ORIGINAL RESEARCH PAPER

Cardiology

APPLICATION OF CARDIAC VECTOR THEORY IN ECG INTERPRETATION

KEY WORDS: ECG Interpretation, Cardiac Vector, Lead Vector

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ABSTRACT

Electrocardiography (ECG) is one of the oldest diagnostic tool in medicine yet it's interpretation remains an arduous task. The concept of Einthoven triangle and the cardiac vector describing the electrical activity of the heart was first described by Einthoven even before a century but he never published a complete detailed description of the same. After many decades, the complete Heart-Lead vector relationship and Einthoven's equilateral triangle hypotheses was published by the current author in previous research articles. The present study summarizes the clinical applications of cardiac vector theory to be applied at the bed side for ECG interpretation.

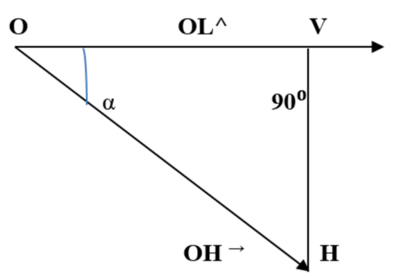
INTRODUCTION:

Electrocardiogram (ECG) is one of the most important diagnostic tool for diagnosis of coronary artery disease. ECG interpretation is the most important part in the initial evaluation of patients presenting with cardiac complaints but it is often difficult and an arduous task especially for the junior medical healthcare professionals. [1,2] The concept of **cardiac vector** describing the electrical activity of the heart and the **equilateral triangle model** with heart at the centre of the **homogeneous volume spherical conductor** was first described by **Einthoven** even before a century. But he **never published** a complete **detailed** description of the same.[3] The **complete heart-lead vector relationship** using cardiac vector and the Einthoven's equilateral triangle hypotheses was explained in detail by **Rajini Samuel (current author).**[4,5]

The heart is situated at the centre of the electric field which it generates and the right arm, left arm and left leg are the extensions of its electrical field. [6] The heart (in zero potential) is at the origin in the centre of the hex-axial reference system. When the heart acquires certain potential (during depolarization and repolarisation) the triangle gets shifted but the **equilateral shape** of the triangle **remains** the **same** in **any of the 4 quadrants** of the hex-axial reference system. The right arm, left arm and left leg are the vertices of an **electrical equilateral triangle** and not an anatomical triangle. **Cardiac vector hypotheses** states that cardiac vector is an **electrical field vector** and the voltage recorded in a particular lead is the result of scalar (dot) product between cardiac and the lead vector.[4,5] The aim of the current research study is to summarize the clinical applications of cardiac vector theory to be applied at the bed side for ECG interpretation.

MATERIALS AND METHODS:

Projection of Heart vector on Lead vector



OH → or **h**→(Heart Vector) is projected onto the **OL**→ or l→ (Lead Vector)

In the right angled triangle OHV :

OV: voltage recorded in that particular lead (**OV= OH COS**α)

OL^: unit vector of magnitude one and has only direction which denotes the orientation of the electrode (lead vector or lead axis). {**OL^ = (OL→)/OL**}

Cardiac Vector Hypotheses:

(OH →). (OL^) = (OH) COSα OR **(h→). (l^)= (OH) COS**α

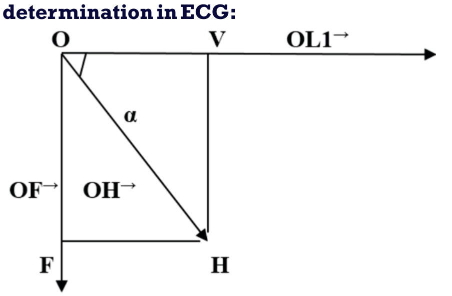
The above equation clearly indicates that voltage recorded in a particular lead is the result of dot product between the lead vector (measured in metre) and the cardiac vector (measured in volt/metre).Hence voltage (measured in volt) is a scalar quantity. [4,5]

Table 1 :The values of cosine (cos) angles

Cos angles	cos0⁰	Cos30⁰	cos45⁰	cos60⁰	cos90⁰	90° < θ < 180° (obtuse)
Values	1	0.866 or [√3/2]	0.707 or [1/√2]	0.5 or 1/2	0	Negative

From the above values, it is very clear that as the **angle increases,** the **cos value will decrease**. The value is **zero** for **90⁰** and **negative** for **obtuse angle.** [4]

Angle determination in ECG:



O: point of **origin** (**zero** at the centre of the hex-axial reference system)

OL1→: lead I Vector ; **OF→:** lead aVF Vector ; **OH→:** Heart Vector

In the right angled triangle OVH:

OV: Voltage recorded in lead I ; **OF:** Voltage recorded in lead aVF

Tan α = OF/OV (from the diagram it is very clear that OF = VH)

Tan α **= aVF/lead I**

The unipolar and bipolar limb leads have different resistance. So, the correction factor of 1.154 is to be applied.[4,5,7] The formulae to calculate the angle determination in ECG is

Tan α**= (1.154*aVF)/ Lead 1**

Table 2: The values of tangent (tan) angles

Tan angles	$\tan 0^0$	$\tan 30^0$	$\tan 45^0$	$\tan 60^0$	$\tan 90^0$
Values	0	$1/\sqrt{3}$ (0.577)	1	$\sqrt{3}$ (1.732)	Infinity

DISCUSSION:

In ECG interpretation it is well known that **T vector** move **away** from the **affected** region, **QRS** vector move **away** from the **infarcted** or **necrosed** region and the **ST** vector (current of injury vector) move **towards** the **injured** surface. More blood is needed to repolarise than to depolarize so reduced blood flow (ischemia) will not be sufficient to cause repolarisation of the muscle. Because **T-wave** is produced by **repolarisation** of the ventricles, **ischemia** causes deviation of T-wave vector. [4,5,6] During ischemia, blood flow to the heart muscle is reduced but it is sufficient to maintain life of the myocardium so it does not die. **ST segment** is an **iso-electric period** in the ECG. If the myocardium of the heart is injured it results in leakage of current during this period which flows between pathologically depolarized and normally polarized areas. This is called the **current of injury**. [4,5,6] In myocardial infarction, the tissue is necrosed, so QRS-vector which denotes the ventricular depolarisation does not get depolarized and it is **electrically inert** which is called **electrical hole**. In intra-ventricular conduction defect (duration of the QRS complex is prolonged), the **T vector** move **away** from the **QRS vector** due to the secondary phenomena and do not indicate primary abnormality. The normal **QRS (Vector)** axis is **-30°** to **90°** and the normal T **wave axis** is between **0°** and **90°**. The T wave axis must be considered in its relationship to the QRS axis. The normal **QRS-T angle** does **not** normally **exceed 60°**.[4,5,6]

There is a gradual resolution of the abnormalities following the fully evolved phase of acute myocardial infarction which is the **chronic stabilized phase** where the **elevated ST** segment gradually **returns** to the **baseline**, becoming predominantly iso-electric once again, the **inverted T wave** gradually **regains** its **positivity** and even the **QRS** complex **may regain some** of its previous **positivity**.[4,6] The **magnitude** and **velocity** of the **vector** can change due to ischemia, injury, infarction, certain drugs(Digitalis, Quinidine) and electrolyte (potassium, magnesium, calcium) abnormalities.[6,8,9] The **reversal** and the **misplacement** of the leads can hinder proper ECG interpretation.[10] The current study **summarizes** the **application** of the **cardiac vector hypotheses** with **proper heading** to the **already well known concepts** in ECG for better understanding which when properly utilized helps in reducing the arduous task of ECG interpretation.

Voltage Recorded in a Particular Lead:

1. **Cardiac Vector Hypothesis** states that voltage recorded in a particular lead in ECG is due to the **projection** of Heart (Cardiac) vector on Lead vector.
2. The cardiac vector is an **electrical field vector** of dimension volt/metre and the **lead** vector (unit vector in metre) denote the **orientation** of the **electrode** position.
3. The voltage recorded in a particular lead depends on **both** the **magnitude** and **direction** of the **cardiac vector** but **only** on the **direction** of the **lead vector**.

Cardiac Vector Orientation to the Electrode Position:

4. If a cardiac vector is **parallel** to a particular lead (α angle is **zero**) then it will make the greatest impression on that lead and the ECG will record the **maximum deflection** on that lead.(**Cos 0** is **one)**
5. If a cardiac vector is directed at **right angles** (90°) or perpendicular to a particular lead axis, the net impression on that lead will be either equiphasic or a **null deflection** (**Cos 90** is **zero**).
6. As the **angle** α between cardiac and lead vector **increases,** the **voltage** recorded in that particular lead will **decrease** and vice versa**.**
7. If the two vectors are in the opposite direction, the voltage recorded in that particular lead will be negative (**Cos value** for **obtuse** angle is **negative**).

Bipolar and Unipolar Limb Leads have Different Resistance:

8. The **overall magnitude** of the **voltage** recorded in the **bipolar limb leads** (leads I, II, and III) will be **higher** than the **unipolar limb leads** (aVR, aVL, and aVF) because the bipolar and unipolar limb leads have different resistance and the **ratio** of their resistance is **4/3**. If the resistance(R) is increased, the voltage(V) is also increased for the same current(I) flowing which is according to ohms law(**V=IR).**

Correction Factor in Angle Determination Formulae:

9. Angle determination can be done using the voltage recorded in **aVF** and **lead I alone** but it has to be **corrected** for the **difference** in **strength** (resistance) between the bipolar and unipolar limb leads.
10. The **correction factor 1.154** is used because bipolar and unipolar limb leads have different resistance. The ratio of their resistance is **4/3** and the **square root** of **4/3** is **1.154**. The formula**{ Tan α= (1.154*aVF) / Lead 1 }** is used for angle determination.
11. The tan value is positive in 1st and 3rd quadrant and it is negative in both the 2nd (**lead I negative** & **aVF positive**) and 4th quadrant (**lead I positive & aVF negative**) in the hex-axial reference system and these should be considered while calculating the angle.
12. If the value of **aVF** is **zero**, the corresponding **angle** for that tan value is **zero degree**. So, the **cardiac vector** is **perpendicular** to **aVF** or **parallel** to **Lead I**. Similarly if the value of the **Lead I** is **zero**, the corresponding **angle** for that tan value (**1/0 =infinity**) is **90°**. So, the **cardiac vector** is **perpendicular** to **Lead I** or **parallel** to **lead aVF**.
13. If **voltage** in any of the limb leads is **zero** (equi-phasic or null), then the **angle** will be **perpendicular** to that **particular limb lead** in the hex-axial reference system. Similarly the angle will be **closer** to the **particular lead** which has the **maximum deflection**(**highest magnitude**).For example if the **voltage** is **maximum** in the **lead II** (rhythm strip of the ECG), then the **angle** will be somewhat nearer to **60°**.

Cardiac Vector Properties:

14. The properties like **magnitude, orientation** and the **velocity** of the Cardiac Vector (**Electrical Field Vector**) and its relationship with the **lead vector** (**Electrode Orientation**) will cause **deflections** in the **ECG Voltage** which will result in the formation of waves in the recorded Electrocardiogram (Eg. P wave, QRS wave, T wave, ST Segment Elevation or Depression, U wave) with **time** in the **X:axis (horizontal)** and **voltage** in the **Y: axis (vertical)**.
15. If the **velocity** of the cardiac vector is **low**, the **conduction time** will **increase** resulting in **Wider Waves**. (Eg. Wide QRS complex, Wide T waves). If the **Velocity** of the cardiac vector is **high**, the **conduction time** will **decrease** resulting in **Narrow Waves**.(Eg. Narrow QRS Complex, Narrow T waves).
16. The **intervals** in the **ECG** (eg PR interval, QRS duration and QT interval) will be **prolonged** if the cardiac vector **velocity** is **lower** or the **distance travelled** by the **vector** is **increased**(Eg. any **Enlargement** or **thickness**). Similarly the **intervals** in the **ECG** will be **shortened** if the cardiac vector **velocity** is **increased** or the **distance** travelled by the **Vector** is **shortened**.(Eg. **any Bypass Route** or **Accessory Pathway**).

Application of Heart-Lead Vector Relationship:

17. The unipolar **lead aVR** and the precordial (chest) **lead V1** will be usually negative because the **heart vector** is **moving away** from the **electrode** placed.
18. The **normal resultant heart vector** is usually **parallel** to **lead II** and so it is used as a **rhythm strip** (continuously recorded for **10 seconds**) to determine the **heart rate** and **rhythm**.
19. If the leads are oriented towards the **ischemic** region, the **T wave inversion** results because the **T wave** vector will

be **moving away** resulting in negative deflection.

20. If the leads are **oriented towards** the current of injury vector (**vector** direction is from **endocardium to epicardium**) it results in **ST -elevation** due to **positive deflection** in that particular leads. If the **leads** are **oriented away** from the current of injury vector, it results in **reciprocal ST-depression** due to **negative** deflection.
21. In **sub-endocardial infarction**, ST-depression is present, because the **direction** of the current of injury **vector** is from **epicardial to endocardium**. ST segment and T wave changes will be **negative** which is **opposite (mirror image)** to those associated with transmural or subepicardial infarction.
22. The **electrode oriented** towards the **infarcted heart wall** will **record** the activation of the **opposite ventricular** wall and so the **QRS** voltage will be **negative** (pathological q waves).
23. The technical errors like **reversal** of the **leads** and the **misplacement** of the leads can hinder proper ECG interpretation. If the lead is **reversed**, the direction of the **vector is opposite,** so the voltage will be **wrongly recorded** in these leads. Similarly, if the **precordial leads** are **not placed** in **correct** position, **magnitude** of the **cardiac vector** will vary and the **voltage** recorded will **not be a true value** which can sometimes mimic pathologies.

CONCLUSION:

Coronary artery disease remains a great threat to the whole world. ECG interpretation plays a vital role in the early diagnosis of the number one killer disease of the world. The cardiac vector hypotheses can be applied to easily explain the difficult concepts of ECG for better understanding and proper interpretation of ECG report resulting in saving millions of patients.

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