

Spatial Refinement of a New Algorithm to Identify Focus of Atrial Ectopic Activity from 64-lead ECGs

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Abstract

Ectopic atrial activity, associated with atrial tachycardia and atrial fibrillation (AF), may predispose to cardiac arrhythmias, death and stroke. This abnormal activity may be reflected in changes to the P-wave morphology (PWM). Compared to the standard 12-lead ECG, more detailed ECG configurations may provide further information for locating the origin of atrial excitation without the need for invasive methods. In this study, we use a biophysically detailed model of the human atria and torso to develop and refine an algorithm for correlating the origin of atrial excitation with PWM.

In simulation tests, the new algorithm had a success rate of 93%, which is higher than 72% of the one based on the 12-lead ECG.

1. Introduction

Rapid atrial arrhythmias such as atrial tachycardia and atrial fibrillation (AF) are a precursor to ventricular arrhythmias, increased risks of stroke and sudden cardiac death [1]. Associated with ectopic and re-entrant activity, the presence of such arrhythmias is reflected in alterations to the P-wave morphology (PWM). Identifying the origin of the ectopic atrial activity from the electrocardiogram (ECG) lead configuration can help to diagnose the early onset of AF in a cost effective manner [2]. Whereas AF can be detected from the 12 lead ECG, the complex and rapid atrial electrical activity make it difficult to obtain further detailed information on atrial activation. Compared to standard 12-lead ECG, more detailed ECG configurations may provide further information about the spatial and temporal behaviour of the body surface potential (BSP) during atrial excitation. This may provide the extra information needed to elucidate the focus of the ectopic AF activity without the need for invasive methods.

In this study, we present further improvements of a previous study to diagnose atrial ectopic origin from BSP [3] based on a male torso geometry, specific position of

the atria according to [4], and refined spatial resolution of the defined quadrants of the heart.

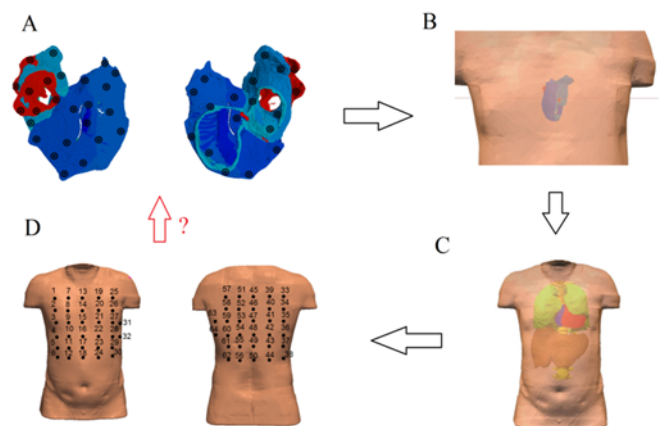


Figure 1. (A) Atrial model with the different stimulated points across its surface. (B) Position of the atria inside the torso model. (C) Torso model with all the considered soft tissues incorporated. (D) Position of the electrodes in the torso mesh view from the front and back, for the 64 lead ECG system.

2. Methods

We apply a recently developed 3D human atrial model to simulate electrical activity during normal sinus rhythm and ectopic pacing (Figure 1A) [5,6]. The atrial model, which accounts for anatomical and electrophysiology difference regions was placed into a newly developed torso model. The position of the atria inside the torso was based on(4) (Figure 1B). The torso model was obtained from segmenting MRI images taken from the male visible human dataset [7]. It considers the presence of the lungs, liver, blood masses and spinal cord (Figure 1C), each of which have different electrical conductivity [8]. A boundary element method is used to compute the BSP resulting from atrial excitation. Elements of the torso mesh corresponding to the placements of the electrodes in 12- and 64- lead ECG system were selected (Figure 1D).

To simulate ectopic focal activity at various origins,

the model is stimulated by a sequence of external supra-threshold electrical pulses applied at various locations across all the different regions of the atria. From the 64-lead ECG P-waves, the polarity pattern on the body surface during the atrial excitation was reconstructed and compared with the experimental data. To do so, we used a red positive sign to mark a lead site with an upright p-wave, a blue negative sign to mark a lead site with an inverted p-wave, and a purple positive/negative sign to mark a biphasic p-wave (Figure 2). In this case we defined a biphasic wave as the one which either the positive or the negative wave is bigger than the half of the other one. Qualitatively, the simulated polarity pattern on the body surface also closely matches to the experimental data as shown in Figure 2. During normal atrial excitation, both experimental and simulation data of the body surface potential shows negative potentials primarily in the superior and right part of the anterior and posterior part of the 64-ECG leads.

We developed and refined an algorithm to obtain the location of the stimulus from a 64 ECG (Figure 4). A test of 60 different atrial focus activities was performed. A possible further refinement was also developed.

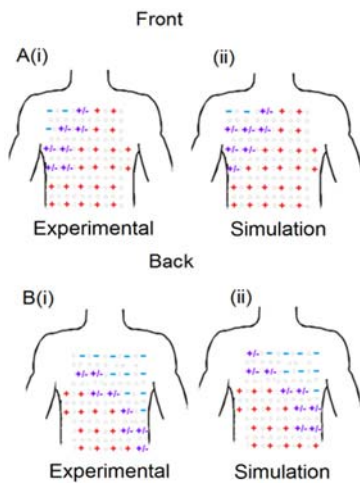


Figure 2. Polarity pattern during normal atrial excitation reconstructed from the 64-lead ECG P-waves. The front figure shows the anterior part of the torso and the Back figure the posterior part of the torso. The red positive sign means we have an upright p-wave, the blue negative sign represents an inverted p-wave, and the purple positive/negative sign represents a biphasic p-wave.

3. Algorithm

A novel algorithm on analysis of the P-wave in multi-

lead ECG systems was proposed. The torso and atria were divided into two set of quadrants (Figure 3). The quadrants in the anterior part of the body were labeled as Qt1 to Qt4, and the four quadrants in the posterior part of the body as Qt5 to Qt8. In the same sense the quadrants in the anterior part of the atria are labeled Qa1 to Qa4, and the ones in the posterior part as Qa5 to Qa8. The algorithm was able to identify from the morphology of 64-lead ECG P-waves, which quadrant of the atria the ectopic focus was originated. The algorithm is based in the assumption that a negative P-wave, in a particular location, is associated with a wave travelling away from that location, therefore the torso quadrant with the most negative P-waves is associated with the atrial quadrant from which the excitation originates. The first approach was to assign a value to all P-waves depending on their polarity: a value of 0 for positive P-waves, a value of 1 for biphasic P-waves, and a value of 2 for a negative P-wave. Then, all the P-waves values in each quadrants are summed, and the algorithm illustrated in Figure 4 is followed.

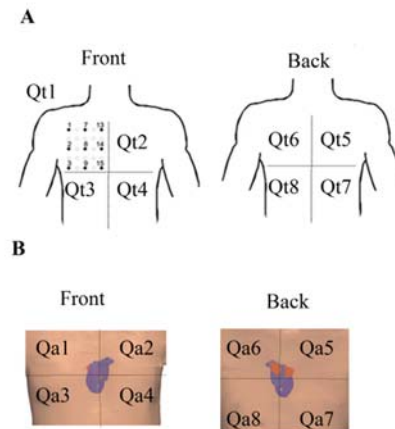


Figure 3. Schematic illustration of the quadrants in the torso and the atria. Qti indexes the quadrants of the torso (A), and the Qai indexes quadrants of the atria (B).

A further refinement was also tested to improve the spatial resolution of the quadrants. If the maximum Qti value is close to any adjacent quadrant value, then the origin of the activation is close to the boundary between the two quadrants. On the contrary, if the difference between the maximum and an adjacent quadrant value is large, then the activation is far from the boundary of the two quadrants. With this further refinement, each quadrant could be divided in eight parts (Figure 4).

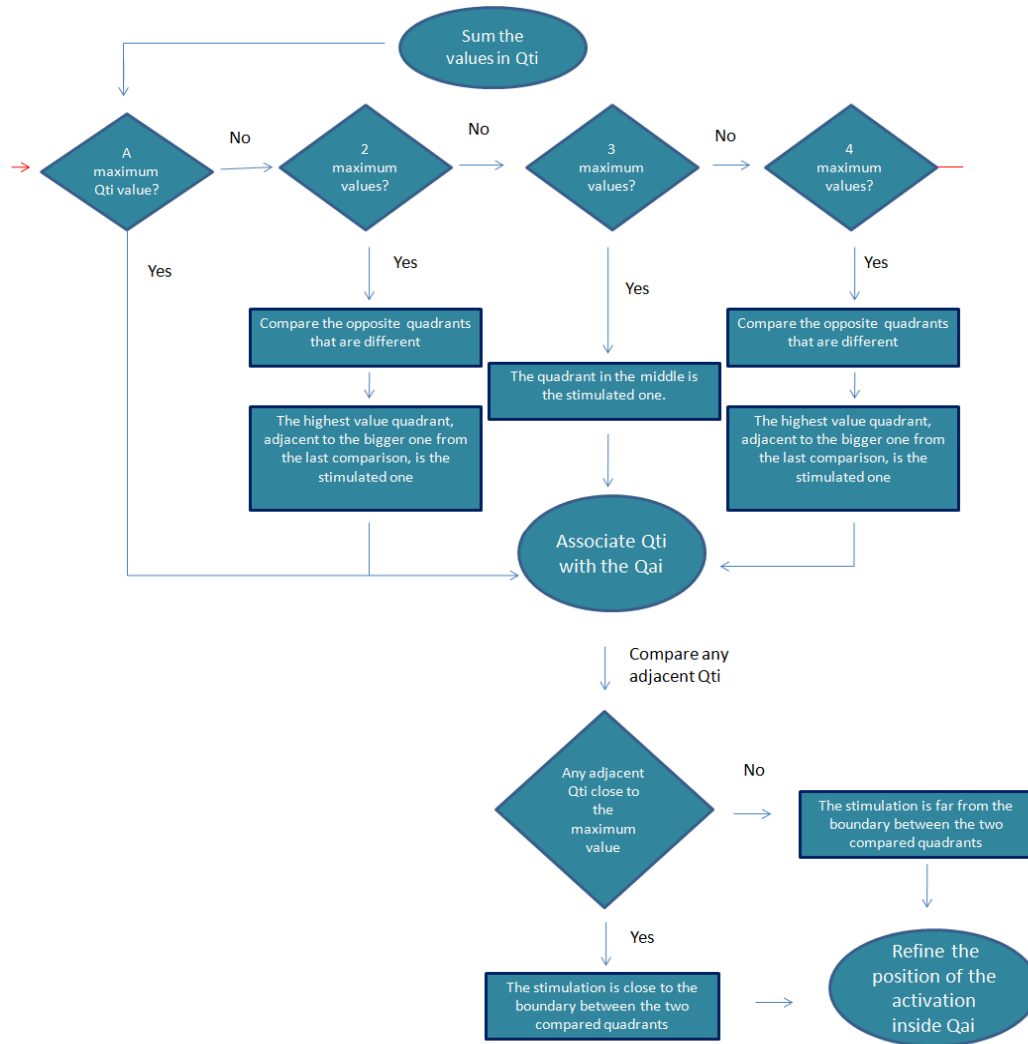


Figure 4. Schematic illustration of the algorithm to identify the quadrant of atrial focal origin based on 64-lead ECG P-waves values. The further refinement is also included at the end of the figure.

4. Results

Our simulation results demonstrated marked differences in the spatio-temporal evolution of the BSP pattern resulting from different atrial activation sequences, associated with different locations of ectopic foci. This is illustrated in Figure 2, in which a schematic illustration of the P-wave polarities is shown for normal activation sequence (Sino atrial node) for experimental and simulated data.

The algorithm presented had a success rate of 93%, meaning that it could correctly identify the origin of atrial focus in 56/60 simulations. We also tested Kistler's algorithm (9) with the same data, and the accuracy was 73%, where the principal concern was the definition of the bifid and biphasic signal. On the other hand, when the

spatial refinement was applied the success rate decrease slightly, down to 89%. This could be because the entire BSP map could not be complete delimited by 64 lead ECG.

5. Conclusion

Computer modelling provides a useful tool to correlate the atrial excitation patterns with the body surface potential distribution, which is almost impossible in an experimental setting. Using a biophysically detailed computer model of the human atria-torso, we have demonstrated a correlation between atrial focal origin and polarity pattern of the BSP. Based on such correlation, a new algorithm has been developed to identify the atrial origin from the BSP reconstructed from the 64-lead ECG.

During sinus rhythm, the simulated P-waves of the 64-lead ECG show strong agreement with experimental data. The algorithm described above had a higher success rate in the simulated data, compared to algorithms based on the 12 lead ECG, e.g. (Kistler's algorithm [9]). This is mainly due to the increment of information obtained with BSP mapping, compared to the standard 12-lead ECG. However, its further spatial refinement showed a slight decrease in the success rate. This could be due to the lack of 64-lead ECG system to map the complete BSP. This study provides a theoretical basis for non-invasively detecting atrial focal origins that is important for designing AF ablation protocol.

Acknowledgements

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