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On a Model for Analysis of the Electrical Activity of the Heart

Evgeny L. Pankratov*

Nizhny Novgorod State Agrotechnical University, 97 Gagarin Avenue, Nizhny Novgorod, 603950, Russia; elp2004@mail.ru.

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Abstract

Study of electrical activity of the heart according to the signals of standard electrocardiographic leads remains one of the fundamental problems of theoretical and practical electrocardiography. The activity of the heart is an autowave, oscillatory in nature, associated with the spontaneous occurrence of excitation impulses in the sinus node. Analysis of the model of the electrical activity of the heart and the formation of an analytical approach for its analysis. The signals of the standard leads of the patient's electrocardiogram record three waves of electrical activity of the heart: two waves of excitation in the atria and ventricles and one wave of relaxation of the ventricles. Prognosis in medicine is an actual question for increasing the predictability of treatment of patients. Modeling the electrical activity of the heart is of great importance, since diagnostic signs are extracted by a cardiologist both directly in the analysis of the patient's cardiographic information and in the analysis of indirect parameters determined on the basis of a model of electrical processes in the myocardium. Using the results of modeling the electrical activity of the heart is a condition for improving the efficiency of diagnosing the cardiovascular system. The main aim of this paper is to analyze the model of the electrical activity of the heart and develop an analytical approach for its analysis.

Keywords: Muscle contraction, Electrical activity of the heart, Model of process, Prognosis of process, Patient's cardiographic information, Analytical approach for analysis.

1 | Introduction

Study of electrical activity of the heart according to the signals of standard electrocardiographic leads remains one of the fundamental problems of theoretical and practical electrocardiography [1–8]. The activity of the heart is an autowave, oscillatory in nature, associated with the spontaneous occurrence of excitation impulses in the sinus node. Analysis of the model of the electrical activity of the heart and the formation of an analytical approach for its analysis. The signals of the standard leads of the patient's electrocardiogram record three waves of electrical activity of the heart: two waves of excitation in the atria and ventricles and one wave of

Corresponding Author: elp2004@mail.ru

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relaxation of the ventricles. Prognosis in medicine is an actual question for increasing the predictability of treatment of patients [9-19]. Modeling the electrical activity of the heart is of great importance, since diagnostic signs are extracted by a cardiologist both directly in the analysis of the patient's cardiographic information and in the analysis of indirect parameters determined on the basis of a model of electrical processes in the myocardium. Using the results of modeling the electrical activity of the heart is a condition for improving the efficiency of diagnosing the cardiovascular system. The main aim of this paper is to analyze the model of the electrical activity of the heart and develop an analytical approach for its analysis.

2 | Method of solution

In this section, we consider a model based on the solution of the following differential equations.

$$\frac{\partial u(x,t)}{\partial t}=\frac{\partial^2 u(x,t)}{\partial x^2}-k(x,t)u(x,t)\left[u(x,t)-a(x,t)\right]\left[u(x,t)-1\right]-u(x,t)\,v(x,t)$$

$$\frac{\partial\left[\mu_2(x,t)v(x,t)\right]}{\partial t}=v(x,t)\frac{\partial\mu_2(x,t)}{\partial t}-u\,(x,t)\frac{\partial v(x,t)}{\partial t}- \tag{1}$$

$$-\left[\varepsilon+\mu_1(x,t)v(x,t)\right]\left\{v(x,t)+k(x,t)u(x,t)\left[v(x,t)-a(x,t)-1\right]\right\}.$$

The considered model takes into account excitation in the heart muscle. The considered model includes two dimensionless functions: quickly changing u (x,t) corresponding to membrane potential; slowly changing ν (x,t), characterizing the properties of the environment. At the same time, the connections between the cells of the myocardium (i.e., the points of the auto wave environment: heart muscle) are described by diffusion terms of the above equations, and the dynamics of a separate myocardial cell are described by reactionary nonlinear terms of the above equations. Also, *Eq. (1)* includes the coordinates of the point of observation x; current time t; ε, μ_1 (x,t), μ_2 (x,t), κ (x,t), a (x,t) are the parameters of the considered model. Initial and boundary conditions for the considered functions u (x,t) and ν (x,t) could be written as

$$u\,(0,t)\ =\ u1, u\,(L,t)\ =\ u2, u\,(x,0)\ =\ 0, v\,(x,0)\ =\ 0. \tag{2}$$

We solved *Eq. (1)* by the method of averaging of function corrections [6], [7]. In the framework of the considered method, we replace the above functions u (x,t) and ν (x,t) on the right sides of *Eq. (1)* with their not yet known average values α_{1u} and α_{1v}. The substitution and integration of the obtained relation on time t gives a possibility to obtain the following relations to determine the first-order approximations of the required functions.

$$u_1(x,t)=-\alpha_{1u}\left(\alpha_{1u}-1\right)\int_0^t k(x,\tau)\left[\alpha_{1u}-a(x,\tau)\right]d\tau-\alpha_{1u}\alpha_{1v}t,$$

$$v_1(x,t)=\alpha_{1v}-\frac{1}{\mu_2(x,t)}\int_0^t\left[\varepsilon+\mu_1(x,\tau)\alpha_{1v}\right]\left\{\alpha_{1v}+k(x,\tau)\alpha_{1u}\left[\alpha_{1v}-a(x,\tau)-1\right]\right\}d\tau. \tag{3}$$

Average values α_{1u} and α_{1v} were determined by the following standard relations [20], [21]

$$\alpha_{1u}=\frac{1}{\Theta L}\int_0^\Theta\int_0^L u_1(x,t)\,dx\,dt,\ \alpha_{1v}=\frac{1}{\Theta L}\int_0^\Theta\int_0^L v_1(x,t)\,dx\,dt, \tag{4}$$

where Θ is the continuous observation on the considered process. Substitution of *Relations (3)* into *Relations (4)* and solution of the obtained equations gives a possibility to obtain the following relations to determine the required average values $\alpha 1u$ and $\alpha 1v$

$$\alpha_{1u} = -\frac{\Theta L}{2\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\,dx\,dt}\left\{\frac{1}{\Theta^2 L^2}\left[\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\left[a(x,t)+1\right]dx\,dt\right]^2 - \right.$$

$$-\frac{4}{\Theta L}\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\,dx\,dt\left[\frac{1}{\Theta L}\int_0^\Theta (\Theta - t)\int_0^L k(x,t)a(x,t)\,dx\,dt + 1\right] - \alpha_{1v}\frac{2}{L}\int_0^\Theta (\Theta - t)\times$$

$$\left.\times\int_0^L k(x,t)\,dx\,dt\right\}^{\frac{1}{2}} + \frac{1}{2\Theta L}\left\{\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\left[a(x,t)+1\right]dx\,dt\right\}^2\left[\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\,dx\,dt\right]^{-1},$$

$$\alpha_{1v} = \frac{1}{2}\left(-\varepsilon\int_0^\Theta\int_0^L \frac{t}{\mu_2(x,t)}\,dx\,dt + \frac{1}{\Theta^2 L^2}\left\{\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\left[a(x,t)+1\right]dx\,dt\right\}^2 - \int_0^\Theta (\Theta - t)\times\right.$$

$$\times\frac{4}{\Theta L}\int_0^L k(x,t)\,dx\,dt\left[\frac{1}{\Theta L}\int_0^\Theta (\Theta - t)\int_0^L k(x,t)a(x,t)\,dx\,dt + 1\right]^{\frac{1}{2}}\frac{\Theta L}{2\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\,dx\,dt}\times$$

$$\times\left[\varepsilon\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t k(x,\tau)\,d\tau\,dx\,dt - \int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)a(x,\tau)\,d\tau\,dx\,dt - \right.$$

$$\left.-\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)\,d\tau\,dx\,dt\right] + \left(\left\{\left[\varepsilon\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t k(x,\tau)\,d\tau\,dx\,dt - \right.\right.\right.$$

$$\left.-\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)a(x,\tau)\,d\tau\,dx\,dt - \int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)\,d\tau\,dx\,dt\right] +$$

$$\left.+\varepsilon\int_0^\Theta\int_0^L \frac{t}{\mu_2(x,t)}\,dx\,dt\right\}^2 + 4\varepsilon\left[\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)\,d\tau\,dx\,dt + \int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\times\right.$$

$$\left.\left.\left.\times\int_0^t \mu_1(x,\tau)\,d\tau\,dx\,dt\right]\int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t k(x,\tau)\left[a(x,t)+1\right]d\tau\,dx\,dt\right)^{\frac{1}{2}}\right)\left(\int_0^\Theta\int_0^L\int_0^t \mu_1(x,\tau)\,d\tau\times\right.$$

$$\times\frac{dx\,dt}{\mu_2(x,t)} - \int_0^\Theta\int_0^L \frac{1}{\mu_2(x,t)}\int_0^t \mu_1(x,\tau)k(x,\tau)\,d\tau\,dx\,dt\left\{\left[\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\left[a(x,t)+1\right]dx\,dt\right]^2\times\right.$$

$$\left.\times\frac{1}{\Theta^2 L^2} - \frac{4}{\Theta L}\int_0^\Theta (\Theta - t)\int_0^L k(x,t)\,dx\,dt\left[\frac{1}{\Theta L}\int_0^\Theta (\Theta - t)\int_0^L k(x,t)a(x,t)\,dx\,dt + 1\right]\right\}^{\frac{1}{2}}\times$$

$$\left.\times\frac{\Theta L}{2\int\limits_0^\Theta(\Theta-t)\int\limits_0^L k(x,t)\,dx\,dt}\right)^{-1}.$$

The second-order approximations of solutions of *Eq. (1)* were calculated in the framework of the standard procedure of method of averaging of function corrections [20], [21], i.e. by replacement of the required functions in right sides of *Eq. (1)* on the following sums: u $(x,t)\to\alpha_{2u}+u_1(x,t)$ and ν $(x,t)\to\alpha_{2v}+v_1(x,t)$. The replacement and future integration of the obtained relations for the required approximations of the considered functions over time gives a possibility to obtain relations for the considered approximations in the following form

$$u_2(x,t)=\frac{\partial^2}{\partial x^2}\int\limits_0^t u_1(x,\tau)\,d\tau-\int\limits_0^t k(x,\tau)\left[\alpha_{2u}+u_1(x,\tau)-a(x,\tau)\right]\left[\alpha_{2u}+u_1(x,\tau)-1\right]\times$$

$$\times\left[\alpha_{2u}+u_1(x,\tau)\right]d\tau-\int\limits_0^t\left[\alpha_{2u}+u_1(x,\tau)\right]\left[\alpha_{2v}+v_1(x,\tau)\right]d\tau$$

$$v_2(x,t)=\frac{1}{\mu_2(x,t)}\int\limits_0^t\left[\alpha_{2v}+v_1(x,\tau)\right]\frac{\partial\mu_2(x,\tau)}{\partial\tau}d\tau-\frac{1}{\mu_2(x,t)}\int\limits_0^t\left[\alpha_{2u}+u_1(x,\tau)\right]\frac{\partial v_1(x,\tau)}{\partial\tau}d\tau-\qquad\textbf{(5)}$$

$$-\int\limits_0^t\left\{\varepsilon+\mu_1(x,\tau)\left[\alpha_{2v}+v_1(x,\tau)\right]\right\}\left\{k(x,\tau)\left[\alpha_{2u}+u_1(x,\tau)\right]\left[\alpha_{2v}+v_1(x,\tau)-a(x,\tau)-1\right]+\right.$$

$$\left.+v_1(x,\tau)+\alpha_{2v}\right\}d\tau.$$

Not yet known average values α_{2u} and α_{2v} were determined by the following average values [20], [21]

$$\alpha_{2u}=\frac{1}{\Theta L}\int\limits_0^\Theta\int\limits_0^L\left[u_2(x,t)-u_1(x,t)\right]dx\,dt,\ \alpha_{2v}=\frac{1}{\Theta L}\int\limits_0^\Theta\int\limits_0^L\left[v_2(x,t)-v_1(x,t)\right]dx\,dt.\qquad\textbf{(6)}$$

Substitution of *Relations (5)* into *Relation (6)* and solution of the obtained equations gives a possibility to obtain relations for the required average values α_{2u} and α_{2v} in the following form.

$$\alpha_{2u}=\left(\left\{\frac{1}{\Theta L}\int\limits_0^\Theta\int\limits_0^L\int\limits_0^t\frac{1}{\mu_2(x,\tau)}d\tau\int\limits_0^t v_1(x,\tau)\frac{\partial\mu_2(x,\tau)}{\partial\tau}d\tau\,dx\,dt-\frac{1}{\Theta L}\int\limits_0^\Theta\int\limits_0^L v_1(x,\tau)\frac{\partial\mu_2(x,t)}{\partial t}\times\right.\right.$$

$$\times\int\limits_0^t\frac{d\tau}{\mu_2(x,\tau)}dx\,dt-\frac{1}{\Theta L}\int\limits_0^\Theta\int\limits_0^L\int\limits_0^t\frac{d\tau}{\mu_2(x,\tau)}\int\limits_0^t u_1(x,\tau)\frac{\partial v_1(x,\tau)}{\partial\tau}d\tau\,dx\,dt+\int\limits_0^\Theta\int\limits_0^L u_1(x,t)\frac{\partial v_1(x,t)}{\partial t}\times$$

$$\times\frac{1}{\Theta L}\int\limits_0^t\frac{d\tau}{\mu_2(x,\tau)}dx\,dt-\frac{1}{\Theta L}\int\limits_0^\Theta(\Theta-t)\int\limits_0^L\left[\varepsilon+\mu_1(x,\tau)\,v_1(x,\tau)\right]\left[k(x,\tau)\,u_1(x,t)v_1(x,t)-1+\right.\qquad\textbf{(7)}$$

$$\left.\left.+v_1(x,\tau)-a(x,t)\right]dx\,dt-\alpha_{1v}\right\}^2-\alpha_{1u}\alpha_{1v}\frac{\Theta}{2}\frac{\alpha_{1u}\left(\alpha_{1u}-1\right)}{\Theta L}\int\limits_0^\Theta\int\limits_0^L k(x,t)\left[\alpha_{1u}-a(x,t)\right]dx\,dt\right)\times$$

$$\times\frac{\Theta L}{2\alpha_{1u}\left(\alpha_{1u}-1\right)\int_0^{\Theta}\int_0^{L}k\left(x,t\right)\left[\alpha_{1u}-a\left(x,t\right)\right]dx\,dt}$$

$$\alpha_{2v}=\Theta L\left(\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\left[\varepsilon+\mu_1\left(x,\tau\right)\alpha_{1v}\right]\left\{\alpha_{1v}+k\left(x,\tau\right)\alpha_{1u}\left[\alpha_{1v}-a\left(x,\tau\right)-1\right]\right\}d\tau\times\right.$$

$$\left.\times\int_0^{t}\frac{d\tau}{\mu_2\left(x,\tau\right)}dx\,dt+\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2\left(x,\tau\right)}\int_0^{t}v_1\left(x,\tau\right)\frac{\partial\mu_2\left(x,\tau\right)}{\partial\tau}d\tau\,dx\,dt\right)\left[\int_0^{\Theta}\int_0^{L}\int_0^{t}u_1\left(x,\tau\right)\frac{\partial v_1\left(x,\tau\right)}{\partial\tau}d\tau\times\right.$$

$$\times\int_0^{t}\frac{d\tau}{\mu_2\left(x,\tau\right)}dx\,dt+\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2\left(x,\tau\right)}u_1\left(x,t\right)\frac{\partial v_1\left(x,t\right)}{\partial t}dx\,dt-\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2\left(x,\tau\right)}\frac{\partial\mu_2\left(x,t\right)}{\partial t}\times$$

$$\left.\times\, v_1\left(x,t\right)dx\,dt\right]^{-1}.$$

The third-order approximations of solutions of *Eq. (1)* were calculated in the framework of the standard procedure of method of averaging of function corrections [20], [21], i.e. by replacement of the required functions in right sides of *Eq. (1)* on the following sums: u (x,t)$\rightarrow\alpha_{3u}+u_2(x,t)$ and ν (x,t)$\rightarrow\alpha_{3v}+v_2(x,t)$. The replacement and future integration of the obtained relations for the required approximations of the considered functions over time gives a possibility to obtain relations for the considered approximations in the following form

$$u_3\left(x,t\right)=\frac{\partial^2}{\partial x^2}\int_0^{t}u_2\left(x,\tau\right)d\tau-\int_0^{t}k\left(x,\tau\right)\left[\alpha_{3u}+u_2\left(x,\tau\right)-a\left(x,\tau\right)\right]\left[\alpha_{3u}+u_2\left(x,\tau\right)-1\right]\times$$

$$\times\left[\alpha_{3u}+u_2\left(x,\tau\right)\right]d\tau-\int_0^{t}\left[\alpha_{3u}+u_2\left(x,\tau\right)\right]\left[\alpha_{3v}+v_2\left(x,\tau\right)\right]d\tau$$

$$v_3\left(x,t\right)=\frac{1}{\mu_2\left(x,t\right)}\int_0^{t}\left[\alpha_{3v}+v_2\left(x,\tau\right)\right]\frac{\partial\mu_2\left(x,\tau\right)}{\partial\tau}d\tau-\frac{1}{\mu_2\left(x,t\right)}\int_0^{t}\left[\alpha_{3u}+u_2\left(x,\tau\right)\right]\frac{\partial v_2\left(x,\tau\right)}{\partial\tau}d\tau-\tag{8}$$

$$-\int_0^{t}\left\{\varepsilon+\mu_1\left(x,\tau\right)\left[\alpha_{3v}+v_2\left(x,\tau\right)\right]\right\}\left\{k\left(x,\tau\right)\left[\alpha_{3u}+u_2\left(x,\tau\right)\right]\left[\alpha_{3v}+v_2\left(x,\tau\right)-a\left(x,\tau\right)-1\right]+\right.$$

$$\left.+v_2\left(x,\tau\right)+\alpha_{3v}\right\}d\tau.$$

Not yet known average values α_{3u} and α_{3v} were determined by the following average values [20], [21]

$$\alpha_{3u}=\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\left[u_3\left(x,t\right)-u_2\left(x,t\right)\right]dx\,dt,\ \alpha_{3v}=\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\left[v_3\left(x,t\right)-v_2\left(x,t\right)\right]dx\,dt.\tag{9}$$

Substitution of *Relations (8)* into *Relation (9)* and solution of the obtained equations gives a possibility to obtain relations for the required average values α_{2u} and α_{2v} in the following form.

$$\alpha_{3u}=\left(\left\{\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{1}{\mu_2(x,\tau)}d\tau\int_0^{t}v_2(x,\tau)\frac{\partial\mu_2(x,\tau)}{\partial\tau}d\tau\,dx\,dt-\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}v_2(x,\tau)\frac{\partial\mu_2(x,t)}{\partial t}\times\right.\right.$$
$$\times\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}dx\,dt-\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}\int_0^{t}u_2(x,\tau)\frac{\partial v_2(x,\tau)}{\partial\tau}d\tau\,dx\,dt+\int_0^{\Theta}\int_0^{L}u_2(x,t)\frac{\partial v_2(x,t)}{\partial t}\times$$
$$\times\frac{1}{\Theta L}\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}dx\,dt-\frac{1}{\Theta L}\int_0^{\Theta}(\Theta-t)\int_0^{L}\left[\varepsilon+\mu_1(x,\tau)\,v_2(x,\tau)\right]\left[k(x,\tau)\,u_2(x,t)v_2(x,t)-1+\right.$$
$$\left.\left.\left.+v_2(x,\tau)-a(x,t)\right]dx\,dt-\alpha_{1v}\right\}^2-\alpha_{2u}\alpha_{2v}\frac{\Theta}{2}\frac{\alpha_{2u}(\alpha_{2u}-1)}{\Theta L}\int_0^{\Theta}\int_0^{L}k(x,t)\left[\alpha_{2u}-a(x,t)\right]dx\,dt\right)\times$$
$$\times\frac{\Theta L}{2\alpha_{2u}(\alpha_{2u}-1)\int_0^{\Theta}\int_0^{L}k(x,t)\left[\alpha_{2u}-a(x,t)\right]dx\,dt}\tag{10}$$

$$\alpha_{3v}=\Theta L\left(\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\left[\varepsilon+\mu_1(x,\tau)\alpha_{2v}\right]\left\{\alpha_{2v}+k(x,\tau)\alpha_{2u}\left[\alpha_{2v}-a(x,\tau)-1\right]\right\}d\tau\times\right.$$
$$\left.\times\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}dx\,dt+\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}\int_0^{t}v_2(x,\tau)\frac{\partial\mu_2(x,\tau)}{\partial\tau}d\tau\,dx\,dt\right)\left[\int_0^{\Theta}\int_0^{L}\int_0^{t}u_2(x,\tau)\frac{\partial v_2(x,\tau)}{\partial\tau}d\tau\times\right.$$
$$\times\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}dx\,dt+\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}u_2(x,t)\frac{\partial v_2(x,t)}{\partial t}dx\,dt-\int_0^{\Theta}\int_0^{L}\int_0^{t}\frac{d\tau}{\mu_2(x,\tau)}\frac{\partial\mu_2(x,t)}{\partial t}\times$$
$$\left.\times\,v_2(x,t)\,dx\,dt\right]^{-1}.$$

Comparison of the second-order and the third-order approximations of the considered functions is presented in *Fig. 1*. The obtained difference between these approximations is a few percent. In this situation, spatio-temporal distributions of functions u (x,t) and v (x,t) were analyzed analytically by using the second-order approximations in the framework of the method of averaging of function corrections. The approximation is usually a good approximation for making qualitative analysis and obtaining some quantitative results. All obtained results have been checked by comparison with results of numerical simulations.

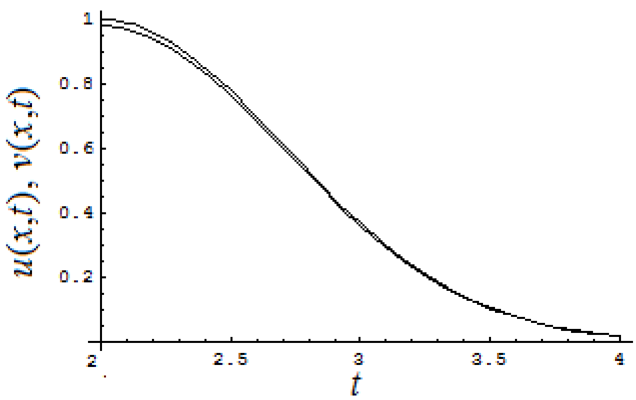

Fig. 1. Typical profile of an excitation impulse.

3 | Discussion

In this section, we analyzed spatio-temporal distributions of the functions u (x,t) and ν (x,t). Changing the values of the parameters of the considered model leads to changes in the considered profile of an excitation impulse. *Figs. 2* and *3* show a typical profile of an excitation impulse. Increasing the values of the parameters μ_i (x,t) leads to a decrease in the values of the considered functions u (x,t) and ν (x,t). In an analogous situation, one can find that when changing the values of the above functions with increasing the parameter k (x,t). Increasing the values of the parameter a (x,t) leads to the opposite result.

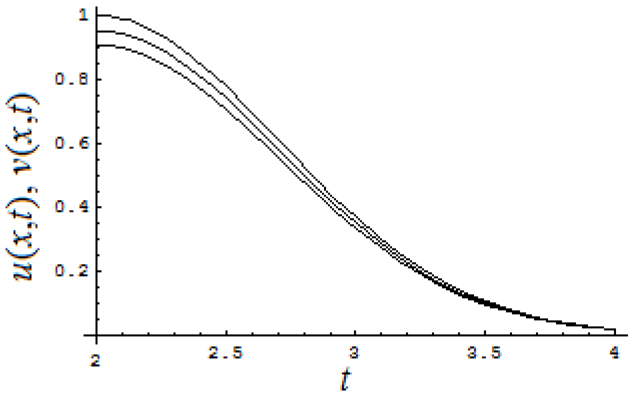

Fig. 2. Typical profile of an excitation impulse. Increasing the values of the parameter μ_i (x,t) leads to a decrease in the values of the considered functions u (x,t) and ν (x,t).

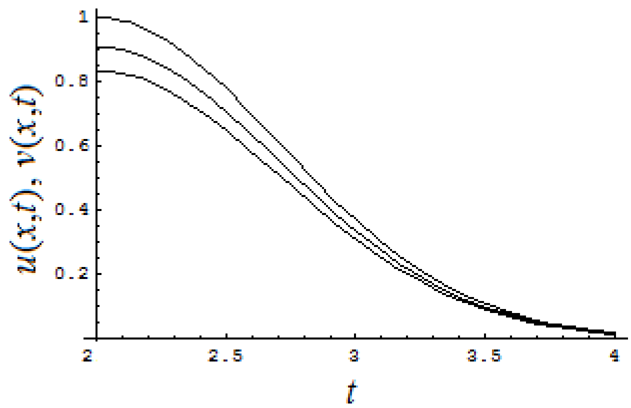

Fig. 3. Typical profile of an excitation impulse. Increasing the values of parameter a (x,t) leads to an increase in the values of the considered functions u (x,t) and ν (x,t).

4 | Conclusion

In this paper, we consider a model of the electrical activity of the heart. We introduce an analytical approach to analyze the considered model. Based on this model, we obtain a typical profile of the excitation impulse with account of possible changes in the conditions of the considered activity of the heart.

Authors' Contributions

All aspects of the research and manuscript preparation were carried out by the author. The author has read and approved the final version of the manuscript.

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Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

Conflict of Interest

The author declares that they do not have any conflict of interest.

Consent for Publication

The author confirms consent for the publication of this work

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants performed by the author.

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