ECG MONITORING USING A LIMITED LEAD SET

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Abstract: A limited bipolar lead set consisting of electrodes in the V2, V4 and V6 positions referred to an electrode at the right shoulder was compared with a similar lead set using electrodes at the V1, V2 and V4 positions. In each case, 12-lead ECGs were derived from the 3 bipolar leads recorded. The residual error (RE), i.e. the difference in area between corresponding QRS complexes in the conventional and limited lead systems, was calculated. Separately, ST amplitude and differences in diagnoses of myocardial ischaemia/infarction were also analysed. 65 patients were entered into the study. The mean residual RE for the conventional ECG compared to V\(_{124}\) was 0.51 (± 0.14) and for conventional compared to V\(_{246}\) was 0.37 (± 0.11) - (p ≤ 0.001). The 12 lead ECG derived from the V\(_{246}\) system provided a good agreement (k = 0.63) with the conventional system in the diagnosis of ischaemia but had only fair agreement (k = 0.46) with respect to myocardial infarction. The V\(_{124}\) system was less successful. The conclusion drawn was that the V\(_{246}\) system was the better of the two and was able to provide a reasonable approximation of a conventional 12-lead ECG recording.

INTRODUCTION

The use of all 12-lead ECGs in a coronary care unit (CCU) or intensive therapy unit for monitoring is prohibitive. For this reason, limited lead systems have been investigated in the past. These have used either 4 electrodes, as in the EASI lead system [1], or a slightly larger number in the Frank lead system [2]. In both cases, the 12-lead ECG has been derived from the 3 leads of the limited set by using transformations [3] which have not all been published as yet. For this reason, it was felt of interest to investigate the possibility of utilising a small number of chest electrodes to develop a lead system that might be useful for patient monitoring in the CCU.

METHODS

A prospective, comparative, within subjects design was used to compare two limited lead systems in which patients served as their own controls. From January to March 2001, in-patients in the CCU and Cardiothoracic Surgical Wards at Glasgow Royal Infirmary (GRI) were asked to participate in the study. Informed consent was obtained as required by the GRI ethics committee, who also approved the study protocol.

Two recordings were made for each patient. For the first, the electrodes were applied in the standard positions in order to obtain the conventional 12-lead ECG. For the second recording, the V3 electrode was moved to the right shoulder to record the potential denoted \(E_R\).

Limited lead system

Two new lead systems were evaluated from the recordings. The first consisted of 3 bipolar leads namely \(E_{V1} - E_R\), \(E_{V2} - E_R\) and \(E_{V4} - E_R\) where \(E_{V1}\) is the potential at the V1 position etc. Each of the conventional 12-leads could be derived as a linear combination of these 3 bipolar leads, e.g.

\[ I = \alpha (E_{V1} - E_R) + \beta (E_{V2} - E_R) + \gamma (E_{V4} - E_R) \]

The co-efficients \(\alpha, \beta, \gamma\) are shown in Table I. They were derived by one of the authors (AvO) specifically for this...
study using his mathematical model of electrical conduction [4] and a database of 50 normal patients.

A second lead system was designed in an identical manner using \( V_2, V_4 \) and \( V_6 \) instead of \( V_1, V_2, V_4 \). The transfer co-efficients for these systems are also shown in Table I.

TABLE I
Transfer coefficients for the two lead systems. Columns refer to bipolar leads referenced to the potential at the right shoulder (see text for further explanation).

<table>
<thead>
<tr>
<th>LEAD</th>
<th>V1</th>
<th>V2</th>
<th>V4</th>
<th>V2</th>
<th>V4</th>
<th>V6</th>
</tr>
</thead>
<tbody>
<tr>
<td>-I</td>
<td>-0.360</td>
<td>0.022</td>
<td>0.231</td>
<td>0.091</td>
<td>0.067</td>
<td>0.255</td>
</tr>
<tr>
<td>II</td>
<td>0.063</td>
<td>-0.150</td>
<td>0.411</td>
<td>0.022</td>
<td>-0.010</td>
<td>0.688</td>
</tr>
<tr>
<td>V1</td>
<td>1.100</td>
<td>-0.020</td>
<td>-0.210</td>
<td>0.431</td>
<td>0.095</td>
<td>-0.480</td>
</tr>
<tr>
<td>V2</td>
<td>0.100</td>
<td>-0.976</td>
<td>-0.210</td>
<td>0.962</td>
<td>-0.20</td>
<td>-0.310</td>
</tr>
<tr>
<td>V3</td>
<td>-0.120</td>
<td>0.464</td>
<td>0.474</td>
<td>0.325</td>
<td>0.713</td>
<td>-0.370</td>
</tr>
<tr>
<td>V4</td>
<td>0.100</td>
<td>-0.020</td>
<td>0.768</td>
<td>-0.040</td>
<td>0.983</td>
<td>-0.310</td>
</tr>
<tr>
<td>V5</td>
<td>-0.020</td>
<td>-0.120</td>
<td>0.643</td>
<td>-0.030</td>
<td>-0.334</td>
<td>0.485</td>
</tr>
<tr>
<td>V6</td>
<td>-0.060</td>
<td>-0.150</td>
<td>0.424</td>
<td>-0.040</td>
<td>-0.020</td>
<td>0.692</td>
</tr>
</tbody>
</table>

The ECGs were transferred to a commercial ECG management system (Megacare) and then subsequently the measurement matrix obtained from the Glasgow ECG Program [5] together with an average beat for each lead was extracted. The average beats were then used to derive the 12-lead ECG using both lead systems.

The average beats of the full recording and the two derived recordings were transferred into MATLAB and the residual error between the derived and original ECG calculated over the QRS complex of 8 independent leads (\( V_1 \) to \( V_6, aVR, aVL \)). The residual error \( R_E \) was calculated as follows:

\[
R_E = \sqrt{\frac{\text{RMS difference}}{\text{RMS original}}} = \sqrt{\frac{\sum_{i=1}^{\text{QRS complex}} (x_i - y_i)^2}{\sum_{i=1}^{\text{QRS complex}} y_i^2}}
\]

where RMS = root mean square, \( x_i \) = QRS value from the limited lead system, \( y_i \) = QRS from the conventional 12-lead system sampled 500 times per second per lead.

The ECG diagnosis of myocardial infarction or ischaemia as identified by the program was used in a comparison between conventional and derived ECGs using a 2 x 2 contingency table. The kappa (K) statistic was used to determine whether percent agreement between the conventional and derived 12-lead ECGs was more than chance agreement.

RESULTS

65 patients participated in the study. The mean RE for the conventional ECG compared to the 12-lead derived from \( V_{124} \)
ECG was 0.51 (± 0.14). For V_{246}, R_E was 0.37 (± 0.11). A box and whisker plot illustrating the differences between the R_E values for the 2 different approaches is shown in Figure 1.

The difference was significant (p < 0.001; 95% CI 0.11 to 0.16). Figure 2 shows the best transformation using the V_{246} lead system where the R_E is 0.16.

There were wide ranging discrepancies in ST amplitude between the original and derived ECGs. For example, the 95% limits of agreement in V3 derived from V_{246} being -46 to 72 µV. With respect to diagnosis, 29 out of 65 patients had a report of myocardial infarction on the original 12-lead ECG.

With respect to diagnosis, 29 out of 65 patients had a report of myocardial infarction on the original 12-lead ECG. The V_{124} system identified 10 (K=0.32) and the V_{246} system identified 15 (K=0.46). For myocardial ischaemia, the corresponding results were K = 0.39 and K = 0.63.

DISCUSSION

This study has shown that it is feasible to construct a full 12-lead ECG from 3 bipolar chest leads with reasonable accuracy. However, the variation in observed R_E, i.e., from 0.16 to 0.9 was large. Thus, the use of a single transform to encompass all patients proved less than satisfactory. ST amplitude certainly has an important role to play in determining whether or not a patient should receive thrombolysis but the data from this study indicate that it is simply not possible to equate such measurements from a derived 12-lead ECG with those from the original. The results also suggest that a simple lead system such as this is not effective and that a redesign should be considered. One possibility would be to utilise a left shoulder electrode in addition, possibly leading to a more accurately derived Lead I and an improved vertically directed lead such as aVF.
REFERENCES


