Limited lead selection for estimating sites of pre-excitation

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Abstract

In this study, we examined the influence of limited lead selection on the localization of pre-excitation sites. To simulate magnetic field maps (MFMs) and body surface potential maps (BSPMs) corresponding to 10 single pre-excitation sites located along the atrio-ventricular ring, we used an anatomical model of the human ventricles. From this database of MFMs and BSPMs, we selected optimal subsets from 8 to 32 leads for each mapping modality by means of the iterative statistical technique (IST). Our results indicate that 20 optimally-selected leads localized the pre-excitation sites equally well as the complete lead systems consisting of 117-BSPM and 128-MFM leads, respectively.

1 Introduction

In multichannel recordings, the redundancy of signal information is well-known and can be readily tackled by creating the transfer matrix, which links the limited array of optimal leads to the full set of leads [1]. This technique has been successfully applied in the field of electrocardiography, while the redundancy of magnetocardiographic signal information has been largely left unexamined. One of the reasons is that the placement of magnetocardiographic leads is constrained by the design of the recording system, while the electrocardiographic leads can be arbitrarily put on the torso. In this particular study, we compared redundancy in electrocardiographic and magnetocardiographic signals as it pertains to the localization of pre-excitation sites. While this is a simple physiological model, it represents a necessary step to application of our methodology to clinically-challenging problems, such as, selection of limited leads in order to distinguish the various groups of patients (e.g., those with myocardial infarction and no ventricular tachycardia and those with myocardial infarction and ventricular tachycardia).

2 Methods

We reduced the number of recording sites by the iterative statistical technique (IST), developed by Lux et al. [1], where the magnetic field or electric potential at unmeasured sites $\mathbf{x}^e$ are estimated from their values at measured sites $\mathbf{x}^m$ by a linear transformation $\mathbf{T}$ such that

$$\mathbf{x}^e = \mathbf{T}\mathbf{x}^m = \mathbf{K}_{um}\mathbf{K}_{mm}^{-1}\mathbf{x}^m, \quad (1)$$

where $\mathbf{K}_{mm}$ is a covariance matrix of the measured potential/field and $\mathbf{K}_{um}$ is a cross covariance matrix between the measured and unmeasured potential/field. This estimator minimizes the root mean square error (RMS) and at each iterative step selects the lead which has the highest correlated power ("information content") with all other sites.

For purposes of simulating pre-excitation sequences under controlled conditions, we used an anatomical model of the human ventricular myocardium [2], which includes anatomically accurate geometry with the resolution of 0.5 mm, realistic intramural fiber structure with rotating anisotropy, and propagation algorithm based on physiological principle of excitatory current flow. The individual pre-excitation sites were placed along the atrio-ventricular ring and are shown in Figure 1. From these sequences we calculated 117-lead BSPMs (Figure 2) and 64-lead and 128-lead MFMs (Figure 3) using the oblique dipole model of cardiac sources in combination with the boundary element torso model [2-4]. We used all simulated maps obtained for single pre-excitation sites in Figure 1 as data base from which we selected optimal subsets with 8, 10, 12… 32 leads for the 117 lead BSPM, 64 MFM and 128 MFM systems, see Figures 2 and 3.

Once we selected optimal leads, we performed the inverse localizations using the single dipole model as the equivalent source of pre-excitation. We evaluated the localization accuracy (i.e., the distance between the single dipole location and the site of pre-excitation) versus a number of optimally-selected leads.

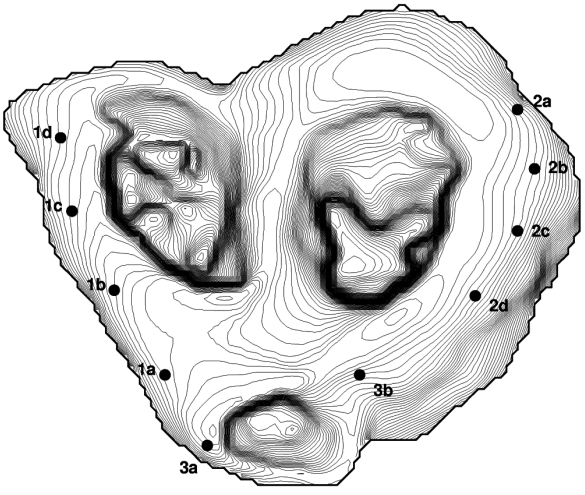

Figure 1. Basal view of the human ventricular model shown with 10 pre-excitation sites along the atrio-ventricular ring. Right ventricle is to the left, left ventricle is to the right, and pulmonary artery is to the bottom.

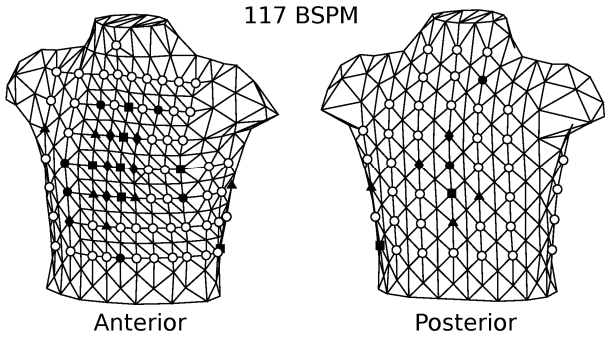

Figure 2. Layout of 117-lead BSPM placed on Horacek torso model [4]. Different labels denote the order of precedence for the optimally selected leads: ■ (1–8), ♦ (9–16), ▲ (17–24), ● (25–32), and ○ (all others).

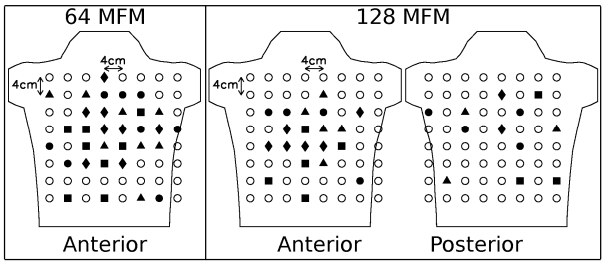

Figure 3. 64-lead MFM placed above the torso, and 128-lead MFM placed both anteriorly and posteriorly. For explanations of labels, see Figure 2.

3 Results

Figures 2 and 3 show the order of precedence for the optimally selected leads from the 117-lead BSPM, 64 MFM and 128 MFM systems, respectively.

Figure 4 summarizes results and compare the localization accuracy when optimal limited selection of leads and full set of leads are employed at 24 ms after the pre-excitation.. It can be clearly seen that the localization accuracy is no longer improved once 20 optimal leads have been selected.

4 Discussion

The main finding of our study is that strikingly smaller number of leads (no more than 20), in comparison to that currently employed in systems for both BSPM and MFM recordings, may be sufficient to localize the pre-excitation sites within few millimeters. This is in agreement with our earlier finding in [5] where we obtained the average weighted correlation coefficient of 0.98±0.01 for estimated MFMs from 20 leads in the whole PQRST interval.

Our results also corroborate the finding in [1] that the "optimal" lead selection is non-unique, i.e., that slightly shifted position of the first lead could generate quite different lead sets, which perform equally well. The methodology developed in this study could also be used in selecting the optimal lead configuration for

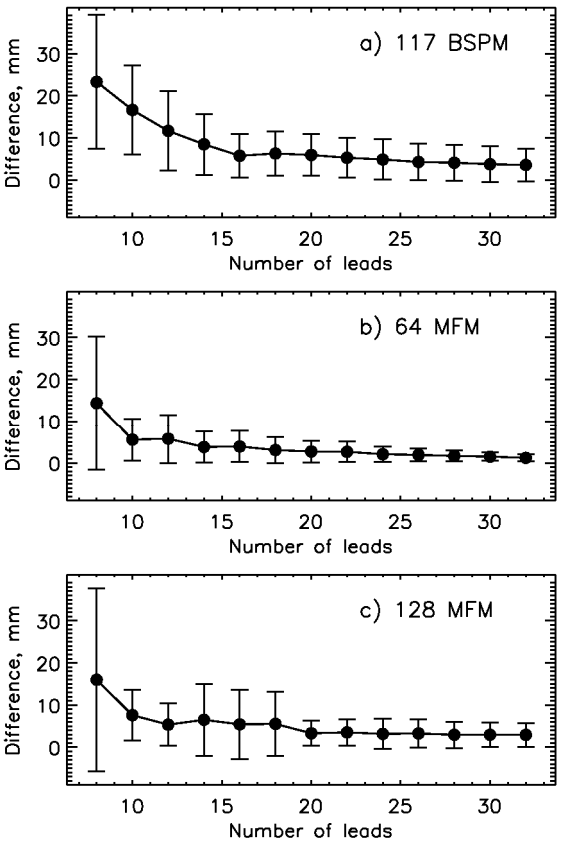

Figure 4. Average difference between localization results obtained by the complete lead system versus various numbers of optimally-selected leads for a) 117-lead BSPM, b) 64 MFM and c) 128 MFM systems, respectively. Error bars indicate ± standard deviation.

specific type of cardiac abnormalities, e.g., the limited array of magnetocardiographic leads for monitoring ST-segment changes caused by acute coronary ischemia.

References

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