The Vectorcardiogram of Left Ventricular Hypertrophy

Analysis and Criteria (Frank Lead System)

By PHILIP VARRIALE, M.D., JOSEPH C. ALFENITO, M.D., F.A.C.P.,
AND RICHARD J. KENNEDY, M.D., F.A.C.P.

Despite several studies, no definitive criteria for the vectorcardiographic diagnosis of left ventricular hypertrophy (LVH) have been proposed. Some reports have been limited to the analysis of cases of the systolic overload type of LVH\(^1\) while others have failed to define specific criteria for the diagnosis or have emphasized the wide overlap of the findings in LVH with those of the normal population.\(^1-3\)

We have employed the vectorcardiogram (VCG) in the study of LVH, utilizing a group of patients with hypertrophy of the left ventricle secondary to the wide variety of causes commonly encountered in clinical practice. Attention has been focused on certain salient qualitative and quantitative features of the VCG in LVH and on the basis of these characteristics, identifiable without painstaking and elaborate measurements, we propose specific criteria for the vectorcardiographic recognition of LVH.

Group Studied

From a group of 80 patients with LVH, 50 were selected for analysis. Thirty-seven were men and 13 were women. Ages ranged from 16 to 94 years with a mean of 53 years. Left ventricular hypertrophy was established by the clinical features of the case, posteroanterior and lateral chest X-rays and accepted criteria present in the 12-lead electrocardiogram.\(^4\) Excluded from the study were patients with LVH who in addition presented any of the following: a history of angina pectoris or myocardial infarction, an ECG consistent with myocardial infarction, a QRS duration greater than 120 msec, or a history or the signs of right heart failure.

The etiology of LVH varied (table 1). The largest group, 30 patients with hypertensive cardiovascular disease had diastolic blood pressure of more than 110 mm Hg. Eight of these more than 65 years of age were considered also to have arteriosclerotic heart disease solely on the basis of age. Eleven patients with rheumatic heart disease had involvement of the aortic valve and a twelfth had involvement of the mitral valve. One case of coarctation of the aorta and one of muscular subaortic stenosis comprised the congenital group. There were four cases of primary myocardial disease and two of syphilitic heart disease.

Methods

Vectorcardiograms were recorded by the system of Frank\(^5\) with the chest electrodes at the level of the fourth intercostal space and the patient in the supine position. The recording equipment consisted of a Sanborn amplifier and oscilloscope mounted on a portable unit. Horizontal, right sagittal, and frontal loops were photographed on Polaroid film from the oscilloscopic screen.

The VCG loops were interrupted 400 times per second, each dash representing 2.5 msec. Calibration was such that 1.0 mv was equivalent to 5.0 cm. Conventional reference frames for the horizontal and frontal planes were employed for the study of angular measurements. The reference frame for the right sagittal plane was aligned so that 0° was anterior, +90° inferior, and +180° posterior.

The following data were analyzed for each planar projection of the QRS loop: (1) loop configuration and the direction of inscription, particularly in the horizontal projection; (2) angle of the maximum QRS vector; the maximum QRS vector was taken as the longest diameter of the loop drawn from the point of origin; the QRS half-area vector was used as representative of the maximum QRS vector only in those loops where the "long axis" was indeterminate; (3) magnitude of the maximum QRS vector; (4) QRS-T angle; (5) the presence of an ST segment vector and

From the Department of Medicine, St. Vincent’s Hospital and Medical Center of New York.

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Table 1

Diagnosis and Age Distribution of Fifty Patients with the Various Vectorcardiographic Patterns of Left Ventricular Hypertrophy

<table>
<thead>
<tr>
<th>Etiology of LVH</th>
<th>Type I A</th>
<th>Type I B</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertensive heart disease</td>
<td>22</td>
<td>5</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(52-63)*</td>
<td>(39-65)</td>
<td>(51-57)</td>
</tr>
<tr>
<td>Hypertensive-arteriosclerotic heart disease</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(75-90)</td>
<td>(71-83)</td>
<td>(72-94)</td>
</tr>
<tr>
<td>Rheumatic heart disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic stenosis and insufficiency</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(22-38)</td>
<td></td>
<td>(65)</td>
</tr>
<tr>
<td>Aortic insufficiency</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(65)</td>
<td>(63)</td>
<td>(71)</td>
</tr>
<tr>
<td>Aortic insufficiency</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16-19)</td>
<td>(47)</td>
<td>(21)</td>
</tr>
<tr>
<td>Mitral insufficiency</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(27)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary myocardial disease</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(34-38)</td>
<td>(54)</td>
<td>(40)</td>
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<tr>
<td>Congenital heart disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarctation of aorta</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(18)</td>
<td></td>
</tr>
<tr>
<td>Muscular subaortic stenosis</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(19)</td>
<td></td>
</tr>
<tr>
<td>Syphilitic heart disease</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aortic insufficiency</td>
<td>2</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(82)</td>
<td>(47)</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>16</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>Mean age</td>
<td>39.2</td>
<td>58.3</td>
<td>64.6</td>
<td>58.2</td>
</tr>
</tbody>
</table>

*Numbers in parentheses represent age or age range.

its direction in the horizontal plane; and (6) the presence or absence of a terminal appendage or S loop in the horizontal plane.

Results

**Horizontal Plane**

*Loop Patterns*

The loop patterns in this plane fall into three main types (fig. 1). Thirty-seven cases were inscribed in a C-C-W direction (type I), usually oval in shape and less often elongated or elliptical. In 16 patients (32%) the initial vector was to the right and anteriorly (type I A) and in twenty-one patients (42%) to the left and anteriorly (type I B). Nine cases were figure-of-eight configuration (type II). In four of these the proximal C-C-W loop was predominant (type II A). In one case the proximal and distal areas of the figure-of-eight were equal (type II B). In the remaining four cases a distal C-W loop predominated (type II C). In four cases a relatively narrow loop with the initial vector to the right and anteriorly was inscribed in a C-W direction (type III).

**Angle of the Maximum QRS Vector**

The range of angular orientation varied between 0° and −80°. There was progressive posterior displacement of the average maximum QRS vector from type I to type III (fig. 1). The average angular position was −31.2° in type I A and −53.8° in type III. In 84% of cases the maximum QRS vector was directed −30° or more posteriorly. In six cases of type I A and two of type I B, the angular position of the maximum QRS vector was between 0° and −29°.

**Magnitude of the Maximum QRS Vector**

The magnitude ranged between 1.4 and 6.2 mv. The lowest average magnitude was present in type I A (2.25 mv) and the highest in type III (3.3 mv). In 76% of all cases the
VECTORCARDIOGRAM OF LEFT VENTRICULAR HYPERTROPHY

Type I A (32%)
- Posterior
- QRS loop C-C-W, open
- Initial Vector Right & Anterior

Type I B (42%)
- Posterior
- QRS loop C-C-W, open
- Initial Vector Left & Anterior

Type II A (8%)
- Posterior
- QRS loop figure of eight
- Predominant Proximal Loop C-C-W

Type II B (2%)
- Posterior
- QRS loop figure of eight
- Proximal & Distal Areas of Loop Equal

Type II C (8%)
- Posterior
- QRS loop figure of eight
- Predominant Loop Distal C-W

Type III (6%)
- Posterior
- QRS loop narrow C-W
- Initial Vector Right

Figure 1

Loop configurations, average angular deviations, and voltages of the maximum QRS vectors in the horizontal plane.

magnitude was 2.0 mv or greater. It exceeded 2.0 mv in 62.5% of type I A, 76.2% of type I B, 88% of type II and 100% of type III cases.

QRS-T Angle

The QRS-T angle ranged from 15° to 200°. The least divergence was present in type I A and the greatest in type II. In 14 cases of type I and one of type II the QRS-T angle was less than 110°.

ST Segment Vector

In 14 cases (28%) the QRS loop did not return to the point of origin. The resulting ST vector was always directed to the right and anteriorly. Twenty-four per cent of type I, 44% of type II, and 25% of type III loops showed an ST vector.

Terminal Appendage or S Loop

A terminal appendage, that is, a distinct deflection of the terminal 5 to 15 msec of the QRS loop into the right posterior quadrant in the horizontal plane, was identified in only seven cases (14%). These were all limited to type I loops.

Right Sagittal Plane

Loop Patterns

In 36 cases (72%) loop patterns were C-W, in five (10%) C-C-W, and in nine (18%) figure-of-eight.

Angle of the Maximum QRS Vector

The angle ranged between +90° and −140°. The smallest average angle (+151°) was present in type I B cases, and the greatest average angle (+177.5°) in type III group. Eighty-four per cent of the patients had a maximum angle of +150° or more. This included 62.5% of type I A, 90.9% of type I B, and all cases of types II and III.
Magnitude of the Maximum QRS Vector

The magnitude ranged between 0.8 and 4.4 mv. The lowest average magnitude (1.68 mv) was found in type I B and the highest (2.5 mv) in type III. A magnitude of 1.6 mv or more was present in 58% of all cases including 51.4% of type I, 77.7% of type II, and 75% of type III.

QRS-T Angle

This angle varied between 15° and 180°. The smallest average angle (124°) was confined to type I A and the greatest average angle (172.5°) was found in type III cases. An angular divergence of 145° or more was present in 62.1% of type I, and in all cases of types II and III.

Frontal Plane

Loop Patterns

Twenty-two (44%) loops were C-C-W, 12 (24%) were C-W, and 16 (32%) were figure-of-eight.

Angle of the Maximum QRS Vector

The angular range was between −25° and +75°. Forty-one cases (82%) fell between 0° and +45°, five (10%) between −10° and −25°, and four (8%) between +60° and +75°.

Magnitude of the Maximum QRS Vector

This ranged between 1.2 and 4.8 mv. The lowest average magnitude (2.06 mv) was present in type I B cases and the highest (2.5 mv) in type III. A magnitude of 2.0 mv or more was found in 68% of all cases, including 62.1% of type I, 77% of type II, and 100% of type III.

QRS-T Angle

The angular divergence was between 5° and 200°. The lowest average was found in type I A (83.8°) and the highest in type II (131.7°). An angular divergence of 90° or more was present in 43.2% of type I, 66.6% of type II, and 75% of type III.

Discussion

In the vectorcardiographic analysis of left ventricular hypertrophy, we have been impressed with the value of the data obtained from the QRS loop of the horizontal plane. In most instances, the diagnosis may be made from this projection alone.

Qualitative analysis of the QRS loop in 50 cases of left ventricular hypertrophy of varied etiology disclosed three distinct patterns in the horizontal plane (fig. I). The predominant pattern was an open counterclockwise loop, designated as type I, which occurred in 37 cases (74%). Two subdivisions of type I, based on the direction of the initial vector were also recognized: one to the right and anterior, type I A (32%), and the other to the left and anterior, type I B (42%). The electrocardiographic counterpart of type I A showed distinct Q waves in V5 and V6 of the unipolar precordial leads whereas an embryonic Q wave or the absence of a Q wave was noted in type I B.

Type I loops occurred in approximately 80% of the 41 cases studied by Bristow and associates2 and in 58% of the 24 cases described by Estes and associates.1

A figure-of-eight loop pattern, designated as type II, occurred in nine cases (18%) and showed three variations. The two main ones related either to a predominant proximal loop (C-C-W), termed "type II A" (8%), or to a predominant distal loop (C-W), termed type II C (8%). In one case the areas of the figure-of-eight were of equal proportion and were designated type II B. In all cases of type II loops, the initial vector was projected toward the left and anteriorly. An almost identical proportion of figure-of-eight loops, approximately 17%, was described by Bristow and associates.2 In the electrocardiogram, this pattern may often be predicted by the appearance of a well-defined saw-tooth notch of the midportion of the QRS complex of one or more precordial leads.

An unusual and infrequent loop pattern, designated as type III, was noted in four cases (8%) and was inscribed in a completely clockwise manner. The initial vector of this type was directed to the right and anteriorly.

In all cases the QRS duration was less than 120 msec, ranging from 56 to 110 msec. In
general, type I loops showed the smallest QRS time duration (average, 75 msec) and type III loops the longest (average, 92 msec).

We believe that the loop patterns other than those of type I A described in left ventricular hypertrophy represent an associated conduction defect of the incomplete left bundle-branch block type. This is supported by several features. The initial vectors of types I B and II loops are directed to the left and anteriorly rather than, as normally, to the right and anteriorly. Indeed, these initial deflections often showed a definite slurring or conduction delay. Moreover, the change in the basic sequence of ventricular activation manifested in type II and III loops resembles closely those described in conduction disturbances of the left bundle with a duration of less than 120 msec. Thus in 68% of our cases a conduction defect of the incomplete left bundle-branch block variety occurred. This observation adds further support to the belief of several investigators\(^6,7\) who have stressed the frequency of the association of left ventricular hypertrophy and incomplete left bundle-branch block. Although the loop configuration and direction of inscription of type III most closely resembles complete left bundle-branch block, it is differentiated by a duration of less than 120 msec and by the absence of conduction delay in the mid or afferent limb.

In all cases, the initial vector was directed anteriorly and either to the left or right. This is an important differential point in excluding anteroseptal infarction in which there is an absence of initial anterior forces.

An ST segment vector directed to the right and anteriorly occurred in 14 cases (28%) with the greatest incidence in type II loops. In most of these cases the patients were receiving digitalis. However, the occurrence of an ST vector was not predictable, and no consistent correlation with LVH was found.

The two most important quantitative parameters of the horizontal plane that reliably correlated with left ventricular hypertrophy were the angle and the magnitude of the maximum QRS vector (table 2). Forty-two cases (84%) demonstrated a maximum QRS vector oriented
at −30° or more posteriorly in the horizontal plane. In no case was this vector directed anterior to 0°. On the average, progressive increments in posterior angular displacement occurred from type I A (average, −31.2°) to type III (average, −53.8°) with consistently significant posterior displacement of the QRS vector in all cases of types II and III.

The magnitude of the maximum QRS vector in the horizontal plane was also of diagnostic importance, being 2.0 mv or more in 38 cases (76%). Similarly, the average magnitude of the QRS vector progressively increased from type I A (2.25 mv) to type III (3.3 mv). An increased magnitude was an almost constant finding of type II and III cases.

The QRS-T angle was highly variable, ranging between 15° and 200°. The widest QRS-T angular divergence occurred most frequently in types II and III. The marked variability of this angle made it an unreliable correlate with LVH.

Analysis of the frontal plane disclosed several interesting features. The only quantitative characteristic that reliably related to LVH was a significant increase in the magnitude of the maximum QRS vector (table 3). In 34 cases (68%) this was 2.0 mv or greater. The average magnitude of type II and III cases exceeded that of type I by a slight margin.

The angle of the maximum QRS vector in the frontal plane was of no diagnostic value. In 41 cases (82%), the orientation of the QRS vector fell between 0° and +50°, showing an overlap with the normal population. Within this group, the majority of QRS loops were either counterclockwise or figure-of-eight with no consistent correlation between the angle and direction of inscription of the loop. In only five cases was the maximum QRS vector directed superiorly between −1° and −25°. In all five a counterclockwise inscription was present. In four cases the angle ranged between +60° and +75° and the loop was inscribed clockwise.

These findings support the conclusion that left axis deviation represents an uncommon feature of LVH in which the axis is usually
normal. Superior orientation of the QRS loop, when it occurs, is almost always associated with a counterclockwise inscription. The occurrence of a clockwise inscription should arouse suspicion of an associated disorder such as infarction of the inferior wall.

The QRS-T angle in the frontal plane showed considerable variability and was an unreliable criterion for LVH.

The two most important quantitative characteristics of the right sagittal plane, as in the horizontal projection, were the angle and magnitude of the maximum QRS vector (table 4). In 29 cases (58%) the magnitude was increased to 1.6 mv or more and in 42 cases (84%) the angle was significantly displaced to $+150^\circ$ or more in a posterosuperior direction. Progressive increments of the average angular displacement and magnitude of the maximum QRS vector occurred from type I to type II. Types II and III showed significant increases in both measurements. Although the loop in this plane was usually clockwise (72%), counterclockwise and figure-of-eight loops also occurred.

From the findings in these 50 cases, specific criteria for the definitive vectorcardiographic diagnosis of LVH are proposed. These include five quantitative characteristics of the three planar projections which in conjunction with the loop patterns of type I, II or III reliably correlate with LVH. These are (1) magnitude of the maximum QRS vector in the horizontal plane of 2.0 mv or more; (2) magnitude of the maximum QRS vector in the frontal plane of 2.0 mv or more; (3) magnitude of the maximum QRS vector in the sagittal plane of 1.6 mv or more; (4) displacement of the angle of the maximum QRS vector in the horizontal plane to $-30^\circ$ or more posteriorly; and (5) displacement of the angle of the maximum QRS vector in the sagittal plane to $+150^\circ$ or more superiority.

These five criteria have been selected on the following basis. Each one exceeded the 90 percentile range of the normal adult population and usually fell beyond the third standard deviation from the normal mean values. In addition, these increased values of magnitude

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### Table 4

<table>
<thead>
<tr>
<th>Right Sagittal Plane Data</th>
<th>Type I A</th>
<th>Type I B</th>
<th>Type II</th>
<th>Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average angle of maximum QRS vector</td>
<td>$151^\circ$</td>
<td>$124^\circ$</td>
<td>$160^\circ$</td>
<td>$172.5^\circ$</td>
</tr>
<tr>
<td>Average magnitude of maximum QRS vector, mv</td>
<td>1.88</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Average QRS-T angle</td>
<td>$180^\circ$</td>
<td>$160^\circ$</td>
<td>$160^\circ$</td>
<td>$160^\circ$</td>
</tr>
<tr>
<td>Direction of inscription, cases</td>
<td>11</td>
<td>15</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>CW</td>
<td>0</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>CCW</td>
<td>5</td>
<td>0</td>
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<td></td>
</tr>
<tr>
<td>Figure-of-eight</td>
<td></td>
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</tr>
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</table>

*Numbers in parentheses represent range.*
and angular displacement closely approximate the mean values of type I cases, the lowest averages in our series.

The following diagnostic scheme based on these five quantitative criteria in association with the three loop types described is proposed for the vectorcardiographic diagnosis of LVH.

If four or five of the criteria are fulfilled, the diagnosis is reasonably definite; if three are satisfied, the diagnosis is probable; if two are present, the diagnosis of left ventricular hypertrophy is, at best, suggested.

The QRS-T angular divergence and ST segment vector are considered associated findings and not diagnostically specific for LVH.

On the basis of these criteria, LVH was definitely present in 30 (60%) of our cases, probable in 13 (26%), and were suggested in five (10%). In two cases of type I A the criteria were insufficient to support the diagnosis. All except one case of type II and all cases of type III satisfied the criteria for definite LVH. A proportionally greater number of cases of type I B were definitely and probably LVH (91%) than of type I A (75%). This suggests that type I loops, particularly type I A, represent the earliest change in LVH and that type II and type III loops are vectorcardiographic manifestations of more advanced change.

These criteria are diagnostically specific for LVH and are easily determined without painstaking measurements. Their sensitivity remains to be determined by future correlative postmortem studies.

Summary

Direct spatial vectorcardiograms were made by using the Frank lead system on 50 patients with known left ventricular hypertrophy of both systolic and diastolic overload types. Three distinctive loop patterns were demonstrated in the horizontal plane. In addition important quantitative measurements are described for the three planar projections. From these data, five criteria are proposed for the definitive vectorcardiographic diagnosis of left ventricular hypertrophy.

References

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