ECG Recording Sites for improving Signal-to-Noise Ratio during Atrial Depolarisation

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Abstract

The objective of this study was to identify optimal recording sites for a bipolar ECG lead that would improve signal-to-noise ratio during atrial depolarisation. Body surface potential map (BSPM) data, recorded using the Dalhousie 120-lead system and transformed into 352-node BSPMs, were used for the study. The absolute median for every sample of a subject's p-wave was calculated across all 352-nodes to determine the point in time where the greatest p-wave amplitude occurred. Normalised p-wave values at this point in time were then extracted across all 352-nodes for each subject. The median of the potentials on each node across all 45 subjects was then calculated to establish a median BSPM from which an optimal ECG lead could be identified. The p-wave amplitudes recorded in this population based optimal ECG lead achieved a median of 83.53% of each subject's attainable maximum attainable p-wave amplitude. In comparison standard Lead II achieved a median of 71.53%.

1. Introduction

Atrial arrhythmias are among the most common cardiac arrhythmias with atrial fibrillation (AF) affecting approximately 1% of the general population [1]. Previous studies [2,3] have shown that P-wave indices such as P-wave dispersion and signal-averaged P-wave duration can detect the presence and predict the reoccurrence of AF.

P-waves recorded from standard electrocardiogram (ECG) leads can frequently be of low amplitude (<0.1mV) and are therefore often indiscernible from electrostatic noise. This noise can be generated from a number of sources including incorrect skin preparation, patient movement and skeletal muscle potential [4]. The presence of electrostatic noise can therefore lead to suboptimal performance of algorithms that rely on p-wave analysis for arrhythmia detection. P-wave detection and classification during standard and long-term ECG monitoring could be improved by an optimised ECG lead capable of maximising signal-to-noise ratio.

The electrical activity of the ventricles is very different to that of the atrium in terms of spatial location, orientation and amplitude [5]. Thus, the optimal positioning of bipolar electrodes for improved recording of atrial depolarisation is a unique problem.

The Lewis Lead described by Thomas Lewis in 1910 was the first ECG lead optimised for the study of atrial activity. Lewis placed electrodes in the right forth-intercostal space and the right second costochondral junction.

Previous studies have shown that the Lewis Lead does improve the recording of atrial activity during wide-QRS tachycardia [6] however, Madias et al. [7] demonstrated that the Lewis Lead does not improve p-wave amplitude compared to the standard 12-lead ECG in patients who were admitted to a coronary unit with a range of conditions.

Another ECG lead implemented for recording of atrial activity is the Barker Lead. The Barker Lead involves bipolar electrodes placed at the xiphoid process and below the suprasternal notch on the manubrium. A study performed by Herzog et al. [8] demonstrated that the Barker Lead produced higher amplitude p-waves than other lead systems including the Lewis Lead.

Waktare et al. [4] investigated the optimal positioning of bipolar electrodes for the recording of atrial activity during both sinus rhythm and atrial fibrillation. They discovered that the optimal electrode location for maximum p-wave amplitude during sinus rhythm was below the right clavicle and the left upper quadrant of the abdomen. It is however worth noting that only a small number of electrode positions were investigated (three bipolar leads and three augmented unipolar leads).

A fundamental objective of any detection problem is to maximise the desired signal relative to background noise [9]. The aim of this study is to determine, from BSPM data, the optimal bipolar electrode placement for recording of maximum p-wave amplitude. In this study we limit this to subjects in normal sinus rhythm (NSR) as maximising p-wave amplitude during NSR may allow for better differentiation between NSR and arrhythmias such as AF.

2. Materials and methods

2.1. Study population

The BSPM dataset consisted of 120-lead ECGs taken from the Dalhousie database. ECGs from 45 patients suffering from single-vessel coronary artery disease who underwent elective percutaneous transluminal coronary angioplasty (PTCA) were used. The 120-lead ECGs were transformed into 352-node BSPMs using the approach outlined by Oostendorp et al. [10]. This dataset is described in depth by Horacek et al. [11].

2.2. Data Analysis

To account for the change in p-wave morphology at different ECG recording sites [12] the absolute median of every sample of a subject's p-wave was calculated across all 352-nodes. The location of the maximum absolute median value was taken as the point in time where the largest p-wave amplitude occurred for that particular subject. Figure 1 illustrates this process for one subject.

This method was applied as the location of the maximum and minimum p-wave amplitude was inconsistent across all leads. Therefore, identification of a point in time where the maximum or minimum p-wave amplitude occurred from a single lead would have provided an inaccurate reflection of the true maximum p-wave amplitude present in the BSPM.

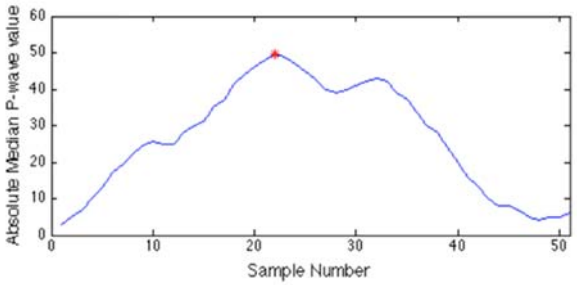

Figure 1. The absolute median atrial waveform with maximum value annotated for one subject.

P-wave values for that particular subject, at this point in time, were then extracted across all 352-nodes. This process was repeated for each subject. Subsequently, all values were normalised to remove any bias attributable to any one subjects p-wave amplitude.

Once all subjects were analysed the median of the p-wave amplitudes on each node across all subjects was extracted and visualised using map3d [13]. This allowed the identification of a population based optimal electrode position. The population based optimal electrode position was defined simply as the location of the maximum and minimum p-wave amplitude on the median BSPM. The subject specific optimal electrode position was defined as the maximum and minimum p-wave amplitude for that individual subject.

The performance of the population based optimal electrode position was then compared to the subject specific optimal electrode position and to standard lead II (Mason-Likar configuration). This allowed for the performance of population based optimal electrode position to be assessed in comparison to each subject's maximum attainable p-wave and a standard ECG lead commonly implemented for p-wave detection.

3. Results

The population based optimal electrode positions for maximum p-wave amplitude was discovered as node 24 and node 257 on the Dalhousie torso [14].

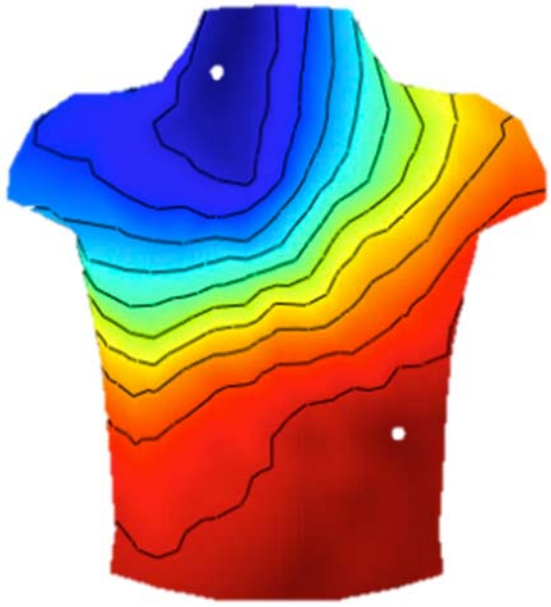

Figure 2. A median BSPM of the normalised P-wave amplitude extracted from all 45 subjects with optimal electrode placement highlighted in white.

Node 24 is located just above the medial third of the right clavicle and node 257 is located one intercostal space below precordial lead V4. This electrode position achieved a median of 83.53% of each subject's maximum attainable p-wave amplitude.

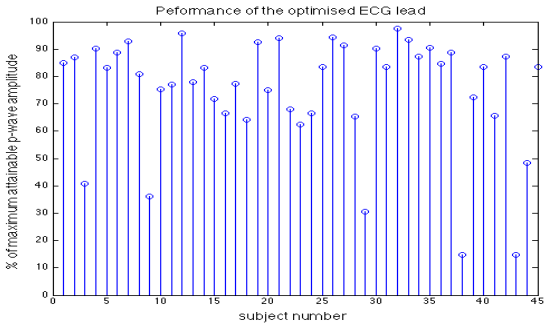

Figure 3. The percentage of each subjects maximum P-wave amplitude captured from the optimised lead.

Table 1. The average performance of the optimised lead compared to standard lead II.

Parameter (Median Value)	**Lead II**	**Optimised Lead**
Peak amplitude (uV)	113.80	124.00
% of maximum p-wave	71.53	83.53
P-wave RMS (uV)	64.23	74.02

The optimised lead, on average achieved 83.53% of each subjects maximum attainable p-wave amplitude. In comparison standard Lead II, on average, achieved 71.53%. Taking into account the median p-wave root mean square (RMS) value, the results demonstrate that on average not only was the peak amplitude greater in the optimised electrode position but as was the overall p-wave magnitude.

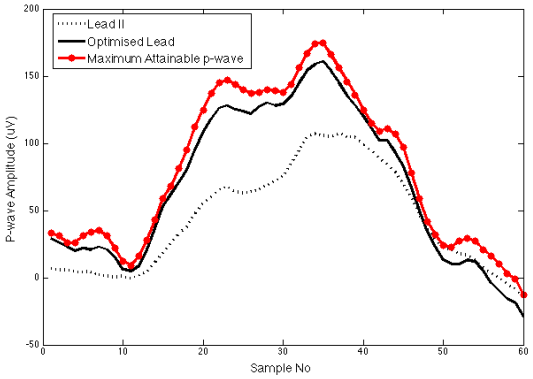

Figure 4. An example of p-waves recorded in Lead II and the optimised lead compared to the maximum attainable p-wave for that subject.

This demonstrates the improved performance of the optimised lead compared to standard lead II, which is commonly implemented in clinical practise for p-wave detection. Standard Lead II has also been shown in previous studies to have greater p-wave amplitudes than other lead configurations [9, 15].

4. Discussion

This study shows that optimised lead selection can improve p-wave amplitude during NSR. To maximise p-wave amplitude from a bipolar ECG lead the ability to effectively define locations on the body that contain the absolute maximum and minimum p-wave signal at a single point in time is crucial. This study describes a method for defining the point in time where the greatest p-wave amplitude occurs across all 352-nodes based on the absolute median of each p-wave sample. P-wave values extracted at this point in time defined the optimal recording sites as above the medial third of the right clavicle and one intercostal space below precordial lead V4.

Although general electrode locations for maximising p-wave amplitude have been described previously, no precise anatomical locations have been identified for the positioning of bipolar electrodes to maximise p-wave amplitude in a population.

The electrode positions described by Lewis and Barker are very different to the locations defined in this study. The electrode positions discovered in this study are similar to regions described by Waktare et al. and Lux et al. Waktare [4] reported the optimal unipolar electrode placement for recording of p-wave amplitude as close to the right collarbone and below the left precordial zone. Placement of bipolar electrodes at these locations would therefore provide an optimised bipolar lead for recording p-wave amplitude. Lux [15] reported optimal electrode placement as the first intercostal space directly inline with V1 and two inches below V4.

The practical application of electrode positions described in this study may prove to be difficult in a clinical setting. Placing an electrode close to the clavicle may increase motion artifact, particularly during ambulation.

5. Conclusions

This preliminary work describes a definition of the optimal electrode positions for maximising p-wave amplitude during NSR.

Bipolar electrodes placed above the medial third of the right clavicle and one intercostal space below precordial lead V4 will improve p-wave amplitude from both standard and ambulatory ECG monitoring systems. This in turn could potentially improve p-wave signal averaging techniques and detection algorithms that rely on p-wave analysis.

6. Future work

Future work will include extraction of other proposed leads from the BSPMs and a comparison of those leads to the optimised lead discovered in this study. Testing of the electrode positions proposed in this study by a clinical physiologist will also be performed. This will assess the feasibility and reliability of applying the electrodes in the desired anatomical locations.

Completion of the future work outlined will allow for a conclusive definition of recording sites for bipolar electrode placement capable of maximising SNR during atrial depolarization.

Finally, an estimation of the optimised ECG lead from standard 12-lead ECGs will be performed. This will determine if p-wave amplitude from standard 12-lead ECGs can be improved by an estimation of atrial activity from an optimised electrode position.

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