

Effects of Electrode Misplacement on the Reconstruction of the 12-Lead ECG

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Abstract

In this study we investigate a limited lead system, that reconstructs 12-lead ECGs from leads I, II, V2 and V5, to assess how slight misplacement of recording electrodes impacts on reconstruction accuracy. The study population consisted of 117 lead body surface potential maps (BSPMs) recorded from 559 subjects (approximately one third normal, one third MI and one third LVH). The BSPMs were interpolated to increase the number of recording sites in the vicinity of V2 and V5. For QRS segments the median RMS error across all reconstructed leads was 220.4 μV , 171.4 μV , and 277.8 μV when V2 and V5 were simultaneously moved -50mm vertically, 0mm, and +50mm vertically respectively. For STT segments these values were 66.8 μV , 54.3 μV and 76.9 μV respectively. We observed that during the QRS segment the most accurate reconstruction was at -15mm (RMS error: 154.4 μV). During the STT segment the reconstruction error was at its minimum at -20mm (RMS error: 48.5 μV). A similar increase in performance for STT reconstruction was observed at 15mm (RMS error: 48.6 μV). The median values taken across all leads masked the fact that electrode misplacement affected different reconstructed leads in different ways.

1. Introduction

Limited lead systems record electrocardiogram (ECG) signals from a reduced number of recording sites. The information recorded from these sites can then be expanded to yield ECG signals at other sites which have not been recorded. A number of limited lead systems have previously been proposed which allow the reconstruction of the 12-lead ECG [1]. One of these approaches uses two of the standard precordial leads, V2 and V5, and standard limb leads, I and II, to reconstruct the missing precordial leads [2]. The remaining limb leads are calculated from I and II. This provides a reconstructed 12-lead ECG from six recording sites as opposed to the ten recording sites that are required to record the standard 12-lead ECG.

The effect of electrode misplacement, when recording

the standard 12-lead ECG, has been the focus of previous studies [3]. Studies have focused mainly on the errors made in the placement of the precordial lead electrodes. These leads present the greatest potential for electrode placement error as the associated anatomical landmarks are often difficult to identify. Limb lead placement is also a controversial issue but this relates more to a conflict in standards rather than the lack of precision or error in electrode placement [4].

The effect of electrode misplacement in limited lead systems has not been widely studied. In this study we assess the effect of electrode misplacement in the limited lead system that has previously been described (I, II, V2, V5). We focus our attention on the precordial component, i.e. leads V2 and V5. Clinical guidelines stipulate that V2 should be placed in the fourth intercostal space at the left sternal border [5]. The recording electrode for V5 should be placed in the same horizontal plane of V4 at the anterior axillary line or midway between V4 and V6 if the anterior axillary line is difficult to identify [5],[6]. Studies have shown that, for the standard 12-lead ECG, a common source of misplacement error is failure to identify the correct intercostal space resulting in V2 often being placed too superiorly in the second or third intercostal space [6]. It has also been shown that V5 is often placed too inferiorly [6],[7]. V5 presents a particular problem in the limited lead system under investigation in this study, as V4 and V6 are not present for spatial reference.

2. Methods

In this study we simulate moving V2 and V5 to assess the impact that this has on the reconstruction accuracy of the missing leads. To do this we move V2 and V5 vertically, up to +50mm (superiorly) and -50mm (inferiorly), away from their standard locations. This is illustrated in Figure 1. We have limited this initial study to consider only vertical misplacements as these errors have been shown to occur most frequently in 12-lead ECG acquisition [7]. We conduct three sets of experiments. In the first experiment we simulate moving recording electrodes V2 and V5 simultaneously. In the latter two experiments we

move V2 and V5 in isolation.

Body surface potential maps (BSPMs) were used to allow simulation of electrode misplacement. The studied BSPMs were previously recorded from a set of 559 subjects (approximately one third normal, one third MI and one third LVH). Each BSPM recording consisted of 117 torso leads along with standard limb leads. A schematic illustrating the electrode layout is provided in Figure 2. Also shown on this format are the positions of the six precordial leads. The recording process has previously been described in [8].

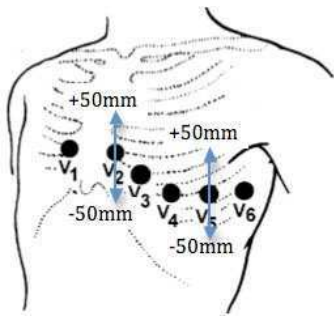


Figure 1. Illustration of electrode movement simulation.

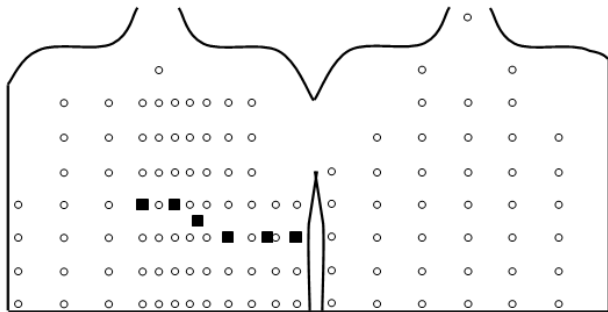


Figure 2. Schematic of 117 lead BSPM format. Circles indicate positions of recording sites. Positions of six precordial leads are indicated using filled squares.

In order to allow the simulation of the misplacement of V2 and V5 the BSPMs were interpolated to yield recording sites at 5mm increments up to +/-50mm, in the vertical plane, from V2 and V5. A combination of Laplacian 3d interpolation and linear interpolation were used [9],[10].

In the first set of experiments V2 and V5 were simultaneously placed at -50mm from the standard position and the 12-lead ECG was reconstructed using published transformation coefficients [11]. V2 and V5 were then simultaneously moved in 5mm steps up to +50mm away from the standard position. At each step the 12-lead ECG was reconstructed. In the second set of experiments V2 was moved in the same manner as above whilst V5 remained in its original position. Again, at

each step the 12-lead ECG was reconstructed. In the third set of experiments the above procedure was repeated this time with V5 being moved whilst V2 remained in its standard location. For each of the above experiments the RMS error (RMSE) was used to compare the reconstructed 12-lead ECG with the actual 12-lead ECG. For each of the three experiments, this comparison was made at each 5mm increment for each lead of each subject. Subsequently the median RMSE for each lead across all subjects was determined. The median across all leads for all subjects was also calculated. RMSE was determined independently for the QRS and STT.

3. Results

The changes in reconstruction accuracy whilst moving V2 and V5 up to +/-50mm from their standard location is illustrated in the plots shown in Figure 3 and Figure 4. These plots show the median RMSE for the QRS and STT for each reconstructed lead for each of the experiments undertaken i.e. moving V2 and V5 simultaneously, moving only V2 and moving only V5. The median across all reconstructed leads, for both QRS and STT, is shown in Figure 5.

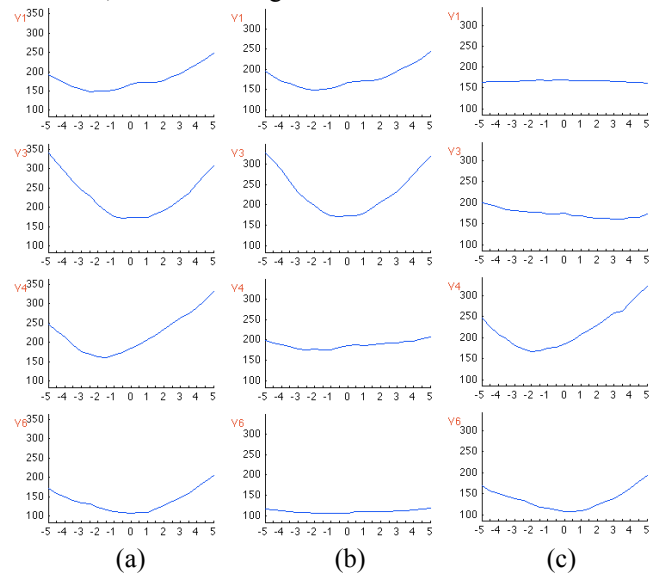


Figure 3. RMSE observed as recording electrodes V2 and V5 are moved between +/-50mm during QRS segment of reconstructed leads (V1, V3, V4 and V6). Graphs in column; a) indicate performance when V2 and V5 are moved simultaneously, b) indicates performance when only V2 is moved, c) indicate performance when only V5 is moved. Y-axis units = μV , X-axis units = cm.

It can be seen from the plots illustrated in Figure 3 that when both V2 and V5 are moved simultaneously the RMSE is most extreme when V2 and V5 are furthest (+/-50mm) from the standard locations. The minimum

RMSE, however, was not always observed when V2 and V5 were at the standard locations. This was the case for V1, where the minimum error was observed when V2 and V5 were at -25mm. Also, for V4 the minimum error was observed when V2 and V5 were moved -15mm from the standard location. Lead V4 was most sensitive to slight movement of V2 and V5 away from the standard positions as the graph shows the RMSE changes most rapidly for this lead as V2 and V5 move between +/-10mm. This in comparison to the other three leads, particularly V3 and V6, where there is relatively small change in RMSE between +/-10mm.

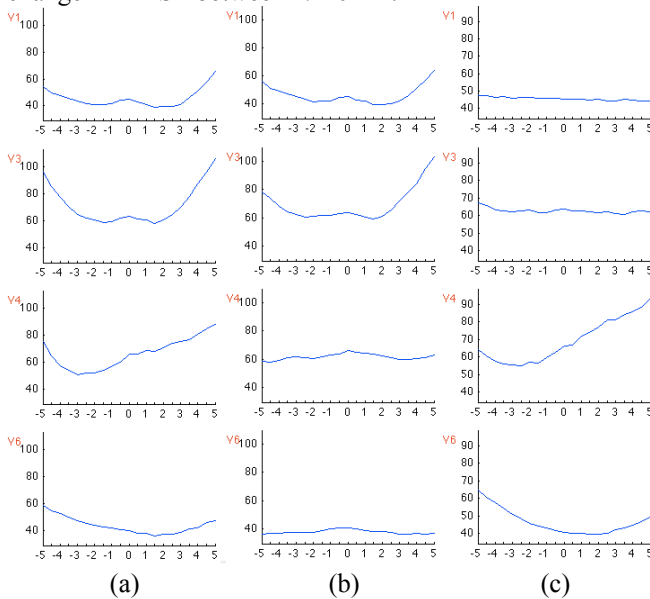


Figure 4. RMSE observed as recording electrodes V2 and V5 are moved between +/-50mm during STT segment of reconstructed leads (V1, V3, V4 and V6). Graphs in column; a) indicate performance when V2 and V5 are moved simultaneously, b) indicates performance when only V2 is moved, c) indicates performance when only V5 is moved. Y-axis units = μV , X-axis units = cm.

When V2 or V5 are moved individually it can be seen that the reconstructed leads in close proximity are most affected. For example, when V2 is moved (Figure 3b), the reconstruction of V1 and V3 are most affected whilst V4 and V6 are largely unaffected. The reverse is true for whenever V5 is moved (Figure 3c). Furthermore, when either V2 or V5 are moved individually the observed pattern on affected leads is similar to that when V2 and V5 are moved simultaneously. i.e. V1 is more accurately reconstructed when V2 is moved -20mm, V4 is more accurately reconstructed when V5 is moved -20mm and reconstruction of V3 or V6 is insensitive to small movements (+/-10mm) of V2 or V5 respectively.

When V2 and V5 are moved simultaneously and the STT performances are considered (Figure 4a) it can be

seen that again the most extreme RMSE is observed when V2 and V5 are furthest from the standard locations. Similar to the reconstruction of the QRS, some of the reconstructed leads exhibit superior performance when V2 and V5 are not at the standard locations. This is particularly obvious for lead V4 where maximum reconstruction performance appears to be when V2 and V5 are positioned at -30mm from the standard location. Several of the leads also appear to be insensitive to the movement of V2 and V5. This is more obvious during the STT as compared to the QRS as it can be seen in Figure 4 that the RMSE for V1 and V3 exhibits minimal fluctuation when V2 and V5 are moved up to +/-30mm. It should be noted that, although there appears to be more erratic changes in reconstruction accuracy as the recording electrodes are moved during the STT segment, the small STT voltages will exaggerate even small changes in RMSE.

When the individual movement of either V2 or V5 during the STT is considered it can be seen the pattern is the same as previously observed. Namely, the reconstructed leads in close proximity, to the recording lead whose position is altered, are most affected. In addition, the overall pattern of error on affected leads is the same as that when V2 and V5 are moved simultaneously.

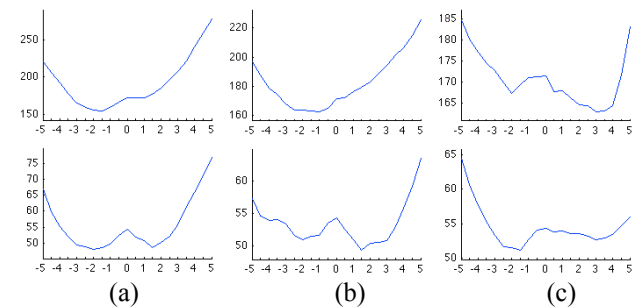


Figure 5. Median RMSE across all reconstructed leads as recording electrodes V2 and V5 are moved between +/-50mm. Top row indicates median RMSE during QRS segment. Bottom row indicates RMSE during STT. Graphs in column; a) indicate performance when V2 and V5 are moved simultaneously, b) indicate performance when only V2 is moved, c) indicate performance when only V5 is moved. Y-axis units = μV , X-axis units = cm.

When the median performance across all four reconstructed leads is considered (Figure 5) it would appear that, during the QRS segment, minimum error occurs when both V2 and V5 (Figure 5a) are moved -15mm from the standard location. The pattern is similar during the QRS when V2 is moved (Figure 5b). When V5 is moved (Figure 4c), the median RMSE suggests that the ideal position for this lead is +30mm from the

standard location. All three graphs for median RMSE during STT indicate small fluctuations (approximately 5 μ V) between \pm 20mm. The median RMSE results mask the fact that individual reconstructed leads respond differently to the misplacement of recording lead electrodes.

4. Discussion and conclusions

This study has investigated how electrode misplacement in a limited lead system, made up of I, II, V2 and V5, can impact on reconstruction accuracy. Overall, the results show that, when recording electrodes are moved, the pattern of reconstruction error differs for each reconstructed lead. As one would expect, most reconstruction error occurs when recording leads are furthest, in this case \pm 50mm, from their standard locations. Conversely, a number of reconstructed leads exhibit minimal reconstruction error when the recording leads are moved 15-20mm from the standard locations. Also, some, but not all, reconstructed leads are insensitive to movement of up to \pm 20mm of the recording leads. These individual lead patterns are not obvious from the median errors calculated across all leads.

This is a preliminary study and further work is required in a number of areas. Firstly, in this study we have only considered the changes observed on the reconstructed leads (V1, V3, V4 and V6) as V2 and V5 are moved. What we have not considered is how the signals on V2 and V5 themselves change during electrode misplacement. Secondly, the effects of horizontal misplacement of recording electrodes requires investigation. This is particularly important with respect to recording electrode V5 where misidentification of the anterior axillary line may result in horizontal misplacement. This is particularly the case in the absence of V4 and V6 for reference. Finally, this study has investigated the effect of electrode misplacement on reconstruction accuracy. A correlation between reconstruction accuracy and diagnostic accuracy cannot be assumed. Further work and more data are required to investigate the effects of electrode misplacement on diagnostic accuracy.

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