Earlier Onset of QRS in Anterior Precordial ECG Leads

Precision of Time Interval Measurements

MICHAEL D. DANZIG, M.D., THOMAS L. ROBERTSON, M.D.,
LARRY S. WEBBER, PH.D., GEOFFREY DAY, AND DONALD S. DOCK, M.D.

SUMMARY Onset of QRS was compared between simultaneously recorded conventional ECG leads in 84 subjects with clinically normal hearts from a defined population sample. Mean onset of QRS was 6.4 msec earlier in lead V1 and 7.4 msec earlier in V2 than in lead II. These differences were statistically significant. The measuring system was adapted from drafting techniques and took into account variations in paper speed which occurred during recording. Interobserver differences equivalent to greater than 1 msec occurred in 3.9% of timeline measurements, but in 38% of QRS onset measurements. The lower precision in measuring QRS onset may be attributed to baseline oscillations and to the relatively slow rate of voltage change at the onset of ventricular depolarization.

ABNORMAL CARDIAC FUNCTION in a variety of disease states has been associated with systolic time intervals which were significantly different from normal. Nevertheless, at the individual level, some normal and abnormal subjects may not be distinguishable by these noninvasively derived measurements. In addition, a few observers have not found systolic intervals useful in studying cardiac performance.

In looking for means to improve the utility of systolic interval measurements it appeared that precision of measurement was worthy of further evaluation. In the present study the onset of QRS activity in simultaneously recorded conventional electrocardiographic (ECG) leads was examined to determine if onset was significantly earlier in a lead other than lead II, the most commonly used lead for recording QRS onset. Since some element of observer variation may be involved in defining onset of QRS, the precision of its measurement was compared with that of timeline intervals, the measurement of which should minimize observer variation. Of additional interest were variations in paper speed occurring during recording. When differences of a few milliseconds are considered, paper speed variations may be significant.

Methods

Subjects

The Atomic Bomb Casualty Commission-Japanese National Institute of Health (ABCC-JNIH) Adult Health Study (AHS) sample is a representative sample of A-bomb survivors and nonexposed controls in Hiroshima and Nagasaki who have been examined biennially since 1958. For the present study a subsample in Hiroshima consisting of high radiation dose survivors born after 1920 and sex-age (±5 years) matched nonexposed controls was selected for noninvasive cardiovascular recordings. Members of the AHS cohort who had not previously been examined in the clinic were excluded. AHS records of biennial examinations were reviewed for evidence of heart disease and hypertension. In addition, cardiac examination was performed at the time of recording. Exclusion from the normal group was based on the presence of abnormal cardiac physical, roentgenographic, or ECG findings; none had intraventricular conduction abnormalities. No subject was considered normal if more than one blood pressure during the previous examinations was 140 mm Hg or greater systolic or 90 mm Hg or greater diastolic, or if the blood pressure equalled or exceeded these values at the time of recording. Between October 1972 and March 1973, 196 persons were examined. Based on the strict criteria above, 66 normal subjects were identified, 31 women and 35 men, aged 28 to 52.

An additional 18 borderline hypertensive subjects, six men and 12 women, aged 41 to 52, were studied. These subjects had intermittent and mild hypertension (less than 160 mm Hg systolic and 95 mm Hg diastolic) either in the AHS medical record or at the time of recording. None of these borderline or labile hypertensive subjects had evidence of heart disease or intraventricular conduction abnormalities. Preliminary analysis revealed no differences between this group and the normals in precision of measurement or QRS onset. Accordingly, for the present analysis data will be presented for the total of 84 subjects together.

Recording Procedures

Subjects were studied supine and were allowed to breathe freely. Clip electrodes with saline conductors were used for the limb leads and a suction cup electrode with conducting paste for the precordial leads. Five ECG leads were simultaneously recorded photographically on Kodak Linagraph 1930 paper with an Electronics for Medicine DR-16 research recorder equipped with one VET (triple ECG amplifier) and two EEP amplifiers. In the frequency range 0.1–2500 Hz the response in these amplifiers is essentially flat. All signals were unfiltered and were amplified to a gain of 5 cm/mV. Paper speed was set at 200 mm/sec and timelines at 0.1 sec intervals. The timing mechanism was calibrated electronically by the manufacturer at the time of installation of the equipment and after 18 months of use and was found to vary less than 0.5 msec on both occasions. Calibration with line voltage oscillation also indicated no
measurable changes during the period of study. Five ECG leads were recorded simultaneously in four separate precordial lead sets as follows: Set 1) leads I, II, III, aVF, V1; Set 2) Leads I, II, III, aVr, V5; Set 3) Leads I, II, III, aVF, V4; Set 4) Leads I, II, III, aVr, V4. With the timing mechanism running continuously to avoid inertia at the beginning of recordings, a single beat was recorded for each set.

**Measuring Technique**

All measurements were made independently by two of the authors using 10× magnification. For each precordial lead set the distance between two timelines (0.1 sec) was measured so that adjustment of time interval measurements for variations in paper speed could be made. The interval between the timelines preceding and following the QRS was selected. QRS onset in each lead of all four sets was identified and the distance between the onset of the QRS complex and the R wave peak in lead II was measured. All measurements were made on an engineering drafting board with a transparent plastic right angle triangle designed for this study. A vernier scale was inscribed on the triangle, allowing measurements to be made to 0.1 mm. The vernier scale was inscribed on the contact surface of the triangle to minimize the effects of parallax on the measurements. The use of this system for measuring QRS onset is illustrated in figure 1. The R wave peak in lead II was used as a time reference. QRS onset was measured from the left edge of the trace where the QRS activity first clearly departed from the baseline. Data for timeline intervals are presented in millimeters and data for timing of QRS onset in milliseconds, using as calibration the observed timeline interval for each set and observer separately.

**Results**

**Interobserver Differences in the Measurement of Timeline Intervals**

Distances between narrow straight lines were expected to be less subject to observer error than measurements of ECG complexes. An analysis of interobserver differences in the measurement of timeline intervals would thus allow an estimate of the precision of the recording and measuring system. Four precordial lead sets were recorded for each of the 84 patients studied. The data are presented for the four sets separately.

In table 1, the means and standard errors of the differences between observers are given. None of the differences between observers within a set is statistically significant. A one-way analysis of variance reveals no significant differences in precision among the four sets. A frequency distribution of absolute differences for all four sets together is shown in table 2. Most measurements (96%) differ by 0.2 mm or less. At a paper speed of 200 mm/sec, 0.2 mm represents 1 msec.

**Variations in Paper Speed**

Figure 2 shows the distribution of the mean timeline intervals for the four sets for each subject, based on the average of the measurements by the two observers. With timelines fixed at 0.1 sec intervals, these measurements can be directly

---

**Figure 1.** Simultaneous 5 lead electrocardiogram to illustrate the method for measuring QRS onset. Amplitude gain 5 cm/mV. The tracing was squared with the rules using the timelines to define the axes and zero was set at lead II R wave peak. QRS onset in each lead was measured at the point where the tracing first clearly departed from the baseline. Note the early appearance of QRS onset in lead V1, in this subject 17 msec earlier than in lead II.
TABLE 1. Means and Standard Errors of Differences in Timeline Measurements between Two Observers for Each of the Four Precordial Lead Sets

<table>
<thead>
<tr>
<th>Set</th>
<th>Number</th>
<th>Mean difference (mm)</th>
<th>Standard error of differences (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84</td>
<td>0.007</td>
<td>0.0135</td>
</tr>
<tr>
<td>2</td>
<td>84</td>
<td>0.033</td>
<td>0.0232</td>
</tr>
<tr>
<td>3</td>
<td>84</td>
<td>-0.021</td>
<td>0.0158</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>-0.002</td>
<td>0.0127</td>
</tr>
</tbody>
</table>

converted to paper speeds and the horizontal scale is graded in mm (timeline interval) and in mm/sec (paper speed).

The distribution of the paper speeds is skewed. The mode of the distribution is at 193 mm/sec and the median at 195 mm/sec. A second mode is suggested at 202 mm/sec. The mean paper speed is 195 mm/sec ±0.48 (±sd). It can be concluded that the paper speed under the conditions of this study was for the most part slower than the nominal 200 mm/sec and that paper speed may vary up to 15%. It should be noted that the variability of the frequency distribution of the mean paper speed of the four sets for each subject is less than the variability observed in the individual sets.

INTEROBSERVER DIFFERENCES IN THE MEASUREMENT OF QRS ONSET

Unlike the timeline measurements, QRS onset measurements may vary to a greater degree due to observer variation. At high gain, the precision of these measurements may be influenced by even mild degrees of AC interference and muscle tremor. A relatively slow rate of voltage change at the onset of ventricular depolarization may also contribute to observer differences in judging QRS onset. The interval between QRS onset in each lead and the peak of the R wave in lead II as a time reference was measured in each set. The means and standard errors of the differences between the two observers are presented in table 3. None of these differences is statistically significant. The standard errors of the differences vary considerably among the leads. Of particular interest is the comparison between lead II (a generally accepted reference lead) and leads V1 and V2. Although the standard errors for the precordial leads are generally lower than the other leads with the exception of lead II set 1, differences between the precordial leads and lead II are not large. Note that interobserver differences are greater for these measurements than for the timeline measurements; at best, lead II set 1, 38% of the differences exceed 1 msec and 7% exceed 4 msec.

EARLIEST ONSET OF VENTRICULAR DEPOLARIZATION

Analysis was performed to determine which ECG lead most frequently reveals the earliest evidence of ventricular

![Graph showing the frequency distribution of the mean timeline interval and the mean observed paper speed of the 4 sets for the 84 subjects. Independent measurements by two observers were averaged.](image-url)
Depolarization. Table 4 presents the mean interval for the 84 subjects between QRS onset in each lead and the R wave peak in lead II. The data are the average of the independent measurements by the two observers. As a result of the choice of time reference, earlier onset is manifested by a longer interval (before R wave peak in lead II). Table 4 shows that the precordial lead in each set records the onset of ventricular depolarization earliest.

To test the significance of these observed differences in QRS onset, a matrix of all differences among the leads was constructed (Table 5), and statistical significance was ascertained by using the Hotelling T² statistic. Many of the observed differences among the leads are statistically significant. In every set the precordial lead has the earliest onset and the differences between the precordial lead and the other leads are highly statistically significant (P < 0.01). Among the limb leads QRS onset in lead aVF generally occurs earliest but these differences are not as great nor as consistently significant as those between the precordial leads and the limb leads.

**Discussion**

QRS onset was compared between simultaneously recorded conventional ECG leads. The earliest QRS onset was found in the precordial leads, usually leads V₁ or V₆. Relative to lead II, mean onset occurred 6.4 msec earlier in lead V₁ and 7.4 msec in lead V₆. This is sufficient justification for the use of these anterior precordial leads routinely in systolic intervals, particularly since it is often difficult to judge the lead of earliest onset from the oscilloscope screen at the time of recording. There is some theoretical basis also for predicting that the first deflection might appear in the anterior precordial leads. Studies of thoracic isopotentials have shown an early potential over the sternum. Studies of isolated perfused hearts have also revealed the earliest epicardial breakthrough of potential in the area pretrabecularis of the right ventricle. It should be noted however that these measurements were made in subjects with clinically normal hearts. In pathologic states these observed differences in depolarization between limb leads and precordial leads may not be present.

Data have also been presented on the precision of these external measurements of physiological variables. The abundant literature on systolic time intervals has in general neglected consideration of methods employed in measuring intervals. In the present study, the precision of a system which utilizes an engineering drafting board with mounted rules and a specifically designed triangle with a vernier scale has been defined. This system permitted measurement of timeline intervals to approximately 0.2 mm (1 msec at a paper speed of 200 mm/sec). The precision of measurement of electrocardiographic timing was lower. The interobserver differences varied among the leads but at best (lead II set I) 93% of the differences were 4 msec or less. It is of interest that the ECG limb leads tended to be more severely affected by AC interference and muscle tremor than the precordial leads. It was anticipated therefore that the precision of measurement would be best in the precordial leads. However, as shown in Table 3, there were no major differences in precision among the leads.

Frank and Kinlaw investigated the differences among observers in the measurement of isovolumetric contraction time (ICT) and tension period (TP). The standard deviation of the differences between observers was 1.7 msec for ICT and 1.9 msec for TP based on the average of ten cardiac cycles for each subject. The present data were obtained from a single cardiac cycle and so cannot be directly compared. Use of additional beats would have improved the precision of the measurements.

Spodick et al. analyzed the precision of measurement of

<p>| Table 3. Means and Standard Error (in msec) of the Differences between Two Observers in Measurement of QRS Onset for Each Lead in the Four Precordial Lead Sets |</p>
<table>
<thead>
<tr>
<th>Set</th>
<th>Number</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>aVF</th>
<th>V₁</th>
<th>V₂</th>
<th>V₃</th>
<th>V₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84</td>
<td>-0.10</td>
<td>0.10</td>
<td>0.82</td>
<td>0.24</td>
<td>0.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.28</td>
<td>0.20</td>
<td>0.55</td>
<td>0.30</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>84</td>
<td>-0.81</td>
<td>-0.28</td>
<td>0.05</td>
<td>-0.07</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.42</td>
<td>0.36</td>
<td>0.40</td>
<td>0.34</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>83*</td>
<td>-0.23</td>
<td>-0.20</td>
<td>0.55</td>
<td>0.36</td>
<td>0.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.40</td>
<td>0.32</td>
<td>0.33</td>
<td>0.43</td>
<td>0.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>83*</td>
<td>-0.28</td>
<td>-0.25</td>
<td>-0.03</td>
<td>-0.24</td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.38</td>
<td>0.35</td>
<td>0.50</td>
<td>0.33</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Data for one lead unobtainable in one subject.

<p>| Table 4. Means and Standard Errors (in msec) of the Intervals between QRS Onset in Each Lead and the R Wave Peak of Lead II for Each Precordial Lead Set |</p>
<table>
<thead>
<tr>
<th>Set</th>
<th>Number</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>aVF</th>
<th>V₁</th>
<th>V₂</th>
<th>V₃</th>
<th>V₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84</td>
<td>29.8</td>
<td>33.1</td>
<td>33.3</td>
<td>35.0</td>
<td>39.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.672</td>
<td>0.679</td>
<td>0.652</td>
<td>0.582</td>
<td>0.615</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>84</td>
<td>30.2</td>
<td>32.8</td>
<td>33.8</td>
<td>34.8</td>
<td>40.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.619</td>
<td>0.723</td>
<td>0.726</td>
<td>0.609</td>
<td>0.615</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>83†</td>
<td>30.7</td>
<td>32.4</td>
<td>32.9</td>
<td>34.6</td>
<td>39.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.614</td>
<td>0.740</td>
<td>0.809</td>
<td>0.632</td>
<td>0.596</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>83†</td>
<td>30.1</td>
<td>32.9</td>
<td>33.5</td>
<td>34.6</td>
<td>37.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SEM</td>
<td>0.668</td>
<td>0.702</td>
<td>0.683</td>
<td>0.630</td>
<td>0.621</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Independent measurements by two observers were averaged.
†Data for one lead unobtainable in one subject.
the left ventricular ejection time at varying paper speeds and found good agreement among five observers regardless of paper speed. Pigott et al.14 also found that the precision of measurement of apexcardiograms was independent of paper speed. In both studies, interspeed differences of the observed measurements were significant although there was no trend toward an optimal recording speed. The present study was performed only at a nominal speed of 200 mm/sec so the influence of recording speed on precision or observed intervals cannot be analyzed. There were, however, considerable variations of actual speed, despite careful preparation of the equipment and paper throughout the study period. This has not received adequate attention in the literature. In many published reports where variations in paper speed were neglected or discounted, such variations are indicated by differences in adjacent timeline intervals in figures. It is not surprising that there are variations in paper speed with mechanical systems of paper advance. Use of simultaneously entered timelines and correction of measured intervals for actual paper speed will eliminate this source of variability.

Lastly, any possible effects of such technical considerations on the value of these measurements as a research tool must be considered. Weisler et al.15 found a mean increase in pre-ejection period of 44 msec and a decrease in left ventricular ejection time of 39 msec in patients with severe heart disease compared with normal subjects. Measurement variations, or errors, of the magnitude defined in this report would not substantially alter the significance of those findings. However, where intergroup differences are smaller, it is entirely possible that any improvement in the reproducibility of the measurements may affect the ability of these techniques to discriminate normal from abnormal.

Acknowledgments
The authors wish to express their gratitude to Mrs. Michiko Kunihara and Mr. Tatsuo Mandai of the Department of Medicine for their assistance in the cardiovascular laboratory.

References
3. Parker ME, Just HG: Systolic time intervals in coronary artery disease as indices of left ventricular function: fact or fancy? Br Heart J 36: 368, 1974
Earlier onset of QRS in anterior precordial ECG leads: precision of time interval measurements.
M D Danzig, T L Robertson, L S Webber, G Day and D S Dock

doi: 10.1161/01.CIR.54.3.447

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1976 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/54/3/447

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/