

A Computer Model of Sustained Atrial Fibrillation to Study Atrial Electrograms

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Abstract. Rate adaptation is one mechanism that can lead to initiation and perpetuation of atrial fibrillation (AF). The aim of this work is to show how other mechanisms such as heterogeneities impact the initiation of sustained AF in an anatomical computer model of human atria without rate adaptation. Using the Courtemanche atrial membrane model, patches of increased vagal action with spatial extent of 2 cm were randomly distributed on the surface. The results showed that sustained AF (> 20 sec) could be initiated in the model using a programmed stimulation protocol provided that the differences in effective refractory period of the patches and surrounding tissue was greater than 35 msec. Simulated unipolar electrograms reveal that the AF patterns are consistent with published experimental data.

Keywords: Computer modeling, atrial arrhythmia, sustained atrial fibrillation, electrograms

1. Introduction

The maintenance of multiple reentrant wavelets appears to be a consistent feature of atrial fibrillation (AF) observed in experimental model. We showed in a computer model of AF with homogeneous properties that atrial restitution dynamics impacts both the initiation and perpetuation of wavelets during AF [Virag, 2002]. Burst pacing could induce AF in our model if the slope of the restitution curve was greater than one, while this feature was not needed for perpetuation. The aim of this work is to show how mechanisms other than rate adaptation can initiate and sustain AF. Kneller *et al.* recently developed a two-dimensional computer model of cholinergic AF using a model of canine atrial tissue [Kneller, 2002]. The results suggest that heterogeneities in acetylcholine (ACh) concentration are sufficient to create fibrillatory conditions despite the complete loss of rate adaptation. In this paper, we investigate how regional heterogeneity in effective refractory period (ERP) due to ACh variation affects the initiation of sustained AF in an anatomically realistic model of the atria. To provide a link with clinical data, unipolar electrograms during AF are computed.

2. Methods

We developed an electro-anatomical model of human atria using a geometry derived from a MRI dataset [Virag, 2002]. The resulting three-dimensional surface includes right and left atrial chambers, and obstacles corresponding to the location of major vessels and valves (see Fig. 1). The membrane kinetics is based on the Courtemanche atrial cell model [Courtemanche, 1998]. An ACh-driven potassium current was added in order to introduce an inhomogeneous vagal action. Its formulation is similar to [Kneller, 2002]:

$$I_{K(ACh)} = g_{K(ACh)} \left(0.0517 + \frac{0.4516}{1 + \exp((V_m + 59.53)/17.8)} \right) \cdot (V_m - E_K) \quad (1)$$

where V_m is the membrane potential, E_K the reversal potential, and $g_{K(ACh)}$ is a variable associated with the presence of ACh. In contrast to [Kneller, 2002], heterogeneity patterns of $g_{K(ACh)}$ were not periodic but assigned randomly with patches having a characteristic length scale of 2 cm on the atrial surface.

The value $g_{K(ACh)}$ was set to 25 in those patches and to 7 everywhere else, leading to an ERP of 45 ms and 95 ms respectively. Propagation was modeled assuming monodomain equations. A finite volume-based approach was applied to an unstructured mesh composed of 200 000 triangles. AF was initiated using a cross-shock S_1 - S_2 stimulation protocol. Unipolar atrial electrograms were computed 1 mm from the atrial surface in the right atrium free wall using a current source approximation [Plonsey, 2000].



Figure 1. Potential map during simulated AF. Membrane potentials are gray level-coded and wavefront edges are reinforced with a black line.

3. Results

For a random heterogeneity pattern with size approximately in the range 1.5-2.5 cm, and a difference in ERP of the patches and surrounding tissue greater than about 35 msec, a complex reentrant activity was sustained for more than 20 seconds (see Fig 1). In the absence of sufficient heterogeneity, the simulated AF converted to a single stable spiral. The sustained simulated AF was characterized by 4.5 ± 1.5 spiral-like interacting wavelets undergoing both functional and anatomical reentries. A few of the reentries served as a stable source of wavelets, mostly located in the left atrium. Fig. 2 displays an example of unipolar electrogram as well as the corresponding membrane potential time course. Fourier transform reveals the presence of a dominant frequency at about 11.2 Hz. This spatio-temporal organization during simulated AF is consistent with experimental data [Berenfeld, 2000].

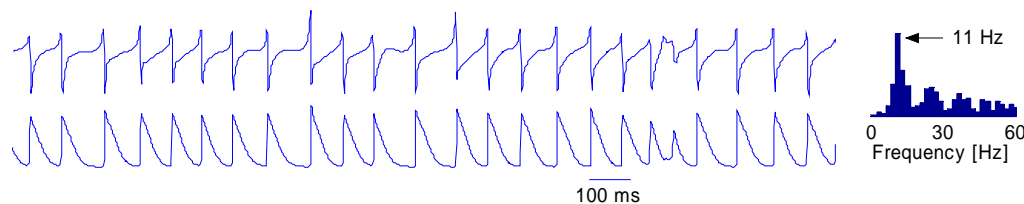


Figure 2. Left: example of unipolar electrogram during simulated AF and its corresponding membrane potential. Right: Fourier transform.

4. Discussion and Conclusion

Our simulations show that sustained AF can be initiated in a model without rate adaptation provided there is an appropriate spatial distribution of heterogeneities. The simulated unipolar electrograms are consistent with experimental data enabling the model to be used to understand the relationship of electrogram morphology and the dynamics of the underlying wavelets as they continuously change size, shape and direction.

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