The Spatial Vectorcardiogram in Left Ventricular Hypertrophy

By L. G. Horan, M.D., G. E. Burch, M.D., J. A. Abildskov, M.D., and J. A. Cronvich, M.S.

A study of 90 patients with left ventricular hypertrophy revealed a typical configuration of the spatial vectorcardiogram in most of the subjects. Typically the QRS $\mathbf{sE}$-loop was smooth, wide and rounded, inscribed in a counterclockwise direction and placed largely to the left and above the isoelectric point in its frontal plane projection. The left sagittal plane projection of the QRS $\mathbf{sE}$-loop was long, narrow and directed largely upward and posteriorly. The typical T $\mathbf{sE}$-loop was small, smooth, horseshoe-shaped and counterclockwise in inscription in both frontal and left sagittal plane projections. In some instances the QRS $\mathbf{sE}$-loop was similar to that of the normal but was always accompanied by an abnormal T $\mathbf{sE}$-loop.

The electrocardiographic features of left ventricular hypertrophy are frequently not clearly separable from those produced by cardiac position and by abnormalities of the myocardium other than hypertrophy. On the other hand, subjects demonstrated to have left ventricular hypertrophy by other methods of examination may have a normal electrocardiographic configuration of the QRS complex with or without T-wave abnormalities. The following study was undertaken to provide a description of the spatial vectorcardiogram in left ventricular hypertrophy recorded with the equilateral tetrahedron reference system and to investigate its possible role in making these distinctions. Others have studied left ventricular hypertrophy with other reference frames.\textsuperscript{1-4}

Materials and Methods

The 90 patients with left ventricular hypertrophy studied ranged in age from 27 to 80 years, and 70 were male and 20 female. Evidence for left ventricular hypertrophy was essentially indirect since only five cases have been followed to autopsy thus far (table 1). Cases were selected on the basis of clinical, roentgenographic and electrocardiographic study from patients with diseases which commonly result in left ventricular hypertrophy. Spatial vectorcardiograms were recorded, using the equilateral tetrahedral reference system and cathode ray oscilloscopes. Projections on the frontal, right, left and superior planes were each photographed simultaneously with a projection on the plane sagittal to each as viewed from the subject's left. Stereoscopic views of the frontal, left, right and superior planes were also recorded. Records were also obtained with the amplification increased to obtain adequate delineation of the T $\mathbf{sE}$-loop and junction J from the isoelectric point.

The standard leads, $V_1$ through $V_6$, unipolar limb leads and a unipolar lead from the back and bipolar leads from the back electrode and each of the other electrode positions defining the equilateral tetrahedron were recorded shortly after the vectorcardiograms. Proper pairs of leads were recorded simultaneously, so that any portion of any lead could be temporally oriented with respect to any other lead. Details of the methods of recording have been published previously.\textsuperscript{5}

The vectorcardiograms were analyzed to determine the location of approximate areas of the QRS and T $\mathbf{sE}$-loops in the frontal and left sagittal planes, the contour and direction of inscription of these loops and the spatial relationship of junction J to the isoelectric point. Measurements were made of the length and direction of the maximal mean instantaneous vectors of the QRS and T $\mathbf{sE}$-loops in the frontal and left sagittal projections and of the maximal extent of the QRS $\mathbf{sE}$-loop posterior to the isoelectric point. Not all of the tracings were suitable for measurement of the T $\mathbf{sE}$-loop and the J displacement.

Results

QRS $\mathbf{sE}$-loop. The typical QRS $\mathbf{sE}$-loop was smooth, wide and inscribed in a counterclockwise direction in the frontal plane projection. Two otherwise typical records in which
the QRS sE-loops were inscribed in a clockwise direction have been included in this group. In 19 records the frontal plane projection of the QRS sE-loop was elliptoid in contour (fig. 1a) while in 21 records the frontal plane projection was roughly circular in form (fig. 1b). The enclosed area was largely located in the first sextant of a triaxial reference frame applied to that plane. The left sagittal projection was usually either thin and line-like or a long, narrow, figure-of-eight shaped loop with the maximal instantaneous vector oriented near the −60 degree axis of a triaxial reference system applied to that plane with its ±180 degree axis located anteriorly. Fifty-three (59 per cent) of the 90 subjects had spatial vectorcardiograms of this typical group, including

Table 1.—Autopsied Cases

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age (yrs.)</th>
<th>QRS sE-loop</th>
<th>Etiology of Heart Disease</th>
<th>Ventricular Thickness (cm.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Left</td>
<td>Right</td>
</tr>
<tr>
<td>F</td>
<td>38</td>
<td>Type 1</td>
<td>HCV with Cong. HF</td>
<td>600</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>51</td>
<td>Atypical</td>
<td>HCV with moderate Cong. HF</td>
<td>640</td>
<td>3.1</td>
</tr>
<tr>
<td>M</td>
<td>66</td>
<td>Atypical</td>
<td>ASHD and HCV</td>
<td>820</td>
<td>2.4</td>
</tr>
<tr>
<td>M</td>
<td>71</td>
<td>Type 1</td>
<td>ASHD and HCV</td>
<td>600</td>
<td>2.0</td>
</tr>
<tr>
<td>M</td>
<td>69</td>
<td>Typical</td>
<td>Syph. HD</td>
<td>650</td>
<td>2.5</td>
</tr>
</tbody>
</table>

HCV, hypertensive cardiovascular disease; Cong. HF, congestive heart failure; ASHD, arteriosclerotic heart disease; Syph. HD, syphilitic heart disease.

Fig. 1. Frontal and left sagittal plane projections of typical spatial vectorcardiograms observed in left ventricular hypertrophy. In the frontal plane projection many of the QRS sE-loops had an elliptoid contour (a) but almost as many had a circular contour (b). Many of the QRS sE-loops were directed posteriorly and to the left (c). The typical horseshoe-shaped T sE-loop is evident.
minor variations attributable to slight rotation of the loop about vertical, transverse or anteroposterior axes through the isoelectric point. In 13 of these subjects the QRS sE-loop appeared to have been rotated backward about the transverse axis, so that it lay almost in a horizontal plane through the isoelectric point thus being largely directed posteriorly and to the left (fig. 1c).

Twenty-eight QRS sE-loops appeared very similar in configuration and orientation to the QRS sE-loops in normal subjects and were subdivided into those which resembled normal types 1 and 2 and transitional patterns as previously described (fig. 2). However, nine of these loops showed a rotation of the distal tip of the loop which will be discussed later (fig. 3). There remained nine QRS sE-loops which could not be classified as typical either of left ventricular hypertrophy or of normal appearance.

Fourteen of the 19 instances of clockwise inscription in the frontal plane projections were found among the 28 QRS sE-loops of normal appearance and 10 of these resembled the normal type 1 pattern (table 3). The inscription of the QRS sE-loop was counterclockwise in the frontal projection in 69 pa-
Fig. 3. Examples of the spatial vectorcardiograms obtained from patients with left ventricular hypertrophy. Records a and b show slight rotation of the distal tip of the QRS sE-loop. Record c shows more marked rotation of the distal portion so that the major area of the frontal plane projection of the QRS sE-loop is enclosed by a counterclockwise inscription. Record d is a typical spatial vectorcardiogram of left ventricular hypertrophy. These spatial vectorcardiograms (a, b and c) may represent progressive variations in amount of rotation of the QRS sE-loop toward the ultimate development of the more typical pattern (d) of left ventricular hypertrophy.

<table>
<thead>
<tr>
<th>Table 3.—QRS sE Configurations of Spatial Vectorcardiograms of 90 Patients with Left Ventricular Hypertrophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Typical LVH (53 patients)</td>
</tr>
<tr>
<td>Similar to normal</td>
</tr>
<tr>
<td>a. Type 1 (12 patients)</td>
</tr>
<tr>
<td>b. Transitional (4 patients)</td>
</tr>
<tr>
<td>c. Type 2 (12 patients)</td>
</tr>
<tr>
<td>Abnormal but not typical LVH</td>
</tr>
<tr>
<td>(9 patients)</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

patients and in the left sagittal projection in 66 patients. The trace of all of the QRS sE-loops, except two, was inscribed in a counterclockwise direction in the superior projection.

The maximal instantaneous axes in frontal and left sagittal planes of all the QRS sE-loops are shown in figure 4, and the average and extreme values in table 2.

Junction J. Junction J characteristically lay to the right of and anterior to the isoelectric point. The variations may be seen in figure 5. There was no apparent constant relationship between the form of the QRS or T sE-loops and the position of junction J.

T sE-loop. The typical T sE-loop was found to be small compared to the normal T sE-loop.
hypertrophy may begin with consideration of the direct effect of increased left ventricular muscle mass on the mean instantaneous pathway of depolarization. The finding of a QRS sE-loop which is traced first slightly downward and forward and which ultimately completes a wide elliptoid configuration directed leftward, upward and posteriorly is in accord with the conventional concept that the intensity and duration of the process of depolarization is, within limits, proportional to the thickness of the muscle mass through which it moves. Contributing to this configuration may be an indirect effect of increased left ventricular mass, namely, rotation of the heart which is usually in a counterclockwise direction as viewed from the apex.

The positions of the heart within the chest with its variations during cardiac and respiratory cycles, variations in electrical conductivity of the extracardiac tissues and other factors were probably responsible for the deceptively wide variations in the configurations of the plane projections of the QRS sE-loop as well as the other components of the spatial vectorcardiograms. Careful examination revealed that many of the differences were only apparent and were in fact the result of visualizing single plane projections thus re-emphasizing the necessity to observe the vectorcardiogram in three dimensions.

There are several possibilities to be considered as to the underlying mechanisms producing displacement of junction J to the right of and anterior to the isopotential point in left ventricular hypertrophy: (1) prolonged depolarization; (2) early but normal repolarization; (3) early but abnormal repolarization and (4) any combination of these factors. Examination of the electrocardiograms of patients with left ventricular hypertrophy reveals that the downstroke of the R passes through the baseline en route to J, but inspection of the spatial vectorcardiogram readily demonstrates that the last portion of the QRS does not pass through the isoelectric point in space. Because the QRS sE-loop usually arrives at neither J nor the isoelectric point within 0.08 second, it is evident that depolarization is longer than usual and that early repolarization (either
normal or abnormal) is not the only factor involved in the spatial displacement of J. Although the reasons for the anterior and dextral displacement of junction J are not known and although the initial forces of repolarization may form the major contribution, certain regions of late depolarization may possibly contribute to this displacement including (1) the posterobasal portion of the left ventricle, (2) the adjacent basal portion of the septum (from left to right) and (3) the pulmonary conus area.

The causes of the abnormal size, shape and orientation of the T sE-loop in left ventricular hypertrophy are conjectural. J displacement produced an open T sE-loop. The greater overlap of depolarization and repolarization may possibly account for some of its reduction in size as compared with that of the normal. In general, the T sE-loops and QRS sE-loops were oriented in opposite directions. This most likely represents a change in the order of repolarization from the normal.

Examination of the 28 records with normal appearing QRS sE-loops disclosed several interesting facts. First, this group accounted for 14 of the 19 instances of clockwise inscription of the QRS sE-loop in its frontal plane projection. Ten of these with clockwise inscriptions were of the type 1 normal configuration but 8 of these 10 (as well as one of the two clockwise transitional loops) showed a slight uptwist of the distal tip of the otherwise normally-directed QRS sE-loop. It is possible that this may be one of the earliest indications of left ventricular hypertrophy noted in the vectorcardiogram and suggests the manner of change from the usual normal clockwise rotation of the loops to the typical counterclockwise rotation of the loop in left ventricular hypertrophy (figs. 1 and 4). Thus as hypertrophy develops and the mass of muscle situated to the left and posteriorly increases, the distal position of the QRS sE-loop is directed upward and posteriorly. The reason that this distal rotation is not seen in the loops which resemble the normal type 2 loops may be due to the fact that these latter loops already bear some resemblance to the QRS sE-loop in left ventricular hypertrophy in being wide and sometimes inscribed in a counterclockwise direction in the frontal plane projection (fig. 3c). Secondly, despite the obvious lack of left axis deviation, the electrocardiograms of 24 of the 28 subjects were suggestive of left ventricular hypertrophy by conventional electrocardiographic criteria. Since these criteria include slight widening of the QRS complex and an intrinsicoid deflection beginning 0.04 second or more after the onset of the QRS, the electrocardiogram has an apparent clinical advantage over the vectorcardiogram as the latter does not readily show such temporal relationships or close correlation with the semidirect leads. The T sE-loops, however, were abnormal in size, shape and direction in the 20 records in which they were satisfactory for analysis. The spatial pattern of the T sE-loops was similar to that seen in the more typical records showing left ventricular hypertrophy. Finally, there was pathologic confirmation of the hypertrophy in two members of this group; each heart weighed 600 Gm. with left ventricular thicknesses of 1.8 and 2.0 cm., respectively.

There are several possible explanations for the normal appearance of 28 of the QRS sE-loops. As has been mentioned they may have represented an early stage in the development of the typical left ventricular hypertrophy pattern. It is also possible that concomitant right ventricular hypertrophy could have balanced the spatial forces and maintained a normal appearance resultant QRS sE-loop. Other possible factors which may have contributed to the normal appearance of the loops but which could not be evaluated were: (1) changes in the order of depolarization such that the resultant vector forces produced a recorded QRS sE-loop of normal appearance, (2) spatial cardiac position and (3) electrical field effects due to the extracardiac tissue either related to or independent of hypertrophy.

No significant correlation of the configuration of the QRS sE-loop with the etiologic type or clinical severity of heart disease was found. All 12 subjects who had QRS sE-loops which were similar to the type 1 normal loops had hypertensive and/or arteriosclerotic heart
disease. However, the group was not large enough for satisfactory analysis.

It has been proposed that the vectorcardiogram might suggest the diagnosis of left ventricular hypertrophy in instances where the electrocardiogram failed to do so. Because, with very few exceptions, electrocardiographic evidence of left ventricular hypertrophy was included among the criteria for selection of cases in this report, this problem cannot be investigated adequately with these data. In fact, as noted, there were instances in this series in which the converse was true.

SUMMARY

1. The spatial vectorcardiograms in 90 subjects with left ventricular hypertrophy have been studied and described.

2. The configuration of the spatial vectorcardiogram in left ventricular hypertrophy was usually different from the normal. Typically the QRS sE-loop was smooth, wide and rounded, inscribed in a counterclockwise direction and placed largely to the left and above the isoelectric point in its frontal plane projection. The left sagittal plane projection of the QRS sE-loop was long, narrow and directed largely upward and posteriorly. The typical T sE-loop was small, smooth, horseshoe-shaped and counterclockwise in inscription in both frontal and left sagittal plane projections. In some instances the QRS sE-loop was similar to that of the normal but was always accompanied by an abnormal T sE-loop.

3. Concepts as to the genesis of the typical and variant configurations of the vectorcardiogram in left ventricular hypertrophy have been discussed.

4. Further study, including autopsy data, is required to define the spatial vectorcardiogram in left ventricular hypertrophy and associated disease of the myocardium and to establish the relative merits of the vectorcardiogram and the electrocardiogram in the evaluation of the state of the heart with left ventricular hypertrophy.

SUMARIO ESPAÑOL

1. Los vectorcardiogramas en 90 sujetos con hiperтроfia ventricular izquierda han sido estudiados y descritos.

2. La configuración del vectorcardiograma espacial en hiperтроfia ventricular izquierda fue usualmente diferente al normal. Tipicamente el anillo QRS sE fue suave, ancho y redondeado, inscrito en una dirección contraria al movimiento del reloj y localizado mayormente hacia la izquierda y arriba del punto isoeléctrico en su proyección en el plano frontal. La proyección de plano sagital izquierdo del anillo QRS sE fue larga, estrecha y dirigida mayormente hacia arriba y posteriormente. El anillo típico T sE fue pequeño, suave, con forma de herradura y en dirección contraria al movimiento de reloj en ambos planos de proyección frontal y sagital izquierdo. En algunas ocasiones el anillo QRS sE fue similar al normal pero estuvo siempre acompañado por un anillo anormal T sE.

3. Los conceptos sobre la génesis de las configuraciones típicas y variantes del vectorcardiograma en la hiperтроfia ventricular izquierda se han discutido.

4. Más estudio, incluyendo datos de autopsia, se requieren para definir el vectorcardiograma espacial en la hiperтроfia ventricular izquierda y en enfermedades similares del miocardio y para establecer los méritos relativaes del vectorcardiograma y el electrocardiograma en la evaluación del estado cardíaco en la hiperтроfia ventricular izquierda.

REFERENCES

The Spatial Vectorcardiogram in Left Ventricular Hypertrophy
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