Choice of Electrocardiographic Leads for Recording the Earliest QRS Onset in Noninvasive Measurements

KENNETH L. WANDERMAN, M.D., GABRIEL LOUTATY, B.S.C., ILYA OVSYSCHER, M.D., ANGEL CANTOR, M.D., YEHOUSA GUSSARSKY, M.D., AND MOSCHE GUERON, M.D.

SUMMARY A significant error may be introduced in intervals measured from the onset of the QRS if an electrocardiographic lead that does not record the earliest deflection is used. To ascertain to what extent the commonly used leads can be relied on to show the earliest QRS onset, 100 normal subjects and 219 patients with heart disease were studied by means of simultaneous recording of three leads: a right precordial lead chosen to show an rS configuration, lead II, and another limb lead chosen to show a qR configuration.

Lead II most frequently showed a delayed QRS onset — in 34% of normal subjects and 36% of the patients. In the other limb lead the initial QRS deflection was delayed in 24% of the normal subjects and 23% of the patients. The QRS onset in the right precordial lead was never delayed in the normal subjects; however, it was delayed in this lead in 6% of the patients. The delays in each of the leads ranged from 5–20 msec.

We conclude that while a right precordial lead is by far the most reliable single lead that can be used for interval measurements, simultaneous recording of a right precordial lead and a limb lead assures the recording of the earliest QRS onset in all cases.

AN ELECTROCARDIOGRAPHIC (ECG) recording is routinely performed simultaneously with recordings made of various noninvasive testing procedures. One of the important uses of this ECG recording is the precise measurement of intervals from the onset of ventricular depolarization (the QRS complex). Such measurements are essential in the assessment of ventricular performance by means of systolic time intervals,1 in the timing of heart sounds on the phonocardiogram and in the timing of the motion of various structures on the echocardiogram such as opening or closure points of the valves2 and systolic wall motion.3, 4 The reliability of all these measurements depends on the accuracy and precision of the determination of the earliest onset of the QRS complex. The onset of the initial QRS deflection is frequently not simultaneous in all ECG leads. Nevertheless, the error in measurement that may be introduced by the use of a lead that does not demonstrate the earliest onset of the QRS is often disregarded. Many laboratories still routinely use lead II. However, Danzig et al.5 showed by comparing simultaneously recorded ECG leads in a large series of subjects that the mean onset of the QRS is significantly earlier in right precordial leads (V1 and V2) than in lead II. They used these results to justify use of a right precordial lead in measurements of the onset of the QRS. Their study, however, was performed on normal subjects only, and it does not necessarily follow that in pathologic states a right precordial lead will always show the earliest onset of the QRS. An orthogonal lead system has been suggested for time interval measurements.6, 7 Such leads have advantages on theoretical grounds, but their superiority over the

From the Cardiology Service, Soroka Medical Center and Faculty of Health Sciences, Ben Gurion University of the Negev, Beer Sheva, Israel.

Address for correspondence: Dr. K. L. Wanderman, Soroka Medical Center, P.O. Box 151, Beer Sheva, Israel.

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routinely used ECG leads in accurately recording the earliest onset of the QRS has not been systematically studied. These leads are also cumbersome and have not gained popularity. Finally, a common approach is to inspect all the ECG leads before the recording and to choose the lead that most clearly demonstrates initial depolarization. This usually means choosing a limb lead that shows a qR configuration or a right precordial lead that shows an rS configuration. However, this technique may not always assure the choice of a lead that records the earliest onset of the QRS complex.

This study was undertaken to determine the frequency and extent of asynchronous onset of the QRS complex in the leads commonly used for measurement (a right precordial lead, lead II and an additional limb lead chosen to show a qR configuration) in a large series of normal subjects and patients with various types of heart diseases. Our objective was to ascertain to what extent each of these leads, if recorded alone, can be relied on to show the earliest onset of the QRS complex, or whether simultaneously recorded leads are necessary to assure that the earliest onset is recorded.

Methods

Subjects

The ECG recordings were performed on unselected subjects during routine visits to the cardiac clinic. Group 1 consisted of 100 consecutive subjects referred for consultation who were subsequently shown to have no organic heart disease on the basis of history, physical examination, ECG and chest x-ray. The ECG tracings were normal in all these subjects. Group 2 consisted of 219 consecutive patients with various types of heart disease. Some of these patients had only mild cardiac lesions and normal ECG tracings, but most had ECG abnormalities (table 1).

<table>
<thead>
<tr>
<th>Electrocardiographic Findings in Group 2</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal ECG</td>
<td>57</td>
<td>26</td>
</tr>
<tr>
<td>Left ventricular hypertrophy</td>
<td>38</td>
<td>17</td>
</tr>
<tr>
<td>Isolated ST-T abnormalities</td>
<td>29</td>
<td>13</td>
</tr>
<tr>
<td>Right bundle branch block</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>Left atrial enlargement</td>
<td>19</td>
<td>9</td>
</tr>
<tr>
<td>Right ventricular hypertrophy</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Left anterior hemiblock</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>Left bundle branch block</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Other intraventricular block</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Right atrial enlargement</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Wolff-Parkinson-White syndrome</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

Recording Procedure

Three ECG leads were simultaneously recorded photographically at 100 mm/sec with an Electronics for Medicine VR6 recorder equipped with a three-channel amplifier, model I/TCV-22, and an ECG preamplifier, model MEP-24. Time lines were calibrated electronically and were set at 40-msec intervals. The leads recorded were as follows: (1) a right precordial lead (lead A), either V1 or V2, chosen to show an rS configuration, or if such a configuration was not present in either, to show the sharpest onset of the initial QRS deflection; (2) lead II (lead B); (3) an additional limb lead (lead I, III, aVL or aVR) (lead C), chosen to show a qR configuration, or if such was not present in any of these leads, to show the sharpest onset of the initial deflection. The signals were unfiltered and were amplified enough to permit clear recognition of the initial deflection. After stabilization of the base line at least five beats were recorded.

Measurement Procedure

In each subject, measurements were made on one beat, chosen for minimal AC interference and muscle tremor. The onset of the initial QRS deflection was marked by a vertical narrow pencil line drawn with the aid of a transparent right-angle triangle aligned with the bottom edge of the paper. The vertical lines were checked to be certain they were parallel to the time lines. The right precordial lead most frequently showed the earliest onset of the QRS complex, so it was used as the reference and the intervals were measured from the onset of the QRS complex in that lead to the onset in each of the other two leads. All measurements were made to the nearest 5 msec. Paper speed was routinely measured and ranged from 97–100 mm/sec. The difference in QRS onset between leads was never more than 20 msec, so correction for paper speed inaccuracy would add no more than 0.6 msec to the measurement.

Results

The means and ranges of the intervals measured from the onset of the QRS complex in the right precordial lead to the onset of the QRS in each of the other two leads are given in table 2. Table 3 shows the frequency (percent) of asynchronous onset of the QRS complex among the leads, as well as the frequency with which each of the three leads can be relied on to record the earliest onset of the QRS.

In both group 1 (normal subjects) and group 2 (patients with heart disease), slightly more than half of the cases showed synchronous onset of the QRS in all three leads (fig. 1).

In the right precordial lead (A), the QRS was never delayed, compared with either of the other two leads in group 1 subjects; the initial QRS deflection was always either synchronous with or earlier than that in the other leads (fig. 2). In group 2, the right precordial lead could not always be relied upon to record the earliest QRS onset; in 13 patients (6%), one or both of
Table 2. Mean Differences (msec) in QRS Onset Among the Leads

<table>
<thead>
<tr>
<th></th>
<th>Lead A – lead B</th>
<th>Lead A – lead C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Group 1</td>
<td>3.9 ± 5.9</td>
<td>0-20</td>
</tr>
<tr>
<td>Group 2</td>
<td>4.0 ± 7.9</td>
<td>-20-20</td>
</tr>
</tbody>
</table>

Lead A—right precordial lead; lead B—lead 11; lead C—other limb lead (defined in the text).

Table 3. Frequency (%) of Asynchronous QRS Onset Among the Leads

<table>
<thead>
<tr>
<th></th>
<th>Leads A, B and C</th>
<th>A earlier than B</th>
<th>A earlier than C</th>
<th>B earlier than A</th>
<th>B earlier than C</th>
<th>C earlier than A</th>
<th>C earlier than B</th>
<th>A records earliest onset*</th>
<th>B records earliest onset*</th>
<th>C records earliest onset*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>58</td>
<td>34</td>
<td>24†</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>18</td>
<td>100</td>
<td>66</td>
<td>76</td>
</tr>
<tr>
<td>Group 2</td>
<td>51</td>
<td>36</td>
<td>23‡</td>
<td>5§</td>
<td>11</td>
<td>6§</td>
<td>22</td>
<td>94</td>
<td>64</td>
<td>77</td>
</tr>
</tbody>
</table>

*QRS onset is either synchronous with or earlier than the other leads.
†17% when qR pattern present in C.
‡16% when qR pattern present in C.
§3% when rS pattern present in A.

The other leads showed an initial deflection that was earlier by as much as 20 msec (fig. 3). Six of the 13 patients in whom the QRS onset was delayed in the right precordial lead did not have a normal rS pattern in that lead, but rather a qR, QS or R configuration; seven patients (3%) had an rS pattern, but the QRS onset was nevertheless delayed.

In both groups, lead II (B) most frequently had a

Figure 1. Synchronous onset of the QRS in all three leads. Time lines are 40 msec.

Figure 2. Delay of 20 msec in the QRS onset in lead III compared to V1.
forces will produce no detectable deflection in that lead. Other factors may also present practical problems in determining the precise onset of the initial QRS deflection. The initial deflection may have a slow onset, producing a slurred configuration and difficulty in delineating the precise point of onset of the deviation from the baseline. The voltage generated by the initial forces of depolarization may be very small, resulting in a tiny initial deflection that is difficult to identify. Furthermore, a small initial deflection may be inconstant and only intermittently present because of respiratory variations. This is a common occurrence in the limb leads, in which a small q may be present only intermittently. Finally, in cases of atrial fibrillation, an f wave may distort the initial QRS deflection. We tried to minimize these difficulties by choosing the right precordial lead and the limb lead that most clearly showed the sharpest onset of the initial deflection and by recording at least five beats after achieving a stable, interference-free baseline.

The mean difference in QRS onset between any two leads in both the normal and abnormal groups was less than 5 msec. Analysis of time intervals based on mean values in large groups of subjects will therefore be little affected by electrocardiographic lead choice. In individual subjects, however, the delay in QRS onset was as high as 20 msec. In almost half the cases in this study, a 5-20-msec delay was found in one or another of the leads. This represents the extent of the error in time interval measurements that may result in the individual subject from the choice of a lead which does not record the earliest QRS onset. Such an error can be highly significant in measurements such as the preejection period of the left or right ventricle, measurements made from the QRS onset to mitral and tricuspid closure, and to ejection sounds. In any subject, if the same lead is always used for making the measurements, the error will be constant and will not affect comparative measurements in that individual. However, such an error may greatly affect comparison of that individual with other subjects or with normal values.

Lead II most frequently showed a delayed QRS onset. Therefore, lead II appears to be a poor choice for measuring time intervals. The choice of a limb lead that shows a qR configuration is more likely to record the initial forces of depolarization. However, a delay of as much as 20 msec in the onset of the QRS is not unusual even in such a lead. The presence of a small q wave in a limb lead is thus no assurance that the earliest QRS onset is being recorded. A right precordial lead is by far the best choice of a single lead for measuring time intervals. In the normal subjects this lead never failed to record the earliest QRS onset. Nevertheless, in patients with heart disease, a right precordial lead may show a delay in the initial deflection of as much as 20 msec in a few cases, even when the QRS complex in this lead has a normal rS configuration.

No association could be found between delays in QRS onset in one lead or another and the type of cardiac lesion or ECG abnormality present. The ECG

delayed QRS onset and showed the largest mean delay. It did, however, record an earlier QRS onset than the right precordial lead in 11 (5%) of the patients in group 2. Nevertheless, lead II never showed an earlier initial QRS deflection than both the right precordial lead and the other limb lead.

The other limb lead (C) also frequently showed a delayed onset of the QRS complex. In group 1, this lead failed to record the initial deflection in 24 subjects (24%) and in group 2, in 51 (23%). Even when it had a distinct q wave, a delay in the QRS onset was sometimes present (17 subjects [17%] in group 1 and 35 [16%] in group 2) (fig. 2). The delay, when present, was as high as 20 msec.

The results are summarized in table 3, which shows the frequency with which each of the three leads records an initial QRS deflection that is either synchronous with or earlier than the initial deflection in the other leads. The percentage for each lead represents the extent to which that lead can be relied upon to record the earliest onset of the QRS complex.

Discussion

The vector of the initial ventricular depolarization forces can be perpendicular or nearly perpendicular to a particular ECG lead. When this occurs, these initial
tracings often recorded a synchronous onset of the QRS in all three leads despite the presence of such abnormalities as bundle branch block, right or left ventricular hypertrophy or myocardial infarction; when the initial deflection was not synchronous among the leads, no lead consistently showed the earliest onset in any of these abnormalities. Recognition of the abnormality was therefore not helpful in predicting which lead would show the earliest QRS onset.

The simultaneous recording of both a right precordial lead and a limb lead assures the recording of the earliest QRS onset in all cases in the present study. Such a simultaneous recording avoids the significant error in time interval measurements in some patients if only one lead is used. In cases in which the initial QRS deflection is small, inconstant or has a slurred onset, a simultaneous recording of the two leads can be particularly helpful in identifying the true onset of the QRS. When the apparatus used is equipped with two ECG channels, the additional time required to perform simultaneous recording is negligible and appears to be well worth the effort.

In conclusion: (1) Lead II should not be routinely used; (2) a limb lead chosen to show a qR configuration is more reliable but also does not assure the recording of the earliest QRS deflection; (3) a right precordial lead, chosen to show an rS configuration, if present, is by far the best single lead that can be used, although in a few cases even this lead will fail to record the earliest QRS onset; (4) simultaneous recording of a right precordial lead and a limb lead assures the recording of the earliest QRS onset in all cases and is recommended for routine use for time interval measurements whenever feasible.

References

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