The Vectorcardiogram in Right Bundle Branch Block
Correlation with Cardiac Failure and Pulmonary Disease

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AND JOHN STARR, M.D.

SUMMARY Frank vectorcardiograms (VCG) and clinical records
of 243 patients with right bundle branch block (RBBB) were com-
pared. The patients were classified into three categories on the basis
of VCG criteria. The first category included 100 patients with a nor-
mal frontal axis, and the second category included 44 patients with
concomitant left anterior hemiblock. The third category consisted of
99 patients with RBBB and myocardial infarction. The VCGs were
classified into three types according to the QRS configuration in the
transverse plane. In type I the initial forces were anterior and coun-
terclockwise and the afferent limb crossed the midline posterior
to E point; in type II the initial forces were anterior and coun-
terclockwise and the afferent limb crossed the midline anterior to or
through E point; and in type III the entire transverse loop was clock-
wise and anterior to E point. The patients were further classified ac-
cording to the presence or absence of cardiac failure or severe
pulmonary disease.

In patients with RBBB and a normal axis, cardiac failure or severe
pulmonary disease was found in five of 49 patients with type I, 17 of
31 with type II, and 18 of 20 with type III pattern. In patients with
RBBB and left anterior hemiblock, significant disease was found in
one of 17 with type I, five of 16 with type II, and eight of 11 with type
III pattern. These data show that, in patients with RBBB, the posi-
tion of the afferent limb in the transverse plane can be used to predict
cardiac failure or severe pulmonary disease.

SINCE THE DESCRIPTION BY WILSON ET AL. in
1932 of the electrocardiographic features of experimentally-
produced right bundle branch block (RBBB), a wide spec-
trum of electrocardiographic (ECG) and vectorcardi-
ographic (VCG) patterns have been observed to be associated
with RBBB. Delay in the right bundle branch produces QRS
prolongation with delayed terminal forces directed right-
ward and anteriorly. The extent to which the classical
pattern of isolated RBBB can be modified by coexisting car-
diac or pulmonary disease has not been adequately charac-
terized in man. Previous studies have shown that in patients
with RBBB, figure-of-eight, and clockwise transverse plane
VCG patterns may be seen in the setting of coexisting left
bundle branch block, left ventricular hypertrophy, right ven-
tricular hypertrophy, and pulmonary disease. Although
several recent texts have suggested that correlations exist
between VCG patterns and the presence of specific disease
states in patients with RBBB, corroborative clinical data have
not been published. The purpose of this study was to
correlate the types of RBBB with the clinical findings of
either cardiac failure or severe pulmonary disease in a large
number of patients.

Methods

The study population consisted of 243 patients with VCG
criteria for right bundle branch block (RBBB) seen at either
Duke University Medical Center or the Durham V. A.
Hospital. The VCG criteria for RBBB used for inclusion
into the study were: A) QRS duration ≥ 120 msec, B) con-
duction delay with anterior and rightward displacement of
the terminal position of the QRS. From the original group

of 270 patients, 27 patients were excluded because of the
presence of either idiopathic hypertrophic subaortic sten-
osis or Wolff-Parkinson-White syndrome, making a study
population of 243 patients. The mean age of the patients was
57 (range 18–69); there were 215 males and 28 females. A
large portion of the study population was obtained from the
Veterans Administration Hospital which explains the male
predominance.

Data Collection

Vectorcardiograms were recorded using the Frank lead
system on a Hewlett-Packard model 1507A vectorcardio-
graph. Chest electrodes were placed at the fourth inter-
costal space as recommended for the supine position. Photog-
raphs of the frontal, horizontal, and left sagittal
planes were taken directly from the oscilloscope screen on
Polaroid type 107 film. A calibration of 1 mV per 2–4 cm
deflection was used, depending on the size of the VCG loop.
To facilitate analysis the initial forces were enlarged using a
calibration of 1 mV per 10 cm and photographed with the P
and T loops excluded. The VCG loops were interrupted each
2.5 msec and all measurements were made by hand from the
Polaroid prints of the VCG loops. A standard 12 lead ECG
was recorded on each patient using a Hewlett-Packard auto-
matic cardiograph (model 1515B). Right and left heart
catheterizations were performed on 41 patients as part of
their diagnostic evaluation.

Data Analysis

The patients were divided into three categories on the
basis of VCG criteria. The first category included 100
patients with "isolated RBBB" and a normal mean frontal
axis (between +12° and +90°). The second category in-
cluded 44 patients with RBBB and left anterior hemiblock
(LAH). The VCG diagnosis of LAH was established when
the frontal plane loop revealed rightward and inferior initial
forces with a superior and leftward afferent limb, resulting in
a counterclockwise loop with a mean frontal axis between
+12° and −60°. Mean axis was determined as the angle of

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1976.
the point of maximum voltage in the frontal plane. The third category consisted of 99 patients with RBBB and both VCG criteria and clinical evidence for myocardial infarction; these patients were analyzed separately. Eighteen of the 99 patients with myocardial infarction had concomitant left anterior hemiblock. The VCG diagnosis of anterior and diaphragmatic myocardial infarction was established using the criteria of Starr et al.10,11

The VCGs of patient categories 1 and 2 were classified into three types according to the QRS configuration in the transverse plane (fig. 1). In type I, the initial forces in the transverse plane were anterior and counterclockwise and the afferent limb crossed the midline posterior to E point (fig. 1, top panel). This configuration represents the classical RBBB pattern and gives a RSR$^1$ in lead V$_1$ of the standard ECG.$^5$ In type II the initial forces were anterior and counterclock-

![Type I](image1)

**Type I**

![Type II](image2)

**Type II**

![Type III](image3)

**Type III**

**FIGURE 1. Classification of VCG transverse plane patterns.** In type I the initial forces are inscribed anteriorly and counterclockwise and the afferent limb crosses the midline posterior to E point (upper panel). In type II the initial forces are inscribed anteriorly and counterclockwise, and the afferent limb is anterior to or through E point at the midline (midline panel). In type III the entire transverse plane loop is anterior and clockwise (lower panel). The calibration bars for each of the leads represent 0.5 mV. The VCG traces are interrupted each 2.5 msec and the arrows indicate the direction of inscription.

wise, and the afferent limb crossed the midline anterior to or through E point thus forming a figure-of-eight loop (fig. 1, middle panel). In type III the entire transverse loop was clockwise and anterior to E point (fig. 1, lower panel).

Analysis of the clinical records of patients in categories 1 and 2 allowed further classification of the patients according to the presence or absence of either cardiac failure or severe pulmonary disease. This classification was done only in the presence of specific clinical data as outlined below; unsupported clinical impressions were not sufficient basis for inclusion. Patients were classified as having cardiac failure when three of the following clinical signs were observed by at least two physicians: 1) ventricular (S3) gallop, 2) crepitant pulmonary rales, 3) peripheral edema, 4) cardiomegaly, 5) increased jugular venous pressure, 6) cephalization of pulmonary blood flow and Kerley B lines on chest roentgenograms, and 7) therapeutic response to digitalis and diuretics. Severe pulmonary disease was established when, in addition to the clinical symptoms of pulmonary disease, pulmonary function studies revealed the vital capacity and forced expiratory one second volume to be less than 60% of the predicted (2 sd from normal), and arterial blood gases showed the pO$_2$ to be <65 mm Hg and pCO$_2$ >50 mm Hg.

Statistical analyses of mean frontal axis and pulmonary systolic pressures for the three VCG types were done using Student's $t$-test for unpaired data on an IBM 1130 computer.$^{12}$ The determination of statistical significance of the number of patients in each group who had disease was done using Chi square analysis.

**Results**

Ninety-nine patients with RBBB also had VCG criteria and clinical evidence for myocardial infarction. Only the VCG classifications were applied to these patients. Therefore the final study population consisted of 100 patients with "isolated" RBBB, and 44 patients with RBBB and left anterior hemiblock. From these 144 patients there were 29 with cardiac failure, 18 with severe pulmonary disease, and seven with both diseases, bringing the total number of patients meeting the clinical criteria for cardiac failure or severe pulmonary disease to 54.

The relationship of VCG type to the presence of cardiac failure or severe pulmonary disease for patients with "isolated" RBBB and RBBB with left anterior hemiblock is shown in table 1. In patients with isolated RBBB, significant

<table>
<thead>
<tr>
<th>VCG pattern</th>
<th>N</th>
<th>Cardiac or pulmonary disease</th>
<th>Insignificant cardiac or pulmonary disease</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>isolated RBBB</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>49</td>
<td>5</td>
<td>44</td>
<td>&lt;0.005</td>
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<tr>
<td>II</td>
<td>31</td>
<td>17</td>
<td>14</td>
<td>NS</td>
</tr>
<tr>
<td>III</td>
<td>20</td>
<td>18</td>
<td>2</td>
<td>&lt;0.005</td>
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<tr>
<td>RBBB with Left Anterior Hemiblock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>17</td>
<td>1</td>
<td>16</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>II</td>
<td>16</td>
<td>5</td>
<td>11</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>III</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>

*P derived from Chi square analysis.

RBBB and left anterior hemiblock classified according to VCG criteria.

N = number of patients; RBBB = right bundle branch block.
disease was found in five of 49 cases (10%) with type I pattern as compared to 17 of 31 (55%) with type II, and 18 of 20 (90%) with type III. Chi square analysis revealed that the difference between the number of patients in the disease category with type I and type III patterns was statistically significant ($P < 0.005$). Similarly in patients with RBBB and LAH, significant cardiac or pulmonary disease was found in one of 17 (6%) with type I pattern, five of 16 (33%) with type II, and eight of 11 (72%) with type III. Chi square analysis of this group revealed that differences in the number of patients in the disease category was significant for VCG types I, II, and III ($P < 0.005$).

In the 60 patients with isolated RBBB who had not met the clinical criteria for cardiac failure and pulmonary disease, there were 26 patients with a normal cardiovascular system. Of these 26 normals, 21 had a type I pattern and five had a type II pattern. Thirty patients with RBBB and LAH did not have cardiac failure or significant pulmonary disease, and ten of these were normal. Of these ten normals, six had a type I pattern and four had a type II pattern. In the remaining 54 patients with cardiac or pulmonary disease of insufficient degree to satisfy the clinical criteria, 33 had a type I pattern, 16 had type II, and five had type III.

To determine if the correlation between clinical status and VCG pattern was supported by hemodynamic findings, the cardiac catheterization data were analyzed in 41 patients. In this group cardiac failure or severe pulmonary disease was found in one of 17 patients with a type I pattern, seven of 12 with type II, and 12 of 12 with type III (fig. 2). In figure 2 the position of the afferent limb (at the midline) is compared to the systolic pulmonary artery pressure. The amount of anterior displacement of the afferent limb shows a linear correlation with increasing pulmonary pressure ($r = 0.79$). Pulmonary artery pressure elevation was significantly more prevalent in patients with type II and type III patterns ($P < 0.001$). The mean systolic pulmonary pressure was $28.8 \pm 1.8$ (SEM) for type I, $35.5 \pm 2.4$ for type II, and $61.3 \pm 2.8$ mm Hg for type III patients. Only three patients with a type I VCG had a pulmonary artery systolic pressure $> 35$ mm Hg, and all type III patients had a pulmonary pressure $\geq 40$ mm Hg.

Only distribution of VCG type was analyzed in the patients with myocardial infarction (MI) (table 2). The distribution of patients according to VCG type in diaphragmatic MI was almost exactly the reverse of that seen in anterior MI. Type I and type II patterns were more prevalent in DMI and type III was more prevalent in AMI.

The location of mean frontal plane axis (VCG) did not correlate significantly with either VCG type or the presence of cardiac or pulmonary disease. The mean frontal axes for type I, II, and III patients with isolated RBBB was $43 \pm 11^\circ$ (SEM) for type I, $31 \pm 9^\circ$ for type II, and $55 \pm 33^\circ$ for type III patients with isolated RBBB. The mean frontal axes for the three VCG types were not significantly different. However, six of 19 patients with isolated RBBB type III pattern had a mean frontal plane axis $> 90^\circ$, and of these six patients, four had severe pulmonary disease (data not shown).

A comparison of the ECG patterns in the standard limb leads and in lead V1 revealed no ECG criteria which could consistently allow identification of the patients with type I, II, and III VCG patterns.

**Discussion**

Right bundle branch block has been observed as a benign finding in approximately one percent of the normal population as well as an accompaniment of various types of heart disease. Right bundle branch block alters the terminal QRS, frequently obscuring the electrocardiographic manifestations of certain disease processes. The vectorcardiographic method affords a two dimensional display of the QRS complex, allowing the changes of RBBB to be more precisely analyzed than is possible with the standard ECG. The broad spectrum of vectorcardiographic patterns seen in patients with RBBB suggests that important diagnostic information may be gained from comparing the various VCG patterns seen in RBBB to the underlying clinical state. Several texts have suggested that certain VCG patterns in RBBB may be associated with heart disease; however data have not been published in support of these hypotheses.

In the present study the position of the afferent limb in the transverse plane afforded an easily identifiable descriptor to correlate with the presence of cardiac failure or pulmonary disease. The purpose of this study was not to associate a VCG pattern with an etiological diagnosis but rather test the value of a specific VCG pattern in predicting the presence of underlying cardiac failure or pulmonary disease. The data show that of 66 patients (without infarction) with the type I VCG pattern only six (9%) had evidence of significant dis-

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**Figure 2.** On the ordinate is expressed the position of the afferent limb as it crosses the midline at E point. This position is expressed as millivolts (MV) anterior or posterior from the E point using the transverse plane of the Frank lead system. On the abscissa is pulmonary artery systolic pressure in mm Hg. Patients with type I pattern are shown as circles, type II patients as squares, and type III patients as triangles. Patients with cardiac failure or severe pulmonary disease are shown as stippled circles (type I), squares (type II), and triangles (type III).

**Table 2.** RBBB with Myocardial Infarction

<table>
<thead>
<tr>
<th>Type</th>
<th>Anterior MI</th>
<th>Diaphragmatic MI</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>II</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>III</td>
<td>51</td>
<td>8</td>
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ease. However, in type II and type III patterns an increasing incidence of cardiac failure or severe pulmonary disease was found; 22 of 47 patients (47%) with type II and 26 of 31 patients (84%) with type III. Cabrera et al. reported a good correlation between magnitude of rightward anterior forces and ratio of right to left ventricular work in patients with RBBB and pulmonary hypertension from a variety of etiologies (mitral stenosis, atrial septal defect, and valvular pulmonary stenosis). Other studies have shown that patients without RBBB but with right ventricular hypertrophy from right ventricular pressure overload frequently demonstrate a vectorcardiographic pattern resembling the type III pattern identified here. This VCG pattern has been termed type A RVH. Therefore, it is not surprising that in patients with RBBB and right ventricular overload there would be a high incidence of type III pattern. Previous studies in patients with known right ventricular hypertrophy with and without RBBB suggest that the anterior displacement of the afferent limb may be manifestation of the accentuated right ventricular forces. Kulbertus et al. suggested that bilateral disease involvement of the conduction system may give rise to type II or type III patterns based on observations in which stimulation of the posterior wall during surgery produced clockwise and anterior transverse plane loops. This observation may in part explain those patients with RBBB who demonstrate type II patterns without evidence of myocardial disease. However, the QRS durations of types I, II, and III were not significantly different in this study, suggesting that coexistent left ventricular conduction defects were unlikely.

In 41 patients the comparison between pulmonary pressure and the VCG pattern showed that a greater number of patients with type II and type III VCG patterns had an elevated pulmonary artery pressure and clinical evidence of cardiac and pulmonary disease (fig. 2). Abildskov et al. noted a direct correlation between the ECG characteristics of RVH and pulmonary pressures in patients with pulmonic stenosis. Scherlis et al. showed a regression of anterior forces and a conversion from clockwise to counterclockwise rotation (transverse plane) in patients following successful repair of congenital heart lesions with subsequent lowering of right heart pressures. These studies support our observations showing a good correlation ($r = 0.79$) between the level of pulmonary systolic pressure and anterior displacement of the afferent limb. The correlation shown here between anterior displacement of the afferent limb and the level of pulmonary pressure suggests that right ventricular overload may be an important factor in the genesis of the type II and type III VCGs. However, it is difficult to quantify a precise diagnosis of right ventricular hypertrophy in living patients because of A) the lack of precise methods to quantitate right ventricular size in living patients, B) the difficulty in separating coexisting left and right ventricular hypertrophy, and C) the difficulty in separating the effects of right ventricular hypertrophy from right bundle branch conduction delays caused by stretch and elevated right ventricular pressure. The lack of correlation of mean frontal QRS axis with either VCG type or the incidence of cardiac failure or pulmonary disease in this study is supported by the findings of Baydar et al. showing no relationship between frontal QRS axis and the presence of ventricular hypertrophy.

The reason for the high incidence of type III patterns in patients with RBBB and anterior myocardial infarction is unknown. Left ventricular infarction and fibrosis may reduce the electromotive forces generated by the left ventricle, diminish the cancellation effect, and thereby accentuate the right ventricular forces. Left ventricular failure may cause elevation of pulmonary and right heart pressures as the left ventricular filling pressures rise, further augmenting right ventricular electromotive forces. Both of these factors may contribute to the high incidence of type III patterns in this group.

It is worthy of emphasis that many patients in this study demonstrated mild to moderate cardiac and/or pulmonary involvement but did not meet the strict clinical criteria required for inclusion into the cardiac failure or severe pulmonary disease categories. More precise methods of hemodynamic and clinical evaluation might have detected a higher incidence of cardiac failure and pulmonary disease. The two disease categories in this study are frequently associated with right ventricular hypertrophy and dilatation and it is tempting to speculate that the anterior displacement of the afferent limb in the setting of RBBB may be an indicator of early RVH.

In summary the data show the clinical usefulness of certain VCG patterns associated with RBBB. First, of the 66 patients with a type I pattern only 9% had cardiac failure or severe pulmonary disease whereas in the patients with a type III pattern (without infarction) 84% had cardiac failure or severe pulmonary disease. Second, none of the 36 patients with a normal cardiovascular system had a type III pattern (27 with type I, and 9 with type II). Third, differentiation between the three VCG types was not possible using the standard ECG. This study demonstrates that in patients with RBBB the position of the afferent limb in the transverse plane does possess predictive value in the recognition of underlying cardiac failure or severe pulmonary disease. The vectorcardiographic method allows this descriptor to be easily identified and extends the usefulness of the VCG in the diagnosis of heart disease.

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The Conducting Tissues in Primitive Ventricular Hearts without an Outlet Chamber

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AND AUDREY SMITH, F.I.M.L.S.

SUMMARY We have studied the disposition of the cardiac conducting tissues in four hearts from situs solitus individuals possessing primitive ventricles without outlet chambers. These hearts correspond to the type of univentricular heart defined as common ventricle by Lev. All the hearts studied possessed normally positioned great arteries. Two groups, each consisting of two hearts, could be distinguished.

The first type possessed a small posterior ridge which divided the posterior portion of the primitive ventricle into right and left ventricular sinuses. The papillary muscles to the atrioventricular valves were separate structures and arose on each side of this posterior ridge. The conducting tissues in these hearts arose from an atrioventricular node situated in the atrial septum but deviated posteriorly. The atrioventricular bundle pierced the fibrous annulus posteriorly and descended on the posterior ridge, lying to its left side. A bifurcation was not identified, and bundle branches were not present.

The other two hearts had no posterior ridge. A common posterior papillary muscle supported both atrioventricular valves, and in one a marked anterior muscle bar produced obstruction of the pulmonary outflow tract. The connecting atrioventricular node was situated laterally in the right atrioventricular valve orifice, and the atrioventricular bundle descended into the right parietal wall of the primitive ventricle. A bifurcation and bundle branches were not observed.

The disposition of conducting tissue in these hearts differs from that found in "primitive ventricle with outlet chamber" in that the connecting atrioventricular node and bundle are situated anteriorly and are intimately related to the transposed pulmonary artery outflow tract in the latter anomaly. The surgical significance of these findings is emphasized.

DESPITE THE CONSIDERABLE INTEREST engendered by hearts which possess an apparently single ventricular chamber, relatively few investigations into the disposition of the conducting tissues in these anomalies have been published. Monckeberg demonstrated that in such hearts the atrioventricular bundle might be related either to a posterior ridge or from an unusually situated atrioventricular node from which it descended anteriorly. Visioli confirmed this first arrangement of conducting tissue in a case of what he termed "cor biloculare." We showed that the anterior distribution of conducting tissue was to be expected in primitive ventricular hearts with outlet chambers and transposed arteries, and our findings have subsequently been confirmed by Bharoti and Lev. Most univentricular hearts possess an outlet chamber. In those patients with univentricular hearts in which the outlet chamber is absent, the ventricle is unseptated, presenting as a huge ventricular septal defect. In this arrangement, the conducting tissue might be expected posteriorly, as found in the cases described by Monckeberg and Visioli.

Traumatic heart block is a well-recognized complication when patients with hearts of this type are submitted to corrective surgery and this is borne out by experience in our own center. Of six cases submitted to surgery in Liverpool, two developed complete heart block; of these one survived with a permanent pacemaker. Three further patients developed variable rhythms with atrioventricular dissociation but without complete heart block, and two of these died. In view of this high incidence of rhythm disturbance in primitive ventricular hearts without outlet chambers, we have investigated the disposition of conducting tissues in the hearts of the three patients who died, and in a similar heart from our cardiopathological collection.

Definitions and Terms

Considerable controversy surrounds the nomenclature of univentricular hearts. Lev and his colleagues divided the
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