The Speed of Ventricular Activation Measured in the Spatial Vectorcardiograms

By Ernst Simonson, M.D., Otto H. Schmitt, Ph.D., Henry W. Blackburn, M.D. and Raphael B. Levine, Ph.D.

The total QRS interval or R wave crest time in single leads is not accurate for measuring the total ventricular activation time, and is inadequate for an estimate of the ventricular activation rate, as related to the directional time rate of excitation of the total contributing muscle mass. For a more detailed and precise analysis of the ventricular activation, the angular speed in the central segment of the spatial QRS loop was determined in 103 normal men and 26 patients, and significant differences independent of the total QRS duration were obtained.

Characteristics of ventricular activation in clinical electrocardiography are commonly given in terms of QRS duration and R wave crest time, and by qualitative descriptions of QRS contour. The QRS duration was found to be insensitive, however, to various stress situations which produce significant changes in other electrocardiographic items. Appreciable changes of activation speed might conceivably take place, however, in one or another segment of the spatial loop, without affecting the total QRS duration significantly. There is, in addition, considerable error in measurement of QRS duration and the values at the upper limits of normality overlap considerably with values in abnormal hearts. The total QRS duration as well as the crest time of the R wave are usually measured in single leads. These intervals will differ significantly in various leads depending on the spatial orientation of the loop and its projection on the various lead axes, since individual ECG components in various leads are not simultaneous. Correct measurements of ventricular activation can be made only from multichannel high speed records with simultaneous leads representing various axes of projection, or on spatial QRS loops oscillographically recorded or their equivalent.

The Stereo - Vector - Electrocardiograph (SVEC) method is ideally suited for analysis of ventricular activation, since the entire QRS complex is obtained as a single loop, combining all of the individual lead components. Electronic rotation of the projection axes, without changing the electrode position, makes possible standardization of projection axes thus reducing the effect of positional variability and, at the same time, permitting the direction of instantaneous vectors to be measured accurately from two dials (one for the azimuth, the other one for the elevation). Corresponding magnitudes can be read off directly from a calibrated screen.

The spatial axis which displays the maximum QRS vector amplitude was chosen as standard reference, this axis being considered as most highly characteristic of the QRS complex. The simple technic for determining this axis has been described in an earlier publication.

For specific features of the SVEC-QRS loop which are accurately measurable and which seem likely to have physiological significance, we have arbitrarily broken up the QRS loop into three segments as shown in figure 1: (1) the initial segment from start of the QRS loop

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SPEED OF VENTRICULAR ACTIVATION

of ventricular activation during the time when a maximal number of fibers are active.

METHOD

For a more detailed analysis, the central loop segment was subdivided into two parts: (1) that...
ascending from half maximum vector amplitude to the maximum amplitude and (2) that descending from maximum to half maximum amplitude on the return to the isoelectric point. Figure 1 shows a photograph of the normal maximum QRS vector loop and an analytical diagram shows the subdivisions. From the measured angles in the spatial plane of the QRS complex and the time marker at intervals of 2 msec., the speed of the QRS sweep was measured as angular velocity in terms of degrees per 10 milliseconds. For the nine items measured in the loop the following symbols are used, subnumerals 1 and 2 applying to the first and second part of the central QRS loop segment; \( t_1 \) and \( t_2 \): time intervals corresponding to these two segments; \( \beta_1 \) and \( \beta_2 \): central angles subtended by segments; \( c_1 \) and \( c_2 \): average angular velocity for each part of the segment in degrees per 10 milliseconds; \( T, \beta, \) and \( C \): respectively time, angle and angular velocity of the total segment \((1 + 2)\). Figure 2 shows these items in a case with typical left bundle branch block.

Measurements were made in a normal group of 103 middle-aged normal men, part of a larger group under observation for seven years in this laboratory. Criteria of normality were based on annual history, routine clinical examination, resting and exercise ECG, ballistocardiogram, and blood chemistry studies. Data from this group were compared with the data of 26 patients with typical patterns of right and left bundle branch block, right and left ventricular preponderance, anterior and posterior myocardial infarct.

To correlate events in the central segment of the QRS loop with the total QRS duration, the latter item was measured in 67 normal subjects and 25 patients. The same bipolar X, Y, Z leads (horizontal, vertical and sagittal) as used for the SVEC records* were employed, in order to detect earliest and latest electrical activity. Simultaneous linear tracings were made with a two-channel, sensitive, high speed direct writing electrocardiograph.* The earliest and latest noticeable QRS deviation from the baseline with reference to the peak of the R wave in the second channel was used for the total QRS duration.

**Results and Discussion**

The frequency of distribution for the normal group of 103 men was fairly symmetrical for most items, but it was somewhat skewed for the time interval \((t_1)\) and the angle \((\beta_1)\) and for the total QRS duration.

The normal frequency distribution is shown in figures 3 to 6 for the total time \((t)\), the total angle, \((\beta)\), the mean angular velocity for the total segment from half to half maximum amplitude, and for the QRS interval.

Above the normal distribution, the values for individual patients are plotted, subdivided into the various groups of pathology.

As must be expected, the upper normal limit for the total QRS interval (fig. 3) is somewhat higher than in the conventional measurement in single leads, as this method includes all directional components of the ventricular complex. Except for patients with bundle branch block and one patient with posterior infarct, all patients have a normal QRS interval.

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* "Mingograf," Elema Company, Stockholm, Sweden, paper speed 100 mm. per second; frequency response to 700 cycles per second.
The distribution of the total angle (fig. 4, half maximum to half maximum) is similar in normal subjects and in cardiac patients. On the other hand, the distribution of the time interval for the total segment (fig. 5) is different in patients and in the normal group. Comparatively few patients fall outside the limits of normal distribution, but most patients are above the normal mean. A similar situation is shown for the angular speed in figure 6. While nearly all patients are inside the normal limits, most are below the normal mean. This is quite independent of the type of pathology.

Table 1 shows the means and standard deviations of the 10 items for the normal group (lines 1 and 2). The means and standard deviations for the skewed items have, of course, only tentative significance.

The average normal angular speed (c) is about 20 degrees per 10 msec, over an average angle (β) of about 40 degrees. The relative group variability, shown by the standard deviation (S.D.), is smallest for the time intervals, and approximately the same for the angles and the angular velocity.

Since there was no striking difference in the

![Graph showing normal incidence vs. total time (msec) and mean speed vs. total segment (msec to msec).](image)

**Table 1.**—Means (M), Standard Deviations (S.D.), and Statistical Significance of Items Related to Ventricular Activation in Normal Subjects and Cardiac Patients

<table>
<thead>
<tr>
<th></th>
<th>M (msec)</th>
<th>S.D.</th>
<th>M (degrees)</th>
<th>S.D.</th>
<th>M (degrees/sec)</th>
<th>S.D.</th>
<th>M (msec)</th>
<th>S.D.</th>
<th>M (degrees)</th>
<th>S.D.</th>
<th>M (degrees/sec)</th>
<th>S.D.</th>
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<tr>
<td>Normal Men</td>
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<tr>
<td>M</td>
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<td>7.8</td>
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<td>18.2</td>
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<td>2.9</td>
<td>11.5</td>
<td>11.5</td>
<td>7.8</td>
<td>10.2</td>
<td>3.6</td>
<td>17.0</td>
<td>7.5</td>
<td>10.3</td>
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**26 Cardiac Patients**

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<th>M (degrees)</th>
<th>S.D.</th>
<th>M (degrees/sec)</th>
<th>S.D.</th>
<th>M (msec)</th>
<th>S.D.</th>
<th>M (degrees)</th>
<th>S.D.</th>
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<td>6.0*</td>
<td>15.7*</td>
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<td>16.3</td>
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<td>8.3</td>
<td>11.7*</td>
<td>9.3</td>
<td>12.8*</td>
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<td>12.1*</td>
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<td>9.3</td>
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<td>11.7*</td>
<td>9.3</td>
<td>12.8*</td>
<td>9.3</td>
<td>11.9*</td>
<td>7.5</td>
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<td><strong>QRS Interval</strong></td>
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<tr>
<td></td>
<td>30.9*</td>
<td>34.0*</td>
<td>34.0*</td>
<td>30.9</td>
<td>100.6†</td>
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**Differences Normals—Patients**

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<th>t Test</th>
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<th>(.9) (.7) (.9)</th>
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<td></td>
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<tr>
<td></td>
<td>(4.9)</td>
<td>(4.7)</td>
<td>(0.9)</td>
<td>(1.9)</td>
<td>(2.3)</td>
<td>(3.9)</td>
<td>(5.6)</td>
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<tr>
<td></td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.05</td>
<td>&lt;.05</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
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</tbody>
</table>

* Significantly different from normal group.
† Mean of group minus 8 BBB cases is 85.6.
distribution of patients between the various lesions, for control segment measurements it was considered justifiable to pool the data for the total group of 26 patients to be compared with the normal group. Lines 3 and 4 in table 1 show the means and standard deviations in the group of 26 patients, line 5 shows the differences between the means, \( \Delta M \) and lines 6 and 7 their statistical significance, evaluated with the t-test.

For the time intervals \( t_1 \), \( t_2 \), and \( t \) the standard deviations of the normal group and of the patients were significantly different, as shown by the F-test (not included in table 1). The standard deviations of the angles \( \beta_1 \), \( \beta_2 \), and \( \beta \) with the angular speeds \( c_1 \), \( c_2 \), \( c \) were nearly identical in normals and patients.

The t-test reveals that the means of the partial angles \( \beta_1 \) and of \( \beta_2 \) are not significantly different in normals and in patients, while the difference of the total angle \( \beta \) just reaches the 5 per cent level of statistical significance.

For \( t_1 \), \( t_2 \), and \( t \), the use of the t-test for statistical significance is not quite proper because of skewness in the distribution. However, the rather high t-values suggest that the greater time intervals in patients are probably statistically significant.

The angular speeds \( c_1 \), \( c_2 \), \( c \) are significantly slower in patients. This is mainly due to longer time intervals \( (t_1, t_2, t) \) although a tendency to a smaller angle \( \beta \) in patients may be contributory. The low angular velocity in patients is not related to the total QRS interval. Elimination of the eight patients with bundle branch block reduces the mean QRS interval to 85.6 msec., which is practically identical with the normal mean of 86.3 msec., but the mean angular speed of the remaining 18 patients is not substantially changed and is still significantly below the normal mean. A typical example is shown in figure 2, in a patient with left bundle branch block. As compared to the normal loop in figure 1, the rotation is clockwise instead of counter-clockwise, and the angular speed is much lower.

It can be concluded that all six fundamental types of lesions will produce a significant slow-down of the sweep in the middle segment of the spatial QRS loop.

<table>
<thead>
<tr>
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<th>003 Normals</th>
<th>26 Abnormals</th>
<th>Diff between normals &amp; patients</th>
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<td>( t_1 )</td>
<td>15.6</td>
<td>11.7</td>
<td>-4.9</td>
</tr>
<tr>
<td>( t_2 )</td>
<td>21.4</td>
<td>12.8</td>
<td>-8.6</td>
</tr>
<tr>
<td>Difference between ( t_1 ) and ( t_2 )</td>
<td>+5.8</td>
<td>+0.9</td>
<td></td>
</tr>
<tr>
<td>Significance</td>
<td>.001</td>
<td>none</td>
<td></td>
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</table>

While the average ventricular activation speed was significantly slower in patients, the overlap in the distribution between normals and patients is too large for general diagnostic use in the individual patient. It is, of course, quite possible that one or the other of the items may be diagnostically useful for individual patients; for instance, only 3 per cent of the normal group exceed values of \( t_1 = 16 \) and \( t_2 = 17 \); as compared to 42 per cent of the patients.

There is still another significant difference between patients and normals. In the normal group, the angular speed \( c_2 \) in the second part of the segment is significantly greater than that in the first part \( (c_1) \), as shown in table 2. In the patients, there was no consistent difference and therefore, the difference between normals and patients was greater in the second part. As mentioned, the patients were pooled because there did not seem to be any difference in the distribution of the various lesions. We are aware, that the groups are very small, and no definite conclusions about possible differences between different categories of patients are possible at the present time.

Since the QRS interval is the only item related to ventricular activation which is routinely measured in clinical electrocardiography, it was interesting to know whether there was any relationship between the total QRS interval and the ventricular activation in the central segment. Practically, this relationship would test whether the events in the central segment can be predicted from the much simpler measurement of the total QRS interval. The correlation coefficient was calculated for the partial normal group of 67 subjects in
whom two channel Mingograf tracings were taken.

There was a statistically significant negative correlation between the angular speeds \( c_1 \) and \( c \) vs. the QRS interval (\( r = -.32 \) and \( -.28 \), respectively), but the correlation is too low to predict the speed \( c \) from the QRS interval effectively. The correlation between \( c_2 \) and the QRS interval (\( r = -.19 \)) was statistically not significant. The lack of correlation between the time interval of the total segment (\( t \)) and the QRS interval is surprising, since \( t \) is an appreciable fraction (27 per cent) of the total QRS interval.

The positive correlation between the angular speed in the first part of the segment (\( c_1 \)) to that in the second part (\( c_2 \)) was statistically highly significant, (\( r = .41 \)) but, surprisingly, there was no significant correlation between \( c \) and \( t \).

**Summary**

From SVEC records in 103 normal men and 26 patients with typical categories of electrocardiographic abnormality, the angular speed of the sweep in the central segment of the spatial QRS loop was determined, as defined by instantaneous vectors at maximum amplitude and half maximum amplitudes in the rising and falling phases.

The mean angular speed in the normal group was about 20 degrees per .01 sec., over a mean angle of about 40 degrees of the total segment, but was faster in the second than in the first part of the segment.

The angular speed was significantly lower in the group of patients independent of the nature of the involvement and independent of the total QRS duration, and for these patients there was no significant difference of the speed in the first and second parts of the segment.

Correlation between angular speeds and time intervals were calculated.

**References**

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