Effect of Electrocardiographic Recording Duration on Ventricular Dysrhythmia Detection After Myocardial Infarction

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SUMMARY To determine the effect of varying the duration of electrocardiographic recording on the detection of high premature ventricular complex (PVC) rates (30 or more PVCs/hour) and/or complex PVCs (multiform PVCs, couplets or runs) in survivors of myocardial infarction, we evaluated 175 24-hour ECG tapes with such arrhythmias for their occurrences detected in the first 1, 2, 6, 12, and 18 hours of the recordings. The first hour of recording disclosed only 47% of the tapes that, over 24 hours, showed high PVC rates or complex PVCs or both, whereas 6 hours of recording uncovered 89% of the tapes with these arrhythmias. Although a 12-hour ECG recording uncovered only 84% of the tapes with couplets and 75% of those with runs, it identified 92% of the tapes with high PVC rates and/or complex PVCs. The detection rate of high PVC rates or complex PVCs is logarithmically related to the recording duration. Seventy-eight percent of the tapes that had complex PVCs and peak PVC rates greater than 100 beats/hour, and 63% of the tapes with these complex PVCs and peak PVC rates of 30–100 beats/hour, showed these complex PVCs in the first hour. In contrast, only 22% of the tapes with complex PVCs and peak PVC rates less than 30 beats/hour were identified during the same interval. We also found that the average number of PVCs/hour was slightly higher in the first than the last 12 hours of the tapes (51 vs 43 PVCs/hour). This study demonstrates that (1) the detection rate for complex PVCs during the first hour of recording is related to the peak PVC rate, (2) a 12-hour recording during the waking period is sufficient to identify most survivors of myocardial infarction who have high PVC rates and/or complex PVCs, and (3) the detection of tapes with high PVC rates or complex PVCs can be predicted from its logarithmic relationship with the recording duration.

THE INCIDENCE and significance of ventricular arrhythmias in patients with coronary artery disease have been well characterized. A standard 12-lead ECG is quite insensitive in detecting cardiac arrhythmias, and a longer duration of recording is required. Kotler and associates reported that analysis of four recordings with standard 12-lead ECGs identified more than twice as many patients with ventricular arrhythmias as did single-recording analysis (35% vs 15%). In another study, 70% of patients with PVCs would have been missed if the recording had been performed for only 1 hour instead of 24 hours. Extended electrocardiographic recording over several hours is now widely used to evaluate patients at high risk of sudden cardiac death. However, the most effective duration of this recording has not been determined. This study was undertaken to evaluate the effect of varying recording periods on the detection of ventricular ectopic activity in survivors of myocardial infarction.

Materials and Methods

The ECG tape recordings in this analysis were part of a prospective sudden cardiac death study in survivors of myocardial infarction who were admitted to the Jewish or Barnes Hospital coronary care units during November 1975 through March 1978. Twenty-four-hour ECG recording was performed 2 weeks after infarction in patients who were ambulatory but not yet discharged from the hospital and consecutively at intervals of 2–3 months after hospital discharge. No additional recordings were made if the initial two recordings failed to reveal frequent, uniform PVCs (30 or more PVCs/hour), multiform PVCs, couplets or runs (three or more PVCs in a row). Most of the in-hospital recordings were begun in the afternoon and the outpatient monitoring was usually started in the morning. To include most of the waking period in the first 12 hours of recording, we chose only tapes started before 11:00 a.m. Our study was not designed to evaluate the change in PVC rate or the presence of various PVC forms at hospital discharge and at the next sequential ECG recording, so no attempt was made to select only sequential tapes for the analysis.

ECG tapes were analyzed by Argus/H, a high-speed computer system for automatic identification of PVCs. All computer-identified PVCs were edited by a trained monitor technician who provided an example of each ventricular arrhythmia for subsequent review by two or more cardiologists. Differences in interpretation were resolved by a group meeting. PVCs were counted for every 15-minute interval in the entire 24 hours. The number of PVCs/hour was calculated by totaling the number of PVCs in every four successive, 15-minute intervals. The maximum number of PVCs/hour (peak PVC rate) and the average number of PVCs in each 12-hour interval were determined for each tape. Regardless of the PVC forms, tapes that had peak PVC rates of 30 or more per hour were classified as tapes with high PVC rates and those with peak PVC rates less than 30 per hour.
TABLE 1. Average Premature Ventricular Complexes (PVCs) per Hour and the Number of Tapes with Peak PVC Rates in the First and Second 12-hour Recordings

<table>
<thead>
<tr>
<th>Tapes with no PVCs</th>
<th>13(6%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapes with PVCs</td>
<td>203(94%)</td>
</tr>
<tr>
<td>Tapes with peak PVC rate in the first 12 hours</td>
<td>122(60%)</td>
</tr>
<tr>
<td>Tapes with peak PVC rate in the second 12 hours</td>
<td>64(32%)</td>
</tr>
<tr>
<td>Tapes with equal peak PVC rate in both 12 hour periods</td>
<td>17(8%)</td>
</tr>
<tr>
<td>Average number of PVCs/hour in the first 12 hours</td>
<td>51</td>
</tr>
<tr>
<td>Average number of PVCs/hour in the second 12 hours</td>
<td>43</td>
</tr>
</tbody>
</table>

were considered to be tapes with low PVC rates. The time of the first appearance of multiform PVCs, couplets and runs was also noted. A tape that had either multiform PVCs, couplets or runs, alone or in combination, was categorized as a tape with complex PVCs.

Analysis was originally performed on 216 ECG tapes recorded on 125 patients between April 1977 and March 1978. However, the tapes that did not have high PVC rates and/or complex PVCs were eventually excluded from the analysis for the influence of varying ECG recording duration on the detection of these arrhythmias. We tabulated the incidence of all PVCs recorded in the first 1, 2, 6, 12, 18 and 24 hours. Arrhythmias detected during each of the five recording periods were then compared with those found in the entire 24 hours. The cumulative percentage of tapes with high PVC rates and/or complex PVCs was plotted against the duration of Holter recordings (log scale) to demonstrate the effect of recording duration on the detection of ventricular arrhythmias.

**Results**

Ninety-four percent of the 216 ECG tapes contained at least one PVC during the 24-hour period of recording. The number of tapes with peak PVC rates in the first vs the second half of the 24-hour recording and the average number of PVCs/hour in each 12-hour interval are shown in Table 1. Eight percent (17 tapes) of the 203 tapes with PVCs showed equal peak PVC rates in both time intervals. Sixty percent (122 tapes) showed peak PVC rates in the first 12 hours. PVCs appeared for the first time in the second 12 hours in only three tapes (1.5%). Although peak PVC rates occurred in the last 12 hours in 64 tapes (32%), in only four tapes (2%) was there a change in peak PVC rates from low (less than 30 PVCs/hour) to high (30 or more PVCs/hour) frequency during the second 12 hours. In addition, the average number of PVCs/hour was slightly greater in the first 12 hours than the last 12 hours of the tapes (51 vs 43 PVCs/hour).

Only 175 tapes that had high PVC rates and/or complex PVCs were subsequently selected for the evaluation of the effective duration of ECG recording in detecting these arrhythmias. Thirteen tapes without PVCs and 28 tapes with infrequent uniform PVCs were excluded from the further analysis. Of these 175 tapes, there were 171 tapes (98%) with multiform PVCs, 82 tapes (47%) with couplets, and 33 tapes (19%) with runs. Some of these tapes had more than one of these PVC types in the same recording. Table 2 shows the cumulative number and percentage of tapes which had high PVC rates, multiform PVCs, couplets, or runs during the entire 24 hours. The first 1 hour of recording disclosed 46% of the tapes with high PVC rates, 46% of the tapes with multiform PVCs, 26% of the tapes with couplets and 21% of the tapes with runs. As expected, the 6-hour recording identified more tapes with PVCs than the 1-hour monitoring. The first 12-hour recording uncovered 95% of the tapes showing high PVC rates at some time during the 24-hour recording, 92% of the tapes showing multiform PVCs, 84% of the tapes showing couplets and 76% of the tapes showing runs. Approximately 97% of each of these arrhythmias was detected by 18-hour recording.

Of the 175 tapes with high PVC rates and/or complex PVCs, only 83 (47%) showed these arrhythmias during the first hour. Ninety-two and 96% of the tapes with these arrhythmias were identified in the first 12 and 18 hours, respectively. Figure 1 demonstrates a linear relationship between the logarithmic recording duration and the detection of tapes with high PVC.

![Figure 1](http://circ.ahajournals.org/)

**Figure 1.** A logarithmic relationship exists between the cumulative percentage of tapes with high premature ventricular contraction (PVC) rates and/or complex PVCs and the recording duration.
rates and/or complex PVCs. This logarithmic relation allows one to predict the discovery rate of these arrhythmias in a recording span.

Table 3 shows the relationship between the peak PVC rates during 24-hour recording and the occurrence of complex PVCs during the first hour of monitoring. Seventy-eight percent of 51 tapes that had complex ventricular arrhythmias and peak PVC rates greater than 100 beats/hour, and 63% of 30 tapes with complex PVCs and peak PVC rates between 30–100 beats/hour, had these complex PVCs detected during the first hour. Only 22% of 94 tapes with complex PVCs and peak PVC rates less than 30 beats/hour showed these complex arrhythmias in the same period. This indicates that the detection rate for complex PVCs during the first hour is related to the peak PVC rate.

### Discussion

Attempts have been made to determine the optimal duration of ECG recording but findings to date have not been conclusive.\(^\text{13, 14}\) Twenty-four-hour recording has been advocated for detecting maximal ventricular ectopy. However, few studies\(^\text{13}\) have dealt with specific types of ventricular arrhythmias. The longer the recording, the more patients with arrhythmias will be identified. However, at some point there must be a compromise between accurate arrhythmia detection and the practical aspects of long-term recording and data analysis.

A linear correlation (\(r = 0.96\)) of the cumulative percentage of tapes with high PVC rates and/or complex ventricular arrhythmias against the duration of ECG recording (log scale) in our study (fig. 1) indicates a logarithmic relationship between the detection rate and the recording duration. A similar relationship is also observed in the data of Kennedy et al.\(^\text{13}\) (fig. 2). These results indicate that if postmyocardial infarction patients are monitored long enough, almost all of them will have some ventricular arrhythmias on ECG recording. Therefore, it seems unreasonable to make any statement that a given duration of recording is necessary for arrhythmia detection without considering the clinical significance and the specific arrhythmias which one desires to detect. For example, a large percentage of tapes with high PVC rates or multiform PVCs will be detected by 12-hour recording (95% and 92%, respectively). However, this length of recording will be less sensitive in detecting couplets or runs, the occurrences of which are sporadic and infrequent. Any recording of less than 12 hours is likely to be too short to detect these arrhythmias reliably.

The logarithmic relationship between the duration of the recording and the cumulative percentage of tapes with either high PVC rates or individual types of complex arrhythmias (fig. 3) allows one to predict the detection rate of a particular type of ventricular arrhythmia in a certain duration of recording. It also shows that doubling the time of recording does not double the yield of arrhythmia detection. Furthermore, increased monitoring duration is not equally effective in increasing the detection rate for all types of ventricular arrhythmias. However, this relationship is obtained from a study with a large number of tapes and may not necessarily be applicable to any individual tape recording.

None of our patients had consecutive ECG recording for more than 24 hours; therefore, no information was available in our study to indicate what percentage of patients without a high PVC rate and/or complex PVCs in the first 24 hours would have had these arrhythmias over a longer period of ECG recording time. However, the longest duration of continuous

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**Table 3. Relationship Between Peak Premature Ventricular Complex (PVC) Rates During 24-hour Recording and the Occurrence of Complex PVCs During the First Hour of Monitoring**

<table>
<thead>
<tr>
<th>Peak PVC rates (beats/hour)</th>
<th>Number of tapes with complex PVCs in 24 hours</th>
<th>Number of tapes with complex PVCs detected in one hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>94</td>
<td>21 22</td>
</tr>
<tr>
<td>30–100</td>
<td>30</td>
<td>19 63</td>
</tr>
<tr>
<td>&gt;100</td>
<td>51</td>
<td>40 78</td>
</tr>
<tr>
<td>Total</td>
<td>175</td>
<td>80 46</td>
</tr>
</tbody>
</table>

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**Figure 2. Logarithmic relationship between the cumulative percentage of postmyocardial infarction patients with high premature ventricular contraction (PVC) rates or complex PVCs and the recording duration (data of Kennedy and associates\(^\text{13}\)).**

**Figure 3. Logarithmic relationship between the cumulative percentage of tapes with high premature ventricular contraction (PVC) rates, multiform PVCs, couplets, or runs, and the recording duration.**
ECG recording commonly used for a sudden cardiac death study is 24 hours, so it seemed reasonable to use this length of recording as an end point in our study. We found that a 12-hour recording will uncover a large percentage (92%) of patients with high PVC rates and/or complex PVCs. Furthermore, most tapes with high PVC rates (96%) are likely to have complex PVCs and the detection rate for these complex PVCs in the first hour is related to peak PVC rate. As in previous reports, our study also shows a decrease in ventricular arrhythmias during sleep; both the average number of PVCs/hour and the peak PVC rate are greater during the waking hours. Thus, a 12-hour recording during the waking period is likely to be more effective in identifying patients with ventricular arrhythmias than a recording obtained during the sleeping hours. However, a 12-hour recording in the waking period will not identify patients with only nocturnal PVCs, the clinical significance of which is presently unknown. Furthermore, although a 12-hour recording is able to identify a large percentage of tapes with high PVC rates and/or complex PVCs, it may not be adequate for certain clinical studies (e.g., antiarrhythmic drug elevation), which require a substantially longer duration of recording.

The importance of more accurate identification of ventricular arrhythmias becomes obvious when one considers studies of antiarrhythmic drug therapy and studies of sudden cardiac death associated with complex ventricular arrhythmias. To identify subjects at risk of sudden cardiac death, previous investigations have used different durations of recording to detect the arrhythmias, varying from less than 1 minute with a standard 12-lead ECG to many hours using long-term ECG recordings. Although a recording of short duration may identify a portion of high-risk subjects, a significant number will not be recognized.

For example, Ruberman and associates found significantly increased sudden cardiac death in patients having complex ventricular arrhythmias (including bigeminy and early PVCs) demonstrated with 1-hour monitoring. However, many of their low-risk patients would probably have been included in the high-risk groups of the present and previous study. Indeed, approximately 41% of the total sudden coronary deaths and 50% of the total deaths in the Ruberman study occurred in their "low-risk" group.

Our findings have the following principal implications on future studies of sudden cardiac death prediction: (1) ECG recording less than 12 hours will not identify a substantial number of patients who have high PVC rates and/or complex PVCs, and who are at high risk for sudden cardiac death; (2) comparison of sudden cardiac death studies based on different lengths of ECG recording should be made with caution; (3) not all types of ventricular arrhythmias have an equal chance of being detected during a given duration of recording; and (4) the linear correlation between the detection rate for a specific type of ventricular arrhythmia and the logarithm of recording duration in our patients may be of great help to other investigators in planning future studies.

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