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Original Article

Assessment of Electrical Heart Axis: Comparison of Hexaxial Reference System with Unipolar and Bipolar Lead Based Formula

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ABSTRACT

Introduction: The assessment of electrical heart axis (EHA) has important applications towards interpretation of electrocardiogram (ECG) of patients in both clinical and epidemiological studies.
Objective: The present study was conducted to assess the EHA from net voltages of QRS complexes in bipolar and augmented unipolar leads.
Methods: The calculation of EHA in the frontal plane were determined using different formulae: $\frac{aVF}{I}$, $\frac{2aVF}{\sqrt{3}I}$, $\frac{I+2III}{\sqrt{3}I}$, $\frac{\sqrt{3}aVF}{aVL-aVR}$ and using hexaxial reference system.

Results: Comparable results were obtained with $\frac{aVF}{I}$, $\frac{2aVF}{\sqrt{3}I}$, and $\frac{I+2III}{\sqrt{3}I}$ for the prediction of normal EHA and Left Axis Deviation (LAD) with $\frac{2aVF}{\sqrt{3}I}$ formula methods showing highest similarity with the hexaxial system. However, none of the formula was suitable for the prediction of Right Axis Deviation (RAD) and Extreme Axis Deviation (EAD).The EHA obtained from the $\frac{2aVF}{\sqrt{3}I}$ leads after applying correction did not differ significantly from the values without correction $\frac{aVF}{I}$ The EHA values calculated using four formula methods different non-significantly except the $\frac{I+2III}{\sqrt{3}I}$ and $\frac{\sqrt{3}aVF}{aVL-aVR}$formula in the prediction of normal EHA.

Conclusion: For all practical purposes, $\frac{2aVF}{\sqrt{3}I}$ and $\frac{I+2III}{\sqrt{3}I}$ formulae may be used for rapid EHA computation of normal heart axis and LAD. These two formulae may be tested for designing nomogram of normal EHA and LAD with large number of cases. Newer formula needs to be developed for the rapid calculation of RAD and EAD.A single formula for the prediction of all types of EHA needs to be formed.

Key words: Electrical Heart axis, hexaxial reference system, ECG lead based formula

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1. INTRODUCTION

The assessment of the electrical heart axis (EHA) constitutes one of the most important diagnostic support for the precise and inferential evaluation of the electrocardiogram (ECG) as it provides information about the ventricular hypertrophy and conduction defects.[1] The ECG represents the record of the potential fluctuations due to summated action potentials of myocardial fibers during the cardiac cycle.[2] The electrical axis of the heart in the ECG recordings is represented by the mean QRS axis which is the average projection in the frontal plane of the electrical activity vector of ventricular depolarization.[3] Normally, the mean electrical axis of the heart is directed downwards and to the left and makes an angle of 59^0 with the horizontal plane. However, this angle may vary between -30^0 and $+90^0$ under normal conditions; $-90^0<EHA<-30^0$ indicate left axis deviation (LAD) while $+90^0<EHA<+180^0$ indicate right axis deviation (RAD) and $-180^0<EHA>-90^0$ specify extreme axis deviation (EAD).[4]

Methods available for the assessment of electrical axis of the heart include measurement of area under R and S waves in bipolar limb leads, plotting the net voltage of QRS complex on the axis of the leads I and III followed by measuring the angle, both of which are complex and lengthy; inspection of isophasic QRS voltage in six frontal limb leads, inspection of R and S voltages in bipolar limb leads, quadrant method of examination of lead I and lead II or aVF, which have characteristic component of clinically insignificant biasness of about $\pm10^0$to $\pm15^0$ and do not give a precise numeric value.[5, 6] In addition, when there is uncertainty about distinction of left axis deviation assessed by inspection method into either hypertrophy of left ventricles or complete/hemi block of the left bundle branches, accurate measurement of the axis becomes necessary to arrive at the correct diagnosis, thus from clinical and epidemiological point of view, precise determination of the axis is imperative.[6] Determination of mean QRS electrical axes correctly and rapidly would be a valuable clinical aids for the unbiased monitoring of progressive modifications in EHA during the disease sequence, besides investigating the effects of therapeutic actions. Previously several authors proposed formulations for obtaining measures of ventricular dominance, which nevertheless were inaccurate for EHA estimation and hence erroneous; [6] later on reports have been published on ECG lead based derived formulae with precision, including $\frac{aVF}{I}$, $\frac{2aVF}{\sqrt{3}I}$, $\frac{I+2III}{\sqrt{3}I}$, $\frac{\sqrt{3}aVF}{aVL-aVR}$for the calculation of EHA.[7, 8 , 3, 9, 6, 10]

The present article is an endeavor to assess the sensitivity of hitherto available formulae for the estimation of EHA and to evaluate the association between commonly applied graphical or hexaxial reference method. The EHA calculated by formula method is convenient and very useful for the rapid determination of a large number of axes in routine practices in different clinical settings. The objective of the present study is to determine the range in which the mean electrical axis of individuals with and without cardiac illness lies and to determine if it corresponds to the established values, and also to compare and correlate the QRS axis from the leads I and aVF, leads I and III, leads aVF, aVL, aVR, as well as hexaxial reference methods in both normal and deviated EHA cases.

2. MATERIALS AND METHODS

Case selection

The study population consisted of 60 individuals, recruited from MGM Medical College & LSK Hospital, Kishanganj, Bihar, who came for the treatment of cardiac illness, were divided into four groups: healthy individuals without any cardiac illness (n=40), patients with LAD (n=11), patients with RAD (n=9), and patients with EAD (n=3). Subjects with history of known cardiovascular abnormalities, uncontrolled diabetes mellitus or systemic hypertension were excluded from the study. The study was carried out with clearance from the Institutional Ethical Committee.

ECG measurements

ECG were taken by experienced technicians using BPL portable electrocardiograph standardized at 25 mm/s and 10 mm/mV.

Determination of EHA

The EHA is graphed using the hexaxial reference system by plotting the net voltage equal to the height of the R wave minus the height of the largest negative deflection in the QRS complex on the axis of the Lead-I and Lead-III and the arrow drawn from the center of hexaxial reference system to the point of intersection of perpendiculars extended from the distances measured off on the respective axes represents the magnitude and direction of the EHA. The EHA is calculated based on augmented unipolar and bipolar limb leads including $\frac{aVF}{I}$, $\frac{2aVF}{\sqrt{3}I}$, $\frac{I+2III}{\sqrt{3}\,I}$, $\frac{\sqrt{3}aVF}{aVL-aVR}$different formula.[7-8,3,9,6,10]

Statistical analysis of data

The data were expressed as mean ± standard error of mean (SEM). Student's t-test was used for statistical analysis of data. Pearson's correlation coefficient was applied to determine the association between parameters. A p value < 0.05 was considered significant.

3. RESULT

Of the 63 subjects, 40 had normal electrocardiographic findings with the electrical heart axis (EHA) lying in the normal range of -25^0 to 82^0 measured by hexaxial reference system; while 11 patients showed LAD, 9 and 3 persons had RAD and EAD respectively. The ECG abnormalities associated with each of the deviated categories of heart axis and the corresponding number of patients are depicted in Table 1.

The mean±SEM (standard error of mean) and the range of values for the angle of EHA measured by applying hexaxial reference system and formula based on a combination of unipolar and bipolar leads are represented in Table 2. The normal arctan EHA obtained by $\frac{I+2III}{\sqrt{3}I}$ formula methods showed highest similarity with the hexaxial graphical system, the mean ± SEM (range) values for which are 54.70^0±2.94^0 (-39.08^0 to 81.09^0) and 40.80^0±4.62^0 (-25^0 to 82^0) respectively. Comparable results for the normal arctan EHA values were obtained between corrected combination leads and bipolar leads using $\frac{aVF}{I}$ and $\frac{2aVF}{\sqrt{3}I}$ formula with values 38.45^0±5.24^0 (-81^0 to 82.87^0) and 41.07^0±5.47^0 (-82.98^0 to 83.85^0) respectively; similarly for the deviated categories of EHA. However, the arctan EHA for LAD, RAD, and EAD cases showed dissimilar values with hexaxial reference system and unipolar and bipolar lead based formula.

The EHA values obtained by different formula methods for the normal axis and deviated axis were compared using p values as shown in Table 3, which indicated insignificant difference among the various formulae except between $\frac{I+2III}{\sqrt{3}I}$ and $\frac{\sqrt{3}aVF}{aVL-aVR}$ (p=0.003) formulae applicable to the calculation of EHA for normal heart axis.

The hexaxial reference system displayed insignificant difference (p>0.05) with both the uncorrected and corrected combination leads based formulae ($\frac{aVF}{I}$ and $\frac{2aVF}{\sqrt{3}I}$) and bipolar leads based formula ($\frac{I+2III}{\sqrt{3}I}$) for the determination of EHA applied to normal cases and LAD; however the EHA estimated for RAD and EAD indicated significant differences between the hexaxial reference system and the formulae mentioned above, while comparison with formulation containing augmented unipolar leads for all cases including normal and deviated EHA yielded significant difference with hexaxial reference system (Table 4).

4. DISCUSSION

The average depolarization force vector in 2-D over the ventricles in the frontal plane of the body is projected from the upper right of the ventricles downward toward apex of the heart in the hexaxial reference system. The EHA is represented by mean QRS vector which is effected by several factors including cardiac location, conduction properties, excitation, repolarization and the size of the ventricles, of which last three factors are most effective, the knowledge of EHA can thus provide important information about avariety of cardiac disorders.[11]An abnormality in the electrical axis of the heart may be encountered in a variety of situations; RAD, with a mean QRS axis of + 90° or more, is found in Right Ventricular Hypertrophy (RVH), lateral myocardial infarction (MI), causing loss of normal leftward depolarization forces leading to a rightward axis; it may also be associated with ventricular conduction disturbance of left posterior fascicular block (hemiblock), chronic lung disease without pulmonary hypertension, acute pulmonary embolism.[5]There were a total of nine RAD patients encountered in our study of which five suffered from right ventricular hypertrophy, left atrial enlargement, left posterior fascicular block, RBBB along with atrial fibrillation, anterior MI, while remaining four were healthy individuals. In RBBB only, the EHA is generally normal, because of the greater muscle mass of the left ventricles that contributes to the normal depolarization.[12] The presence of RBBB in combination with left anterior fascicular block represents bifascicular block that is indicative of LAD with extensive injury to the conducting system; however, the presence of RBBB along with bifascicular obstruction of the LBB causes complete heart block.[13] LAD, with a mean QRS axis of –30° or less, is seen with LVH, left anterior fascicular block (hemiblock; deviation more negative than –45°); LAD may be seen in association with left bundle branch block.[11] The LAD in the present study was found in nine out of 11 patients with partial and complete LBBB, left anterior fascicular block, RBBB, Left Ventricular Hypertrophy (LVH), mostly anterior MI, atrial fibrillation. The remaining 2 LAD patients did not exhibit any apparent cardiac illness. Often minor degrees of RAD and LAD occur in long, thin persons and in short, fat persons, respectively which are rarely significant.[4] In LBBB due to anterior fascicles, the net depolarization vector at the left ventricles passes through the posterior fascicles causing the EHA to rotate upward, leading to LAD; however RAD is indicated in selective obstruction of the posterior fascicles.[5] RAD and LAD may also take place in the absence of apparent cardiac ailment, however, the presence of any deviation is often responsible for LVH or RVH, left anterior or posterior hemiblock.[13] Some of the pathological factors causing indeterminate or Northwest axis include emphysema, hyperkalaemia, lead transposition, artificial cardiac pacing, ventricular tachycardia etc or it may occur as normal variant; under both situation, the six extremity leads display biphasic (QR or RS) complexes.[14] In our study, we found three EAD cases with atrial fibrillation, ventricular premature contraction, and left anterior fascicular block, left anterior fascicular block, ischemia in anterior-lateral leads, and prolonged QT, lateral MI.

The electrocardiographic findings in the healthy cardiac-disease free individuals (n=40) showed their EHA values in the normal range of -25^0 to 82^0 measured by hexaxial reference system.The electrical axis of the heart in the frontal plane can be estimated using any combination of two of the leads, but leads I and aVF have benefits over other pairs.[15] The EHA expressed as a function of aVF and I voltages is given by $\frac{aVF}{I}$, the modified form of which is expressed as $\frac{2aVF}{\sqrt{3}I}$ to account for the differential electrical strength of bipolar lead aVF and unipolar lead I through incorporation of a $\frac{2}{\sqrt{3}}$ correlation factor.[7] Comparable results for both the normal and deviated arctan EHA values were obtained in the current article between corrected combination leads and bipolar leads using $\frac{aVF}{I}$ and $\frac{2aVF}{\sqrt{3}I}$ formula with values $38.45^0 \pm 5.24^0$ (-81^0 to 82.87^0) and $41.07^0 \pm 5.47^0$ (-82.98^0 to 83.85^0) respectively(p=0.73) in healthy population and similarly insignificant difference were obtained for the deviated categories of EHA ($p< 0.05$). The EHA obtained from the augmented leads after applying correction did not differ significantly from the values without correction, for all practical purposes two of these methods are clinically insignificant; however corrected formula may be preferably used for computation of EHA. The electrical axis of healthy subjects determined using leads I and aVF without correction yielded lesser values (34°±4°, n = 48) compared to that using corrected formula (37°±4°, n=48; p<0.005)[8]. Singh and Athar (2003) derived the formula $\frac{I+2III}{\sqrt{3}I}$ for calculation of EHA and compared this with the method of quantitation of EHA by plotting I and III voltages on hexaxial reference system (graph method) and that calculated by the computer software; with good agreement between each other for normal, LAD, and RAD cases.[9] Similarly, in our studies, the normal arctan EHA using augmented bipolar lead based formula methods showed highest similarity with the hexaxial graphical system, the mean±SEM (range) values for which are $54.70^0 \pm 2.94^0$ (-39.08^0 to 81.09^0) and $40.80^0 \pm 4.62^0$ (-25^0 to 82^0) respectively (p=0.54). The electrical axis of healthy subjects determined using leads I and III such that $EHA = \frac{I+2III}{\sqrt{3}I}$ were 37°±3°, n=48; p<0.005).[8] A very high statistically significant ($P < 0.0001$) correlation were obtained between the graphical and formula $\frac{I+2III}{\sqrt{3}I}$ methods applied to normal subjects without any cardiac disorder.[6] An insignificant difference between the various formulae for the calculation of EHA were obtained except between $\frac{I+2III}{\sqrt{3}I}$ and $\frac{\sqrt{3}aVF}{aVL-aVR}$ (p=0.003). The hexaxial reference system displayed insignificant difference (p>0.05) with $\frac{I+2III}{\sqrt{3}I}$ formula applied to normal cases and LAD; however for RAD and EAD significant differences between the two were found. The EHA values calculated using various methods different non-significantly. With the formula methods, comparable results were obtained with different formulae, which accounted for the comparative lead strength of augmented unipolar and bipolar leads of the ECG. For all practical purposes any of methods except $\frac{\sqrt{3}aVF}{aVL-aVR}$ may be used for the rapid computation of normal EHA and LAD.

Table 1: Electrocardiographic Findings

Sn	Electrocardiographic findings	Number of cases
1	Normal	40
2	Left axis deviation	11
i.	Right Bundle Branch Block with Left Anterior Fascicular Block and Inferior Myocardial Infarction	1
ii.	Right Bundle Branch Block with Left Anterior Fascicular Block and Antero inferior Myocardial Infarction	1
iii.	Left Bundle Branch Block	2
iv.	Partial Left Bundle Branch Block with Left Ventricular Hypertrophy and Antero inferior Myocardial Infarction	1
v.	Partial Left Bundle Branch Block and Anterior Myocardial Infarction	1
vi.	Left Ventricular Hypertrophy	1
vii.	Left Ventricular Hypertrophy and Antero septal Myocardial Infarction	1
viii.	Atrial fibrillation and Anterior Myocardial Infarction	1
3	Right axis deviation	9
i.	Atrial Fibrillation and Right Bundle Branch Block	1
ii.	Right Ventricular Hypertrophy (Pulmonary hypertension)	2
iii.	Left Atrial Enlargement and Anterior Myocardial Infarction	1
iv.	Left Posterior Fascicular Block	1

4	Extreme axis deviation	3
i.	Atrial Fibrillation, Ventricular Premature Contraction, and Left Anterior Fascicular Block	1
ii.	Left Anterior Fascicular Block, Ischemia in Anterior-Lateral leads, and prolonged QT	1
iii.	Lateral Myocardial Infarction	1

Table 2: Arctan electrical heart axis in degrees

Mean± SEM (Range) EHA	$\frac{aVF}{I}$	$\frac{2aVF}{\sqrt{3}I}$	$\frac{I+2III}{\sqrt{3}I}$	$\frac{\sqrt{3}aVF}{aVL-aVR}$	**Hexaxial reference system**
Normal (n=40)	38.45±5.24 (-81 to 82.87)	41.07±5.47 (-82.98 to 83.85)	54.70±2.94 (-39.08 to 81.09)	44.63±4.27 (-46.1 to 76.73)	40.80±4.62 (-25 to 82)
LAD (n=11)	-43.50±6.39 (-72.89 to 0)	-46.80±6.53 (-75.14 to 0)	-41.68±11.2 (-73.97 to 64.81)	-26.01±5.86 (-73.97 to 0)	-52.55±3.57 (-73 to -33)
RAD (n= 9)	-9.96±29.88 (-82.87 to 74.05)	-10.65±31.0 (-83.85 to 76.16)	-12.08±28.32 (-81.09 to 69.03)	-1.86±24.59 (-55.15 to 81.52)	119.33±5.03 (100 to 137)
EAD (n=3)	-61.73±6.23 (50.19 to 71.56)	64.98±5.76 (54.3 to 73.97)	64.43±4.34 (60.11 to 73.08)	11.73±29.13 (-46.1 to 44.41)	-121.67±9.57 (-138 to -105)

SEM: Standard error of mean; LAD: Left axis deviation; RAD: Right axis deviation; EAD: Extreme axis deviation; n = Number of cases

Table 3: Comparison between formulas based measurement of EHA

p values	Normal	LAD	RAD	EAD
$\frac{aVF}{I}$ and $\frac{2aVF}{\sqrt{3}I}$	0.73	0.72	0.99	0.72
$\frac{2aVF}{\sqrt{3}I}$ and $\frac{I+2III}{\sqrt{3}I}$	0.61	0.70	0.98	0.94
$\frac{I+2III}{\sqrt{3}I}$ and $\frac{\sqrt{3}aVF}{aVL-aVR}$	0.003#	0.23	0.81	0.21

p value < 0.05 significant; EHA: Electrical heart axis; LAD: Left axis deviation; RAD: Right axis deviation; EAD: Extreme axis deviation

Table 4: Comparison between hexaxial and formula based measurement of EHA

p values	Normal	LAD	RAD	EAD
HM and $\frac{aVF}{I}$	0.74	0.24	0.016#	0.00023#
HM and $\frac{2aVF}{\sqrt{3}I}$	0.97	0.45	0.018#	0.034#
HM and $\frac{I+2III}{\sqrt{3}I}$	0.54	0.37	0.012#	0.0006#
HM and $\frac{\sqrt{3}aVF}{aVL-aVR}$	0.02#	0.001#	0.009#	0.034#

p value < 0.05 significant; HM: Hexaxial reference system; LAD: Left axis deviation; RAD: Right axis deviation; EAD: Extreme axis deviation

5. CONCLUSION

Formulae such as $\frac{2aVF}{\sqrt{3}I}$ and $\frac{I+2III}{\sqrt{3}I}$ may be used for rapid EHA computation of normal EHA and LAD. However, since the ECG machines could be the cause of erroneous calculation leading to misinterpretation of cardiac illness, that various methods for estimation of EHA must be investigated with huge sample size before being applied for routine practice in ECG machines. The $\frac{2aVF}{\sqrt{3}I}$ and $\frac{I+2III}{\sqrt{3}I}$ formulae may be tested for designing nomogram of normal EHA and LAD. Newer formula needs to be developed for the rapid calculation of RAD and EAD. A single formula for the prediction of all types of EHA needs to be formed.

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