto the Lead Vector in 4 Quadrant Graph



The magnitude of the cardiac vector from the ECG graph can be easily calculated using the **voltages recorded** in the Bipolar limb **lead LI** and unipolar limb **lead aVF** by the application of **pythagoras theorem**.

$[\overrightarrow{OH}]^2 = LI^2 + (1.154*aVF)^2$

$[\overrightarrow{OH}]$ = Square Root of ($LI^2 + (1.154*aVF)^2$)

The unipolar and bipolar limb leads have different resistance. So, the **correction factor** of **1.154** is to be applied to compare them (Novosel D et al.,1999, Rajini Samuel T 2012, Samuel TR 2024). The **magnitude** of the **heart vector** is represented by the **square root** of **($LI^2 + (1.154*aVF)^2$)**.

Cosα=

Voltage recorded in lead I / Magnitude of Heart vector

Cosα= Lead I / (Square Root of ($LI^2 + (1.154*aVF)^2$)

Sinα =

Voltage recorded in aVF/ Magnitude of Heart vector

Sinα =

1.154 *aVF/ (Square Root of ($LI^2 + (1.154*aVF)^2$)

Tan α = sin α / cos α

The formulae to calculate the angle determination in ECG is as follows.

Tan α= (1.154*aVF)/ Lead I

RESULTS:

Cardiac vector magnitude and angle determination was done by applying the cardiac vector theory using trigonometric mathematics. The relationship of the voltages of the various limb leads were utilized to derive the **voltages** measured in **each leads** which are shown in **mm**.

The determination of magnitude and angle(axis) of Cardiac Vector is clearly cited with 11 examples in the **table 2**. Voltages recorded (according to Cardiac Vector Theory) in X and Y coordinates (X axis: Lead I and Y axis: 1.154 *aVF) in the 4 Quadrant hex-axial reference system is clearly depicted with examples in the **figure 5**. **Cardiac α angle determination** and **cardiac vector magnitude** [**OH]** determination using the voltages recorded in X and Y coordinates (X axis: Lead I and Y axis: 1.154 *aVF) in the 4 Quadrant graph is clearly depicted in **figure 6** and **figure 7** respectively.The cardiac vector magnitude and angle determination in **1st, 2nd , 3rd and 4th quadrant** of the hex-axial reference system is individually shown in **figure 8,9,10 and 11** respectively for detailed understanding and better clarity.

Table 2: Determination of magnitude and angle(axis) of Cardiac Vector using voltages measured in mm in ECG

S.NO	Lead 1	aVF	1.154*aVF	$[\vec{OH}]^2$	$[\vec{OH}]$	α Angle
1st Quadrant : Left Lower Quadrant in Hex-axial Reference System						
1	14	7.5	8.655	270.91	16.46	31.72°
2	8	10	11.54	197.17	14.04	55.27°
3	4	18	20.77	447.48	21.15	79.10°
2nd Quadrant: Right Lower Quadrant in Hex-axial Reference System						
1	-10	21	24.23	687.29	26.22	180° - 67.58° = 112.42°
2	-18	7	8.08	389.25	19.73	180° - 24.17° =155.83°
3rd Quadrant: Right Upper Quadrant in Hex-axial Reference System						
1	-14	-12	-13.85	387.77	19.69	-180° + 44.69° = -135.31°
2	-10.5	-18	-20.77	541.73	23.28	-180° + 63.18° = -116.82°
4th Quadrant: Left Upper Quadrant in Hex-axial Reference System						
1	12	-16	-18.464	484.92	22.02	- 56.98°
2	6	-20	-23.08	568.69	23.85	- 75.43°
Cardiac Vector Perpendicular to Lead I Vector						
1	0	-12	-13.85	191.77	13.85	- 90°
2	0	15	17.31	299.64	17.31	90°

Figure 5: Voltages Recorded (in mm in ECG) in X and Y coordinates (Lead I VS 1.154 *aVF) of 4 Quadrant Graph with 11 examples

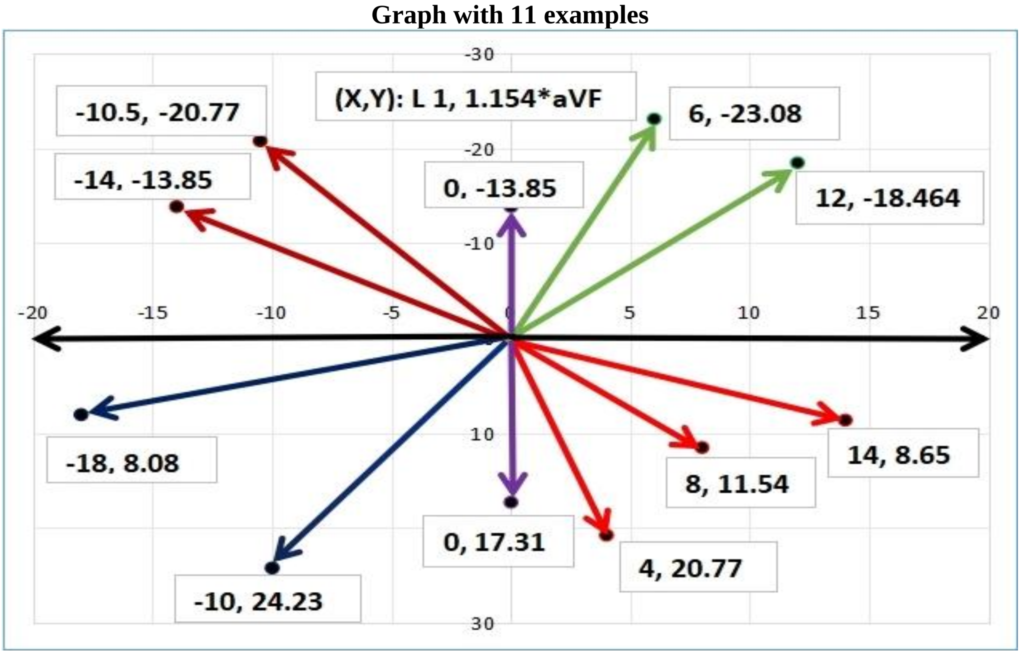


Figure 6: Cardiac α Angle Determination using voltages recorded in X and Y coordinates (Lead I VS 1.154 *aVF) of 4 Quadrant Graph with 11 examples

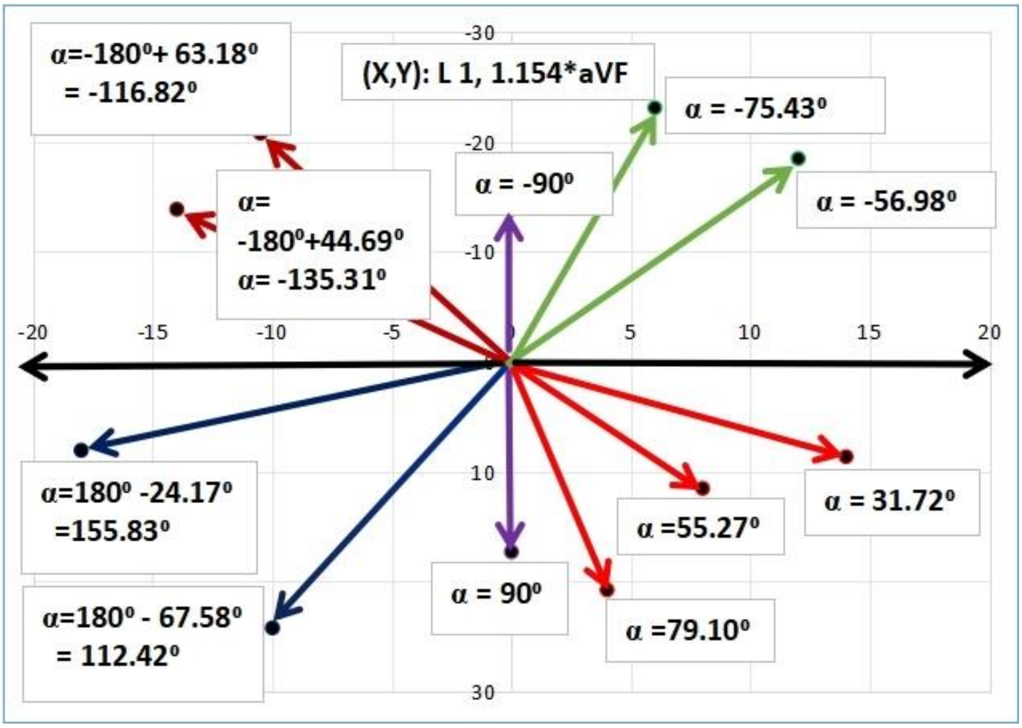


Figure 7: Cardiac Vector Magnitude [OH] determination using voltages recorded in X and Y coordinates (Lead I VS 1.154 *aVF) of 4 Quadrant Graph with 11 examples

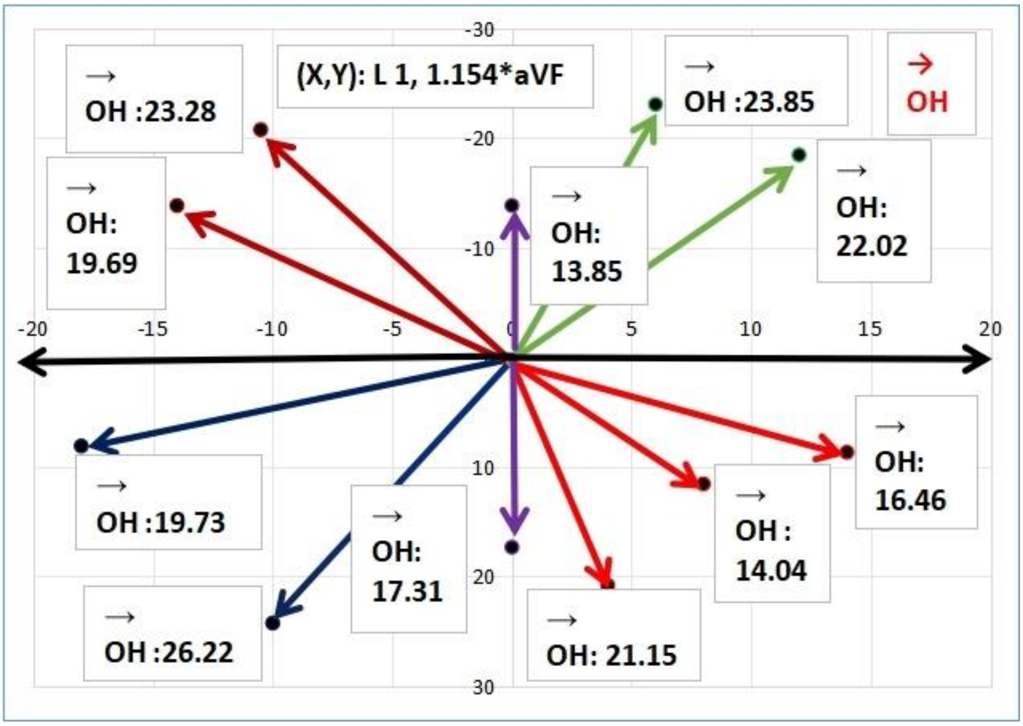


Figure 8: Cardiac Vector Magnitude and Angle determination in 1st Quadrant

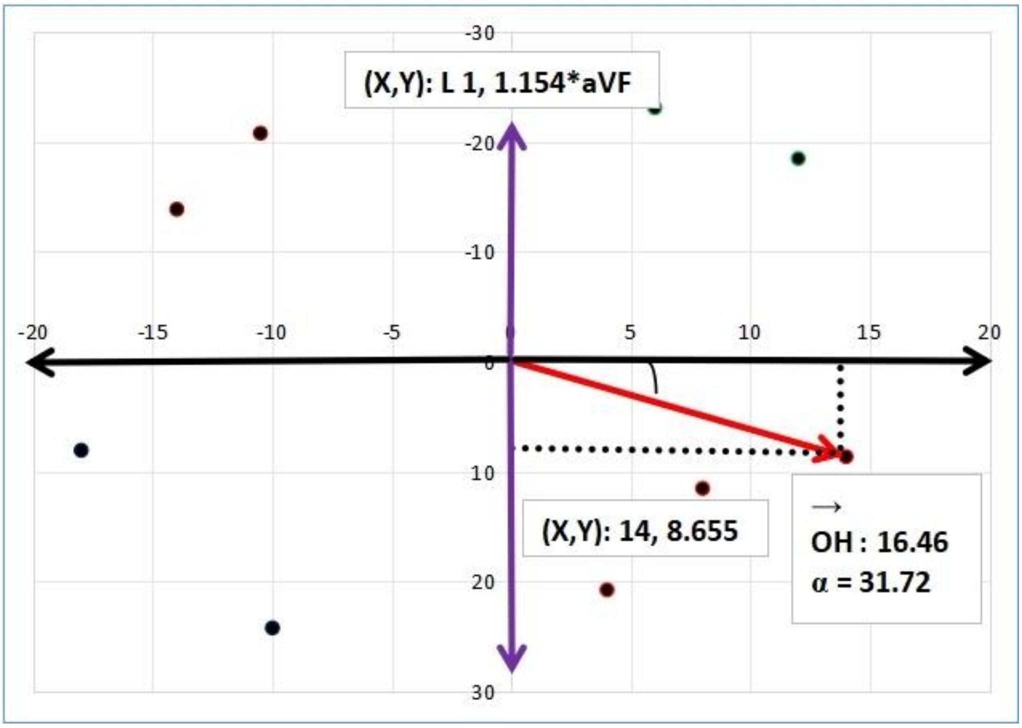


Figure 9: Cardiac Vector Magnitude and Angle determination in 2nd Quadrant

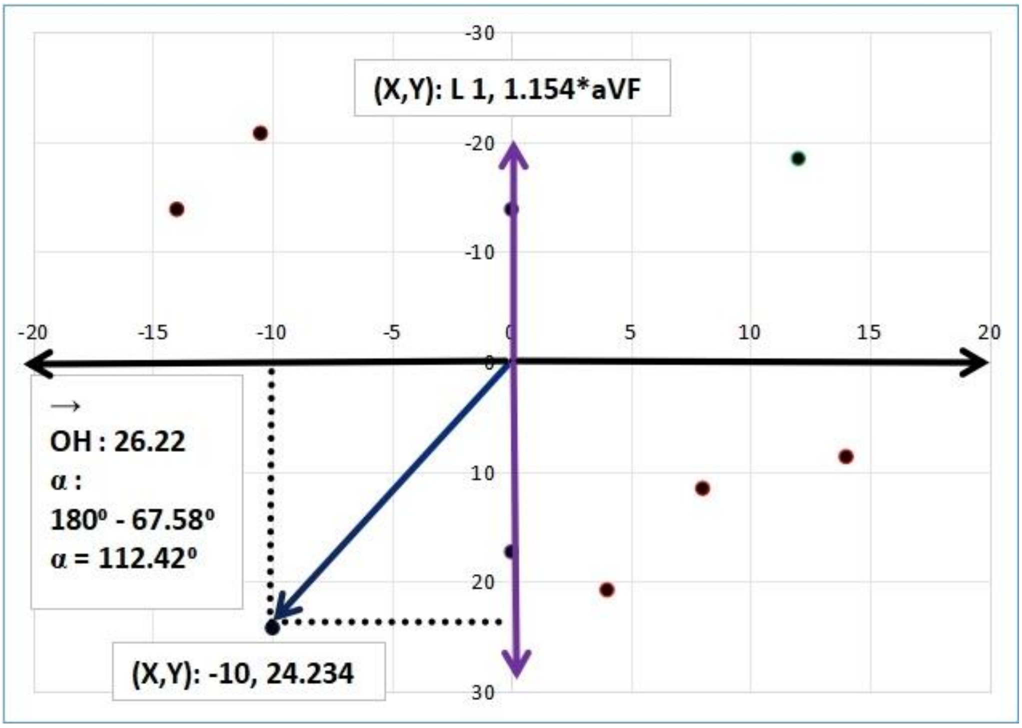


Figure 10: Cardiac Vector Magnitude and Angle determination in 3rd Quadrant

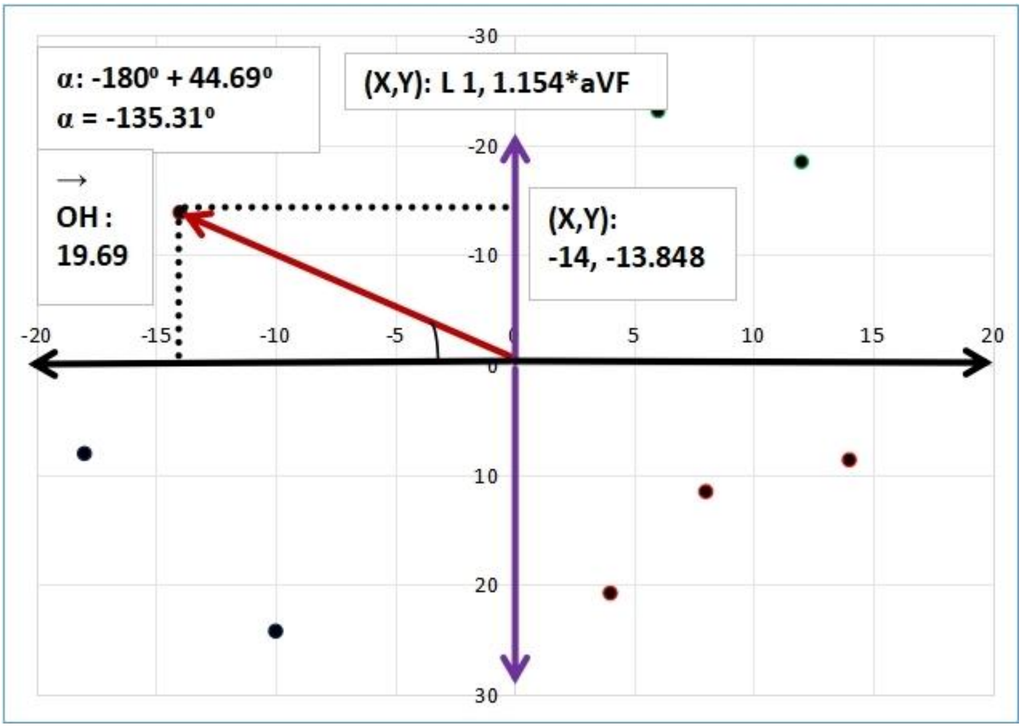
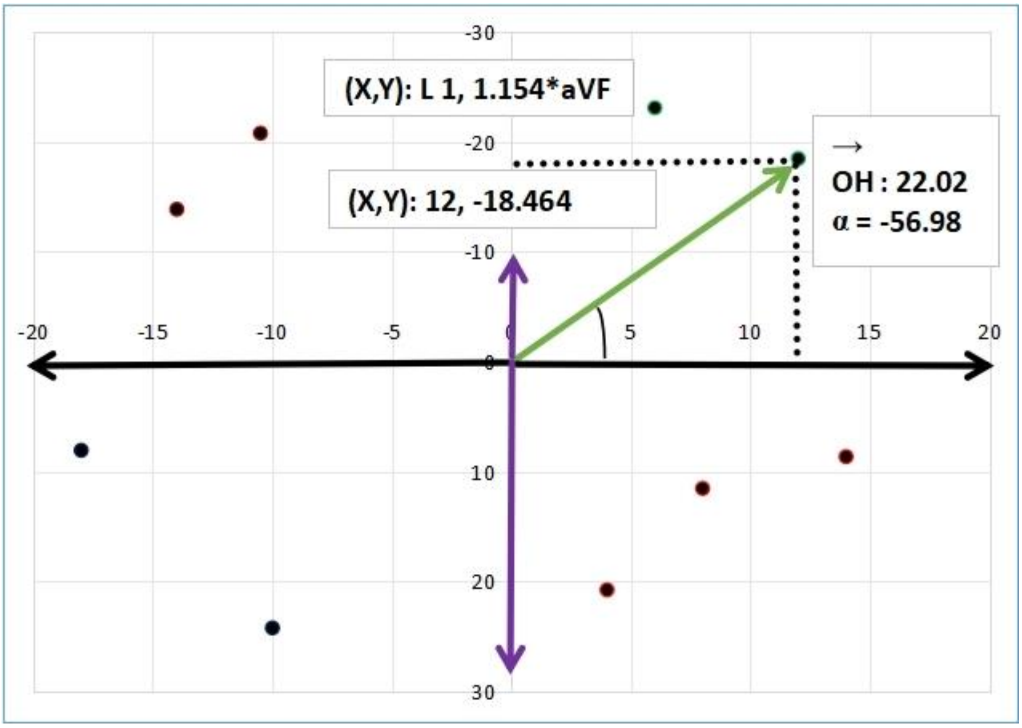


Figure 11: Cardiac Vector Magnitude and Angle determination in 4th Quadrant



DISCUSSION:

The **cardiac vector theory** can be applied to calculate the cardiac vector angle and magnitude. The voltage recorded in Lead I depends on the magnitude of cardiac vector and the angle between heart vector and lead I vector(0^o).The voltage recorded in aVF lead depends on the magnitude of cardiac vector and the angle between heart vector and aVF lead vector(90^o).

Similarly the voltage recorded in any of the bipolar limb leads [LI(0^o), LII(60^o),LIII(120^o)] and any of the unipolar limb leads [aVR(-150^o),aVL(-30^o) and aVF(90^o)] can be explained using the magnitude of the heart vector and the angle between heart vector with that particular lead vector (Rajini Samuel T 2024).The unipolar and bipolar limb leads have different resistance. So, the **correction factor** of **1.154** is to be applied (**multiplied**) to **each unipolar limb lead voltages** to compare them.

The magnitude of the heart vector is determined using the application of pythagoras theorem. In the **X coordinate** the **voltage (vertical deflection in mm in ECG)** recorded in **lead 1** is used and in **Y coordinate 1.154 *aVF** is used. The angle can be determined using either Sinα, Cosα or Tanα and all will give the same results only. The calculation of cardiac angle using sin α and cos α involves the magnitude of heart vector. So only if the heart vector magnitude is calculated, the cardiac angle can be determined using sin α and cos α. But if Tanα (Tanα = sinα / cosα) is used, then only the voltage recorded in lead 1 and 1.154 *aVF is sufficient to calculate the cardiac angle.

The cardiac vector angle is the angle between heart vector and the positive axis of lead vector LI(0^0). In the **1st Quadrant,** both lead 1 (x axis) and 1.154 *aVF (y axis) are positive. So the angle calculated using **Tanα directly gives** the cardiac angle value (shown in **figure 8**). In the **2nd quadrant**, 1.154 *aVF(y axis) is positive but the lead 1 (x axis) is negative and the orientation of LI is 180^0. So the angle calculated using Tanα gives the heart vector oriented with the negative axis of Lead 1. So it has to be **subtracted from 180^0** to get the cardiac vector angle which is the angle between the **heart vector** and the **positive axis** of **lead 1 vector**(shown in **figure 9**).

In the **3rd quadrant**, both lead 1 (x axis) and 1.154 *aVF(y axis) are negative. The angle calculated using Tanα gives the heart vector oriented with the negative axis of Lead 1. The **angle** in **this quadrant** can be given in **two forms** either as **positive** (between **180^0 and 270^0**) or in the form of **negative** (between **-90^0 and -180^0**). The positive form can be directly given by the **addition** of **180^0** to the **angle calculated** using **Tanα**. But in **ECG**, in routine clinical teaching and practice, **this quadrant** is given in **negative angle values**. The negative form can be given by the **addition of -180^0** to the angle calculated using Tan α. The cardiac vector angle is the angle between the heart vector and the positive axis of lead 1 vector which is not changed in both the calculations, so **both representation** is **correct** and **accurate**(shown in **figure 10**). In the **4th quadrant**, lead 1 (x axis) is positive and 1.154 *aVF(y axis) is negative and the angle is between **0^0** and **-90^0.** So the angle calculated using **Tanα** is directly represented in negative value (shown in **figure 11**).

The normal QRS vector is oriented from -30° to 90° and the normal T wave vector is oriented between 0° and 90°. The normal QRS -T angle does not usually exceed 60° in the frontal plane in the hex-axial reference system (Leo Shamroth 2010).The T wave vector should be analyzed always with QRS vector. ST vector denote the direction of the current of injury. The understanding of the derivation and calculation of cardiac vector magnitude and angle in each of the 4 quadrant of the hex-axial reference system plays a significant role in the determination of cardiac axis.

CONCLUSION:

Cardiac vector theory helps in the understanding and determination of cardiac vector magnitude and angle in ECG interpretation. The cardiac axis calculation remains an arduous and challenging task. Therefore, this detailed approach using vector principles will serve as an important guide to the medical students to understand and analyze the cardiac axis in various clinical conditions.

Source(s) of support: NIL

Acknowledgement: NIL

REFERENCES:

1. Leo Shamroth. An introduction to electro cardiography.7TH edition. Blackwell science Ltd, 2010, pp:7-172
2. Atul Luthra ECG Made Easy.Third Edition.Jaypee Brothers Medical Publishers. 2004
3. Hurst JW.The use of the Grant method to interpret electrocardiograms.J Am Coll Cardiol. 2002;39(11):1878-80.
4. Rajini Samuel T. What to the world Einthoven talking about?, Journal of Pharmaceutical and Biomedical Sciences(JPBMS).2012; 23(23):1-7
5. Rajini Samuel T. Formulation and Clinical Application of Cardiac Vector Hypotheses in ECG Interpretation Using Vector Physics Principle.EJPMR. 2018;5(11):523-536
6. Rajini Samuel. Application of Cardiac Vector Theory In ECG Interpretation, PARIPEX - Indian Journal of Research. 2021;10(10): 30-32
7. Rajini Samuel T. Unlocking the Cardiac Vector Theory and Einthoven Equilateral Triangle Model for an Efficient Teaching Tool in ECG Interpretation.ARC Journal of Cardiology.2023;8(1):12-22
8. Novosel D, Noll G, Luscher TF. Corrected formula for the calculation of the electrical heart axis. Croat Med J.1999;40(1):77-79.
9. Samuel TR. Angle Determination in ECG Using Trigonometric Formula. Adv Nursing Patient Care Int J. 2024;7(1):180084
10. Rajini Samuel.Stepwise Approach In ECG Interpretation Using Vector Concepts Involved In Cardiac Vector Theory.African Journal of Biomedical Research.2024; 27(3S):3389 -3397