Optimal Electrode Placements for the Identification of Old MI and LVH

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Abstract

Past studies have demonstrated the improved diagnostic utility of the electrocardiogram by utilizing alternative recording sites to that used in the standard 12-lead. The present study proposes new lead sets based on the developments of innovative computational models. Utilizing 744 117-lead body surface potential maps the diagnostic value of different recording site combinations was evaluated. Three lead sets were derived; sites discriminating between subjects with evidence of old myocardial infarction and healthy subjects; sites discriminating between subjects with left ventricular hypertrophy and healthy subjects; and sites discriminating between the two disease types. A wrapper approach incorporating a nearest neigbour classifier was adopted to facilitate the lead selection process. Following 10-fold cross validation the recording sites chosen for LVH vs Normal, MI vs Normal and MI vs LVH yielded sensitivities of 89%, 89% and 75%, and specificities of 91%, 94% and 65%, respectively.

1. Introduction

For over a century the electrocardiogram (ECG) has been used to non-invasively assess cardiac function [1]. In particular, the 12-lead ECG has been the most widely adopted recording format [2]. Specifically, 3 bipolar limb leads and 6 unipolar chest leads are utilised in this procedure. While this technique is the most widely used and accepted ECG recording technique it is appreciated that under certain conditions it fails to detect cardiac dysfunction and a study [3] has shown it to be only 50% accurate in the detection of acute myocardial infarction (MI). Furthermore, there exists little scientific rationale for the standard positioning of the precordial chest leads which was essentially a committee decision introduced in 1938 to permit researchers to compare their work. At that time the committee stressed that the introduction of the standard should not hinder future investigations into alternative recording sites [4]. Nevertheless, the establishment of such a standard, almost 70 years ago, has provided confidence to clinicians and researchers, many of whom are reluctant to adopt alternative recording sites.

Some researchers have attempted to improve upon the diagnostic utility of the ECG by searching for alternative recording sites [5][8]. Such research has utilised body surface potential map (BSPM) systems which, similar to the 12-lead ECG, non-invasively record ECGs but incorporate many more electrodes (32-219) with the aims of capturing the total ECG information. Such recordings permit the retrospective determination of the diagnostic contribution of each recording site.

BSPM recordings are typically presented as isopotential maps each of which represent the signal captured, at each recording site, for a particular instance in the cardiac cycle. Typically, recordings last for 10-15 seconds usually resulting in several hundred isopotential frames per recording. To assist in dealing with the thousands of resulting variables the temporal isopotential frames can be presented as isointegral maps. With such maps a summation of the temporal potentials, recorded from each electrode site during a significant phase of the cardiac cycle, are presented as a single map. Specifically, those signals captured during ventricular depolarization (QRS), ventricular repolarisation (ST-T), and across the complete ventricular cycle (QRST) are often summarized as isointegral maps.

In the present study BSPMs, recorded from a cohort of 744 subjects, are examined to establish alternative recording sites which are viewed as optimal for the detection of old MI and left ventricular hypertrophy (LVH), respectively. The approach used to derive the new recording sites differs from past studies [6][8] which have relied on statistical methods. With the advances in computational power and data-driven mining techniques, vast arrays of data can now be searched, and important features selected based on their ability to fulfil some predefined criteria. One such feature selection technique is the wrapper approach [9] which evaluates each variable in a dataset and extracts those features which collectively work best to maximise some predefined criteria. The wrapper approach utilises a classifier in its search strategy as the means for evaluating the value of each potential feature. In the present study an instance based classifier in the form of a nearest neigbour (NN) was adopted.

2. Methods

2.1. Data

The BSPMs, from which the data was recorded, consisted of 117 unipolar recording sites. A comprehensive description of the electrode array is provided in [10]. In summary, 81 of the electrodes were located anteriorly with the remaining 36 positioned posteriorly. The electrode array consisted of 18 columns of differing row heights with approximately 5cm between the rows. Using Wilson's central terminal as the reference potential data was sampled simultaneously at 500Hz. The quality of the signals was visually monitored and, following the acquisition, selective averaging and further validation was performed [10].

The dataset contained 744 subject recordings. Of these, 229 subjects exhibited no disease symptoms (Normal). A further 278 were diagnosed as having MI, and a remaining 237 were diagnosed with LVH.

2.2. Pre-processing

Initially, three isointegral maps, summarizing cardiac activity during the QRS, ST-T and QRST segments were derived from each of the recordings contained in the dataset. Subsequently, three datasets were created from the available data. The first dataset (507 records) contained all of the MI and healthy subjects (MI/Norm). The second dataset, containing 466 records, included all of the LVH and Normal subjects (LVH/Norm). Finally, a third dataset (515 records) contained all the MI and LVH subjects (MI/LVH). This provided a platform from which three dichotomies of classes could be considered resulting in the proposal of three optimal lead configurations.

2.3. Data partitioning

Prior to the feature selection each of the datasets were appropriately partitioned. Initially, the 744 available QRS, ST-T, and QRST isointegral maps were merged to provide 351 (3×117) possible features per subject recording. Subsequently the data was subdivided into train, validation, and test sets as shown in Table 1.

Table 1. Composition of each dataset investigated.

	MI/Norm		LVH/Norm		MI/LVH	
Train	177	146	151	146	177	151
Valid	45	37	38	37	45	38
Test	56	46	48	46	56	48
Total	507		466		515	

Essentially, for each dataset 20% of the records were extracted for use in the evaluation of the final models. These records were not used to influence the features chosen during development. Of the remaining 80%, 20% was used as a validation set to guide the learning of the wrapper.

2.4. Feature selection and classification

A wrapper approach was utilised to search for and locate recording sites which, collectively, offered most to the diagnostic assessment of the diseases investigated. When implementing this type of feature selection a classifier must be incorporated within the wrapper to guide the selection process. As such, the wrapper is viewed as classifier dependant as the resulting features are only optimal when used with the guidance classifier.

A forward selection search strategy was implemented whereby the model was initially empty and features were incrementally added at each stage of the selection process. Initially, each variable in the training set was selected, independently, and used to train the classifier. The accuracy of each variable based on validation set submission was recorded. The variable yielding the highest accuracy was extracted from the data as a new feature and added to the final model. This process was repeated, however, in each case the remaining variables were selected based on how well it performed when grouped with those variables already chosen for the model. The selection process terminated when no further increase in validation performance was witnessed or after 32 leads (possibility of 96 features) had been selected. This upper number of leads has previously been reported as the maximum practical number of leads which would be acceptable in a clinical setting [4]. Subsequently, the final model was used for test set classification.

In the present study NN was chosen because of its simplistic implementation and the ability to replicate experimental studies. In selecting an appropriate number of k-neighbours several different k values were evaluated. Consequently a single NN model was found as the most appropriate choice. Following the feature selection process the test set, utilizing the prescribed features, was presented to the NN classifier. To provide a more stable and less biased performance measure a 10-fold cross validation (CV) was conducted.

3. Results

This section presents the features chosen by the wrapper and the results attained from the CV. The comparative performance of the standard lead positions, to the proposed optimal lead systems, is also described. Highlighted in Figure 1 are the recording sites chosen by the wrapper approach and also indicated is which isointegral the feature was selected from.

In the MI/Norm dataset (Figure 1(a)) three of the chosen sites were located on the posterior with two features selected from a site over the dorsal spine. Four

sites were located on the lateral regions with the remaining sites found anteriorly. In considering the first six selected sites only two leads were selected from the precordial region.

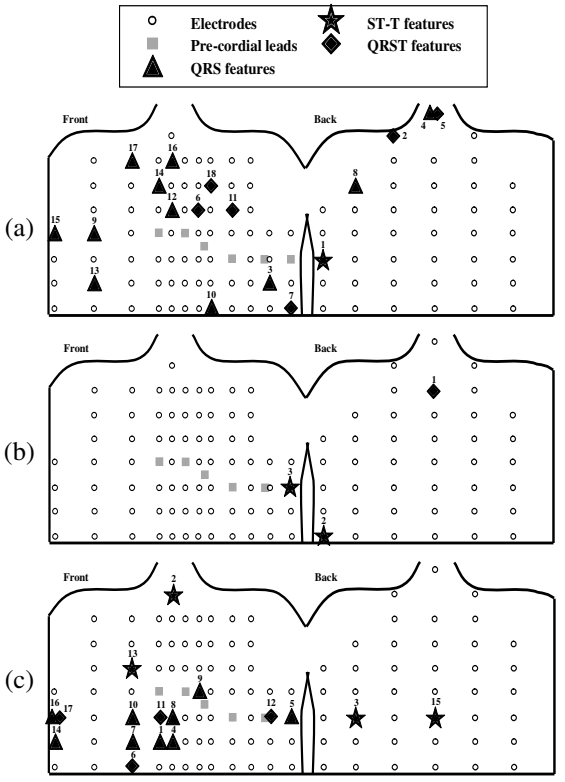

Figure 1. Illustration of 117-lead BSPMs indicating the locations of the recording sites and isointegral features selected for (a) MI/Norm, (b) LVH/Norm, and (c) MI/LVH datasets. The order in which the features were selected is highlighted above each feature.

None of the sites chosen from the LVH/Norm dataset (Figure 1(b)) were located in the precordial region. Two sites were located laterally and one posteriorly. To facilitate a comparison with the precordial leads the wrapper was forced to continue its selection process. Of these extra sites two were located near the umbilical level and one was located in the upper lateral region.

In Figure 1(c) two sites were found posteriorly with remaining sites in close approximation to the precordial sites. Two sites were especially close to V5 and V6.

3.1. Precordial leads

In order to provide some comparative measure the six precordial lead measurements were extracted from each dataset and a 10-fold CV, using the NN model, was performed. The results from these tests are summarized in Table 2.

Table 2. Results following experiments using the six precordial leads as input features.

	MI/Norm	LVH/Norm	MI/LVH
Sensitivity	74.82%	76.37%	64.03%
Specificity	78.60%	86.03%	64.14%
Accuracy	76.53%	81.12%	64.01%

In the dataset containing MI and Normal records the six precordial leads yielded a sensitivity of 74.82% and specificity of 78.60%. This compares with 76.37% achieved for the scenario were it was attempted to distinguish between LVH and Normal. In this case the specificity was also over 86% providing an accuracy of 81.12% which was nearly 5% more than that resulting from the MI/Norm dataset. When presented with the dataset representing MI and LVH subjects the accuracy was only 64.01% with similar sensitivity and specificity.

3.2. Optimal leads

Prior to evaluating the optimal features (recording sites) chosen by the wrapper for each dataset the performance of the first six chosen recording sites was evaluated (Table 3). This was conducted to permit a direct comparison with the standard leads and furthermore to ascertain whether the performance attained by the standard leads could be improved by repositioning.

Table 3. Results following submission of the first six recording sites as selected by the wrapper approach.

	MI/Norm	LVH/Norm	MI/LVH
Sensitivity	86.33%	89.03%	66.55%
Specificity	90.39%	92.58%	56.96%
Accuracy	88.17%	90.77%	62.13%

In comparison with the results from Table 2 it can be viewed that there was evidence of improved performance in two out of the three scenarios investigated. Improvements in sensitivity was witnessed across all datasets with over 10% increase resulting for the LVH/Norm and MI/Norm datasets, with similar results for the specificity of the latter. There was a 6.55% increase in specificity for the LVH/Norm dataset; however, a decrease of 7.18% was witnessed for the same measurement in the MI/LVH dataset.

Table 4 presents the results attained by the optimal features chosen by the wrapper. In comparison with Table 2 the accuracy attained by the chosen features for each dataset resulted in an increase of over 15% for the MI/Norm dataset; more than 9% increase for the LVH/Norm dataset and over 6.5% was witnessed for the MI/LVH dataset. The 17 recording sites (18 features) selected by the wrapper for use with the MI/Norm dataset attained a 3.55% improvement over the first six best leads

presented in Table 3. Furthermore, a minor decrease was witnessed for features chosen for the LVH/Norm dataset. Finally, an accuracy increase of over 8% was attained using the 16 chosen MI/LVH recording sites (17 features) compared to the first six sites presented in Table 3.

Table 4. Results attained from optimal features.

	MI/Norm	LVH/Norm	MI/LVH
Sensitivity	89.93%	89.03%	75.18%
Specificity	93.89%	91.27%	65.40%
Accuracy	91.72%	90.13%	70.68%

4. Discussion and conclusions

Based on the figure and tables presented this study has highlighted that much of the available diagnostic information is projected outside the precordial area. Considering that the wrapper selected relatively few leads from the precordial region supports previous findings which suggest that the standard leads contain redundancy because of their close proximity. Nevertheless, from this study it is suggested that at least one electrode should be placed within the precordial region. This seems reasonable considering that electrodes placed in this region are in close proximity to the anterior surface of the heart. Therefore utilizing non-standard recording sites in unison with a few precordial leads could add considerably to the diagnostic value of the ECG.

To further examine such diagnostic benefits consider the Tables previously presented. The best discrimination was witnessed in the MI/Norm dataset, although this increase was only marginally better than the performance of the LVH/Norm dataset which required 14 fewer recording sites. This suggests that characteristics of LVH isointegral maps differ greatly from Normal maps. On examining the amplitude values for the features chosen it was found that on average the posterior lead recorded higher values from LVH subjects while the reverse was true for the other two leads. In considering the MI/LVH dataset, while an improvement in sensitivity was witnessed, overall the accuracy was considerably less than that achieved by the other lead sets. On examining the amplitude from the selected features there was no clear distinction between the classes.

In summary, this study has attempted to discover whether it is possible to improve upon the diagnostic utility of the ECG by selecting alternative recording sites to the standard leads. It was demonstrated for two of the datasets that repositioning the six precordial leads can improve their diagnostic utility. Furthermore, it was shown that utilizing only three sites permits discrimination between LVH and Normal subjects; however, identifying MI cases from Normal cases is considerably more complicated. Finally, whilst an improvement upon the precordial leads was witnessed, distinguishing MI from LVH has proven to be a more difficult task and one that perhaps requires features not present in the summarized isointegral maps.

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