The Reliability of Intermittent ECG Sampling in Arrhythmia Detection

By Lars Rydén, M.D., Anders Waldenström, M.D., and Stig Holmberg, M.D.

SUMMARY

Although intermittent ECG sampling is a commonly used method for arrhythmia detection there are no controlled studies of its efficiency. In the present study a continuous ECG was recorded for three hours in 52 patients with ventricular tachyarrhythmias. All ECGs were interpreted minute by minute to get the true arrhythmia content. Intermittent ECG samples were simulated by analyzing the first, second, and third minutes of every 15 minutes in the ECG material. Two minute long ECG samples were also used every 30 minutes. The 15 and 30 minute long periods were classified as containing arrhythmias or not according to the arrhythmia content of the samples. These findings were subsequently compared with the true arrhythmia content. The arrhythmia detection rate depends on the sampling time and true arrhythmia occurrence. The distribution of arrhythmias within the periods was also of importance. With a five minute long ECG sample about 80% of the intervals containing any type of ventricular tachyarrhythmia will be detected. This is reduced to about 50% when one minute long ECG strips are used. Infrequent types of VPCs such as R on T or ventricular tachycardia are very poorly detected also when sampling as much as one-third of the total time.

The study also included a comparison between the results obtained from the clinical material and the results obtained by the use of computerized arrhythmia models.

It is concluded that intermittent ECG sampling, besides a low detection rate for infrequent arrhythmias and short ECG samples, also brings a risk of underestimating or overemphasizing the arrhythmia occurrence depending on a periodic type of arrhythmia distribution among the patients. These factors make intermittent ECG sampling an unsuitable method for evaluating antiarrhythmic drugs.

With the Introduction of coronary care units (CCU) there has been an increasing interest in ventricular arrhythmias complicating acute myocardial infarction (AMI). Early detection and treatment of potentially dangerous ventricular ectopic activity can markedly decrease hospital mortality in AMI. The increased possibilities of detecting ventricular ectopic activity with improved monitoring facilities have also increased the interest in arrhythmias complicating other types of cardiac diseases. Intermittent ECG sampling is one of several methods used for arrhythmia detection when evaluating the efficiency of antiarrhythmic drugs. There does not, however, seem to be any critical analysis of the accuracy of this method. This study was designed in order to compare intermittent ECG sampling with a continuous ECG record in detecting different types of ventricular arrhythmias.

Material and Methods

The material consisted of 52 patients admitted to the CCU with a proven or suspected AMI. Pertinent clinical data are presented in Table 1. As part of another study all patients received lidocaine either as an intravenous bolus injection of 75 mg followed by a constant infusion of 2 mg/min or as an intramuscular injection of 300 mg into the vastus lateralis muscle. Except for this antiarrhythmic therapy the patients were managed according to routine procedure in the CCU. A multichannel ink writing ECG recorder with a paper speed of 10 mm/sec (Mingograf 81, Elema-Schönander AB, Sweden) was started as soon as the patient received lidocaine and was continued for three hours thereafter. This electrocardiographic paper record was used for the subsequent arrhythmia analysis and all data concerning the occurrence of ventricular ectopic activity referred to this continuous ECG. This method of arrhythmia detection has been previously described by Mogensen. The continuous ECG was analyzed on a minute to minute basis and each 1-min interval was analyzed separately to determine the presence or absence of ventricular arrhythmias. When ventricular premature contractions (VPC) were present they were classified into the following groups: 1-5 VPCs/min; >5 VPCs/min; R on T VPC; multifocal VPCs; paired VPCs; and ventricular tachycardia (VT) defined as three or more VPCs in sequence at a rate of >100/min.

To illustrate the effect of intermittent ECG sampling, the continuous ECG record from each patient was divided into consecutive 15-min and 30-min periods. To be included in the analysis the ECG of a 15-min period had to be interpretable for at least ten of the fifteen 1-min intervals including the first five 1-min intervals of the period. If these criteria were not fulfilled that particular 15-min period was discarded. The same criteria were applied in analyzing the 30-min periods except that the number of interpretable 1-min intervals had to be more than twenty.

Intermittent ECG samples were simulated by selectively
taking the first, the first two and the first five 1-min intervals of each consecutive 15-min period. For the 30-min periods the samples consisted of the first two 1-min intervals. The arrhythmia content of these intermittent samples was analyzed using the same criteria as described previously and the findings were compared with the true arrhythmia content obtained from analysis of all the 1-min intervals in the respective 15- and 30-min periods. This method of comparison is illustrated in figure 1. Panel A shows sampling periods of 1-min, 2-min and 5-min duration, each sample being taken at the beginning of a 15-min period. If period 1 of panel B is used as an example that 15-min period would have been classified as nonarrhythmia containing if only the 1-min sample had been taken despite the fact that the total 15-min period contains three 1-min intervals with VPCs. In an analogous manner if a 2-min long ECG sample was used period 1 in panel B would be classified as arrhythmia containing, whereas period 2 in panel B would not be classified as arrhythmia containing even if a 5-min long ECG sample was chosen. The results of the analysis of all the 15-min and 30-min periods were summed and the number of arrhythmia containing periods as detected by the intermittent sampling techniques described above were compared with the actual number of arrhythmia containing periods obtained from the continuous ECG.

To demonstrate that the data obtained from the patient material also holds true in general two statistical models were tested. The distribution of arrhythmia containing 1-min intervals may vary between two extremes, either as a random distribution exemplified in figure 1 panel B 1 or as a periodic distribution (panel B 2). Periodic distributions means that all 1-min intervals containing arrhythmias always have to be located next to each other. A computer was used to calculate the detection rate for a varying content of arrhythmias at these two extremes of distribution. Consequently the computer was programmed to distribute arrhythmia containing 1-min intervals randomly and periodically within the 15-min periods. This distribution was made for an increasing number of arrhythmia containing 1-min intervals ranging from one to fifteen within the 15-min period.

Again using figure 1 as an example, panel B 1 shows a random distribution with three 1-min intervals containing arrhythmias. Panel B 2 shows an example of a periodic distribution of three 1-min intervals which may be located at any place within the 15-min period. The computer then simulated 1, 2 and 5 min long ECG samples. The results were plotted to illustrate the detection rate at an increasing number of arrhythmia containing 1-min intervals from one to fifteen. The broken line in figures 4, 5 and 6 represent this relationship for the periodic distribution and the solid line represents the same for the random distribution.

The second statistical model was designed to evaluate the probability of detecting arrhythmias of a low and a high frequency respectively over a long period of time. For each consecutive 1-min interval within the 15-min period a random number which was allowed to vary from 0 to 1 was drawn. If this number happened to be < 0.3 that particular 1-min interval was considered to be arrhythmia containing, thus constituting 15-min periods with a high frequency of arrhythmias. The same was performed for random numbers < 0.03 to constitute 15-min periods with a low frequency of arrhythmias. It was then noted if there were any arrhythmias in the first, first two or first five 1-min intervals. This was repeated for one million 15-min periods. All calculations were done in Fortran IV on a PDP 8 E computer with a floating point processor.

The absolute incidence of arrhythmias was determined by a minute to minute evaluation of the continuous paper recording. According to the protocol for the comparative lidocaine study five of the original 52 patients were excluded during the period of observation leaving 592 accepted 15-min periods, that is, 8880 1-min intervals. One hundred and sixty-three 1-min intervals were not interpretable for technical reasons (1.9%). Thirty-two of the 15-min periods were excluded, 23 due to exclusion of patients and nine because of lack of full ECG information during the first five minutes of the respective period. The prevalence of 1-min intervals containing different types of VPCs as determined by minute to minute

### Table 1

<table>
<thead>
<tr>
<th>Clinical Data</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (yr)</strong></td>
<td></td>
</tr>
<tr>
<td>≤ 40</td>
<td>1</td>
</tr>
<tr>
<td>41-50</td>
<td>7</td>
</tr>
<tr>
<td>51-60</td>
<td>20</td>
</tr>
<tr>
<td>61-70</td>
<td>21</td>
</tr>
<tr>
<td>&gt; 70</td>
<td>3</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>143</td>
</tr>
<tr>
<td>Female</td>
<td>98</td>
</tr>
<tr>
<td><strong>Diagnosis</strong></td>
<td></td>
</tr>
<tr>
<td>AMI</td>
<td>43</td>
</tr>
<tr>
<td>Angina pectoris</td>
<td>5</td>
</tr>
<tr>
<td>VPC of unknown cause</td>
<td>3</td>
</tr>
<tr>
<td>Cardiac insufficiency</td>
<td>1</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td></td>
</tr>
<tr>
<td>l.v. lidocaine</td>
<td>23</td>
</tr>
<tr>
<td>i.m. lidocaine</td>
<td>29</td>
</tr>
</tbody>
</table>

Abbreviations: AMI = acute myocardial infarction; VPC = ventricular premature contractions; l.v. = intravenous; i.m. = intramuscular.
evaluation of the three hour continuous paper recordings are presented in figure 2 A. Figure 2 B shows the prevalence of 15-min periods containing the defined ventricular arrhythmias. Since the patients were treated with lidocaine from the beginning of the study it was of interest to see whether there was a successive change in the arrhythmia prevalence as a function of time. This is illustrated in figure 2 C. The prevalence of all arrhythmias and especially > 5 VPCs/min diminished during the first three 15-min periods.

A 5-min long ECG sample reveals about 80% of the 15-min periods containing any type of VPC (fig. 3). The detection rate decreases for the 2-min and 1-min long samples. The detection rate also decreases with a decreasing arrhythmia content. Consequently, low frequency arrhythmias such as paired or multifocal VPCs are poorly detected; this is even more pronounced if only a 1-min long ECG sample is used. A 1-min sample will only reveal about 10% of the 15-min periods containing paired VPCs.

When comparing sampling of 1/15 of the ECG time either as a 1-min ECG sample every 15 min or a 2-min long ECG sample every 30 min no significant difference could be found in arrhythmia detection (table 2). The results of the detection rates at different sampling time and arrhythmia frequencies as worked out by the computer when using the previously described statistical method are presented in table 3.

In figure 4 the detection of 15-min periods with ventricular arrhythmias is plotted against a varying number of arrhythmia-containing 1-min intervals when using 1-min long ECG samples. The same type of relationship is shown in figures 5 and 6 using 2-min and 5-min long ECG samples. When this relationship is computerized according to the statistical models above this is described by the solid curve for random distribution and by the broken curve for periodic distribution. The interpretation of figures 4, 5 and 6 is that a certain decrease of the number of 1-min intervals containing arrhythmias is of different importance for the rate of arrhythmia detection depending on the length of the ECG sample and whether the arrhythmia content is low or high. The distribution of arrhythmia containing 1-min intervals in the patient material is neither random nor periodic but tends to approach the periodic type which is best illustrated in figure 6.

Discussion

Although some studies have shown that oscilloscope

![Diagram](http://circ.ahajournals.org/Downloaded_from)
monitoring under optimal conditions can reach a relatively high precision\(^4\) other studies have demonstrated the unreliability of ECG monitoring particularly in the detection of ventricular arrhythmias with a relatively low frequency of occurrence (i.e., intermittent VT).\(^9\)\(^{-11}\) Continuous tape recordings of the ECG with subsequent replay and interpretation by means of an automated arrhythmia detection system has also been employed.\(^11\)\(^{-14}\) Intermittent ECG sampling is another often used method for evaluation of the efficacy of antiarrhythmic drugs.\(^4\)\(^{-6}\) Until now no study has been performed to test any of the above mentioned methods as to their accuracy when compared to the true arrhythmia occurrence as is the case for the continuous paper recording.

In the present investigation the ECG records were analyzed minute by minute to get the true arrhythmia content. The 1-min intervals were chosen because the frequency of arrhythmias is commonly expressed as VPCs/min. The continuous ECG record subsequently served as a reference against which the accuracy of intermittent ECG samples of various lengths could be tested. Continuous monitoring may be considered one type of intermittent ECG sampling depending on how long and how often the oscilloscope is being watched. Studies where sampling techniques \(^4\)\(^{4}\) or continuous monitoring\(^7\)\(^{-11}\)\(^{-18}\) have been used in evaluating antiarrhythmic agents seem to obtain much the same results. As none of these methods have been evaluated and compared to the true arrhythmia content the consistency of the results is no proof of the adequacy of the methods. Although antiarrhythmic effects have been noted by the use of intermittent ECG sampling,\(^4\)\(^{-6}\) the conclusions concerning the antiarrhythmic efficacy may have been different if a higher precision of arrhythmia detection had been used. The patients in this study were all treated with lidocaine for defined ventricular arrhythmias. Thus, the general arrhythmia content was relatively low (fig. 2). It was possible, however, by the subdivision of the 15-min periods, to illustrate the effect of the varying frequency of arrhythmia content on the accuracy of the detection rate. The administration of lidocaine is of minor importance as the true arrhythmia content is

### Table 2

**Detection Rate when Sampling 1/15 of the Observation Time either as 1 min of 15 or 2 min of 30**

<table>
<thead>
<tr>
<th>Type of VPC</th>
<th>15-min periods with arrhythmia</th>
<th>15-min periods discovered</th>
<th>30-min periods with arrhythmia</th>
<th>30-min periods discovered</th>
<th>Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any</td>
<td>355</td>
<td>174</td>
<td>49.0</td>
<td>206</td>
<td>89</td>
</tr>
<tr>
<td>&gt; 5/min</td>
<td>140</td>
<td>61</td>
<td>43.6</td>
<td>86</td>
<td>33</td>
</tr>
<tr>
<td>Paired</td>
<td>69</td>
<td>6</td>
<td>8.7</td>
<td>51</td>
<td>5</td>
</tr>
<tr>
<td>Multifocal</td>
<td>53</td>
<td>11</td>
<td>20.8</td>
<td>42</td>
<td>7</td>
</tr>
<tr>
<td>Ventricular tachycardia</td>
<td>28</td>
<td>5</td>
<td>17.9</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td>R on T</td>
<td>24</td>
<td>7</td>
<td>29.2</td>
<td>17</td>
<td>4</td>
</tr>
</tbody>
</table>

*According to \(\chi^2\) discrimination.

### Table 3

**Percent Detection of Arrhythmias in Relation to Decreasing Incidence of Arrhythmias and at Different Lengths of ECG-samples. (Computerized Results)**

<table>
<thead>
<tr>
<th>1-min interval with arrhythmia</th>
<th>15-min periods with arrhythmia (N = 10(^5))</th>
<th>Detected 15-min period % Sampling time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>1 min</td>
</tr>
<tr>
<td>33</td>
<td>995199</td>
<td>30</td>
</tr>
<tr>
<td>3.3</td>
<td>366827</td>
<td>8</td>
</tr>
<tr>
<td>Quotient:</td>
<td></td>
<td>3.8</td>
</tr>
</tbody>
</table>

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known from the continuous paper recordings. During the initial 15-min periods there was a decreasing content of all VPCs and especially > 5 VPCs/min (fig. 2 C). This fact would improve the accuracy of detecting arrhythmias by the intermittent sampling techniques since the samples were always taken at the beginning of the 15-min periods where the arrhythmia content was highest. As the patients were suffering from acute coronary insufficiency (table 1) and, moreover, treated with lidocaine the arrhythmia incidence varied. To illustrate the applicability of the method to the different types of arrhythmia distributions and frequencies a computer was programmed to test the detection rate when the arrhythmia prevalence varied from low to high, and when the distribution was varied from periodic to random. The sampling time was 1, 2 or 5 min (figs. 4, 5 and 6).

The arrhythmia detection rate in the patient material is consistent with that of the computer based material and is well situated within the theoretical margins provided by the detection rate for random distribution (solid line) and for periodic distribution (broken line). This suggests that the results of the described sampling technique are generic and applicable to the patient material.

The results obtained in this study illustrate the importance that the length of the ECG sample, the distribution of the arrhythmias and the rate of arrhythmia occurrence have on the detection rate of arrhythmias by intermittent sampling.

Considering the length of the ECG samples it was found that the collection had to approach one-third of the total time (5-min long ECG samples) to produce a representative discovery of arrhythmia containing periods (fig. 6 and table 3). This holds true only for a high arrhythmia prevalence. For patients with a low arrhythmia frequency a long ECG sample will still be insufficient to adequately detect the true arrhythmia occurrence. Subgroups such as R on T VPC and VT which are considered important predictors of ventricular fibrillation\(^a, 10-17\) will be very poorly detected.

The arrhythmia distribution in the patient material tended to be of the periodic type which is best illustrated in figure 6. This means that if a specific 1-min interval contains arrhythmias the probability is high for the next interval to be arrhythmia containing as well.

This study demonstrates that if the arrhythmia occurrence is high from the beginning and has a periodic distribution it can be reduced considerably without being detected by the use of intermittent ECG samples (fig. 6). On the other hand, if the arrhythmia occurrence is low from the beginning the decrease in detection rate is proportionally higher than the decrease in arrhythmia containing 1-min intervals. Thus in such a case the reduction of arrhythmias will be overestimated as shown by looking at the left part of the periodic curve in figure 6. This is, however, not the case if 1-min long ECG samples are used (fig. 4).

The detection rate is to a large extent dependent on the actual arrhythmia content. This explains the poor discovery of relatively infrequent arrhythmias such as paired VPCs, multifocal VPCs, R on T VPC, and VT by the means of intermittent ECG sampling.

When making a final evaluation of the accuracy of intermittent ECG sampling the various factors of importance in the detection rate must be considered together. This is because the relative influence of each factor may vary with the actual condition.

\(^a\) Ryden, Waldenström, Holmberg

\(^{10-17}\) Ryden, Waldenström, Holmberg

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arrhythmia content tends to be more and more underestimated the shorter the ECG samples are and the lower the true arrhythmia content is. Therefore intermittent ECG sampling must be considered an unsuitable method for evaluating the effect of antiarrhythmic drugs. The detection rate would only be adequate in patients with stable arrhythmias. As soon as the arrhythmia frequency changes so does the detection rate. The present results should be considered when investigating the accuracy of other types of intermittent ECG sampling.

Although very time-consuming, continuous ECG interpretation must remain the base against which a more practical automated arrhythmia detection system should be tested.

Acknowledgment

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