Investigation of Myocardium Cell Membrane Properties on Luo-Rudy Mammalian Ventricular Model II

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***Abstract* — With use of Cell Electrophysiology Simulation Environment (CESE) a myocardium cell membrane model properties are investigated. At comparison with other models it is established, that Weiss-Lapicque model most precisely describes reaction of the given model to influence of rectangular current pulses.**

Keywords: heart, defibrillation, myocardium cell membrane, Luo-Rudy mammalian ventricular model.

I. INTRODUCTION

Investigation of defibrillation pulses influence on heart are carried out on the animal or isolated hearts of animals. Such experiments are expensive and take a lot of time. For reduction of expenses it is desirable to use the preliminary results obtained on this or that model, describing influence defibrillation pulse on heart.

First of such models, Weiss-Lapicque empirical model, has appeared in the beginning of XX century (1901, 1909)) on the basis of the experimental data obtained on a frog nerve [1]. In 30th years of XX century (1932) there was Blair's model, used a RC-circuit for modeling a cell membrane [2]. Such model is used in the “charge burping” theory [3] a characteristic energy method [4] and a repolarization hypothesis [5].

Progress of computer technical equipment and successes in research of cellular membranes have allowed to develop more complex models, one their which is the Luo-Rudy mammalian ventricular model [6], presented on Fig. 1.

II. MATERIAL AND METHODS

Freely-available Cell Electrophysiology Simulation Environment (CESE) OSS 1.4.7 has been used for modeling [7]. Window of the modeling environment is presented on Fig. 2.

The environment software structure includes 5 base models, among which and Luo-Rudy Mammalian Ventricular Model II (dynamic), 1994-2000 which has been used for research of influence of electric pulses on a myocardium cell membrane. CESE environment allows to model response of a membrane to current pulses of any duration and the form.

III. RESULTS

A. Membrane Model Properties

For investigation of model response the rectangular pulse by duration of 100 ms has been used. This duration considerably exceeds duration of transients in model.

For such pulse the threshold value of amplitude of current density I_{thr} above which there is a action potential (Fig. 3) has been ascertained. Then response to pulses with amplitude of current density 0.1…0.9 from I_{thr} (Fig. 4) has been investigated and transient responses of model at the front (Fig. 5) and trail (Fig. 6) of a current pulse are graphed. Transients at the pulse front have much greater duration, than on at the pulse trail.

Further dependences of a membrane model properties from transmembrane potential value in a range -86 mV up to -75 mV were evaluated. Dependence of membrane specific resistance from transmembrane potential is presented on Fig. 7.

For an estimation of dependence of specific capacity of membrane model from transmembrane potential the membrane model time constants at the low-signal pulse front and trail have been evaluated. For this purpose the model was influenced a current with duration 100 ms, providing in a static condition transmembrane potential U_m, then a current duration 100 ms, providing in a static condition transmembrane potential U_m + 0,5 mV, and with the following 100 ms again a current providing in a static condition transmembrane potential U_m. The obtained

dependences are presented on Fig. 8. Values of a membrane model time constant at the influencing pulse front and trail slightly differ from each other. Presumably these differences are determined by methodical errors.

On the obtained values of membrane specific resistance and a membrane time constant at the pulse front the values of specific capacity of a membrane were calculated. Dependence of membrane specific capacity from transmembrane potential is presented on Fig. 9.

B. Comparison of Weiss-Lapicque, Blair and Luo-Rudy models

For comparison of models the dependences of relative energy threshold of cell activation on duration of influence of rectangular current pulse have been graphed.

On Luo-Rudy model the power factor was calculated for each threshold value of amplitude of current density I_{thr} at which a action potential was appeared:

$$K_E(t_{pulse}) = I_{thr}^2 \cdot t_{pulse} \ [\mu A^2 \cdot ms/cm^4]$$

Pulse duration at minimal value of power factor $K_{Emin} = 264\ \mu A^2 \cdot ms/cm^4$ is 11 ms, that corresponds to a time constant $\tau_m = 8.8$ ms (at the human 2…5 ms [8]). Relative threshold energy was calculated by division of power factor $K_E(t_{pulse})$ on its minimal value K_{Emin}. Response of membrane model to current pulses of a duration 11 ms with various amplitude presented on Fig. 10

Relative threshold energy of cell activation for Weiss-Lapicque model was calculated under the formula:

$$E_{rel}(t_{pulse}) = 0.0227 \cdot (1+11/t_{pulse})^2 \cdot t_{pulse},$$

where t_{pulse} in ms.

Relative threshold energy of cell activation for Blair model was calculated under the formula:

$$E_{rel}(t_{pulse}) = 0.0463/(1-\exp(-t_{pulse}/8{,}8))^2 \cdot t_{pulse},$$

where t_{pulse} in ms.

The obtained dependences are presented on Fig. 11. For Luo-Rudy model relative threshold energy of cell activation does not exceed value 1,1 in a influencing of rectangular pulse duration range from 6.1 up to 19.7 ms.

IV. CONCLUSION

Specific resistance, specific capacity and time constant of myocardium cell membrane model depend on value of transmembrane potential.

The time constant of myocardium cell membrane model τ_m depending on value of transmembrane potential changes over a wide range — from 2.5 ms at –86 mV up to 12.5 ms at –75 мВ.

Weiss-Lapicque model most precisely describes response of myocardium cell membrane model to influence of rectangular current pulses.

V. REFERENCES

[1] Nicolas Brunel and Mark C.W. van Rossum, “Lapicque’s 1907 paper: from frogs to integrate-and-fire,” in Biological Cybernetics, vol. 97(5), December 2007, pp. 337-339.

[2] G.A. Mouchawar, L.A. Geddes, J.D. Bourland and J.A. Pearce, “Ability of the Lapicque and Blair strength-duration curves to fit experimentally obtained data from the dog heart,” in IEEE Transactions on Biomedical Engineering, vol. 36(9), September 1989, pp. 971-974.

[3] Mark W. Kroll, “A minimal model of the single capacitor biphasic defibrillation waveform,” in Pacing and Clinical Electrophysiology, vol. 17(11), November 1994, pp. 1782-1792.

[4] B.B. Gorbunov, “Characteristic energy method for evaluation of monopolar defibrillation pulse efficiency,” in Biomedical Engineering, vol. 43(2), 2009, pp. 56-61. Translated from Meditsinskaya Tekhnika, vol. 43(2), 2009, pp. 8-13.

[5] V.A. Vostrikov and B.B. Gorbunov, “Optimization of bipolar pulses of external defibrillators based on the repolarization hypothesis,” in Biomedical Engineering, vol. 43(2), 2009, pp. 62-67. Translated from Meditsinskaya Tekhnika, vol. 43(2), 2009, pp. 14-19.

[6] G.M. Faber and Y. Rudy, “Action Potential and Contractility in [Na+]i Overloaded Cardiac Myocytes,” in Biophysical Journal, vol. 78(5), May 2000, pp. 2392-2404.

[7] http://www.simulogic.com/products/platforms/

[8] Mark W. Kroll, Charles D. Swerdlow, “Optimizing defibrillation waveforms for ICDs,” in J Interv Card Electrophysiol, vol. 18(3), April 2007, pp. 247–263.

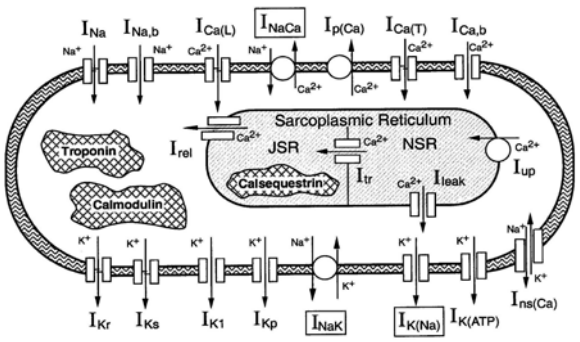

Figure 1. Luo-Rudy Mammalian Ventricular Model.

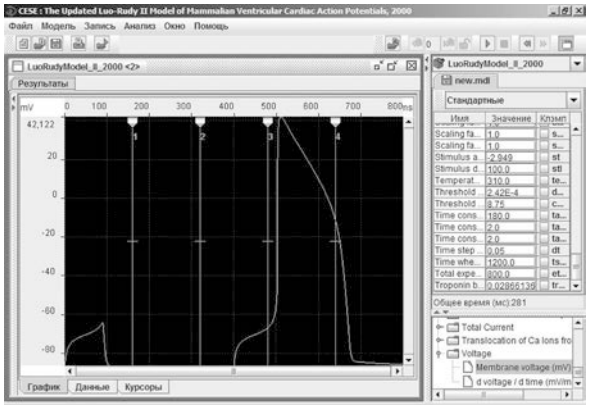

Figure 2. Window of the CESE modeling environment.

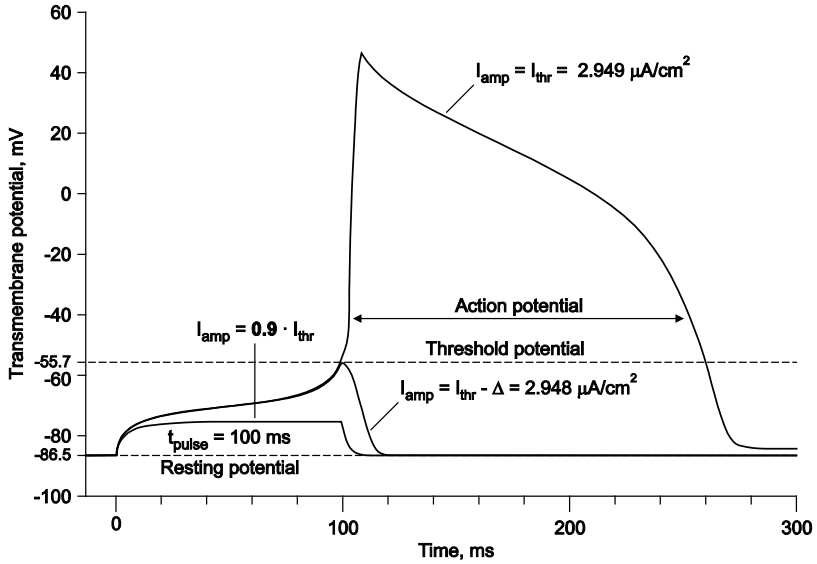

Figure 3. Action potential.

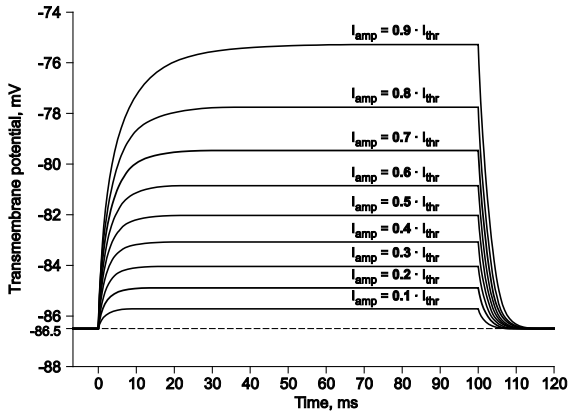

Figure 4. Model response to influence of pulses of various amplitude.

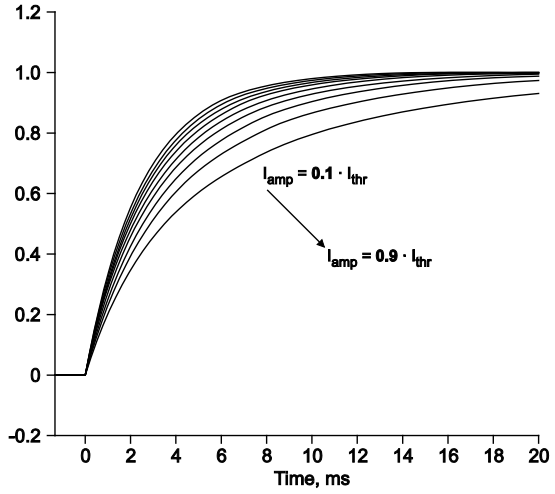

Figure 5. Transient responses of model at the pulse front.

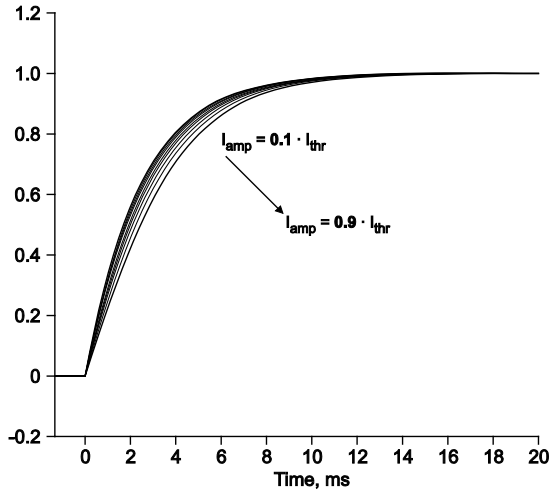

Figure 6. Figure 5. Transient responses of model at the pulse trail.

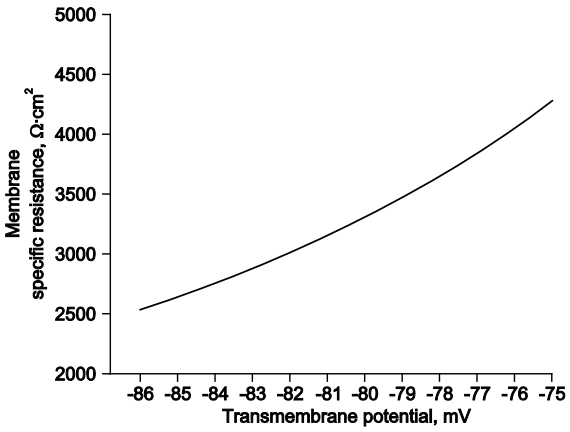

Figure 7. Dependence of membrane specific resistance from transmembrane potential.

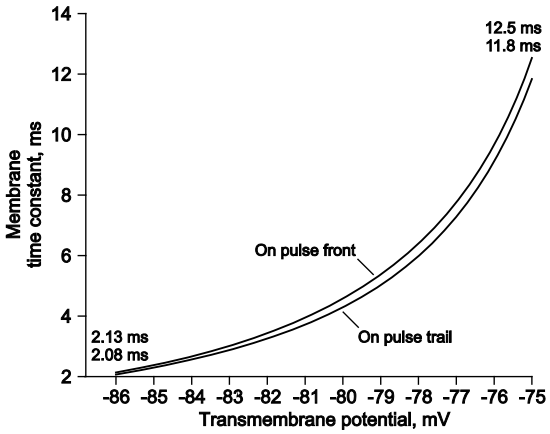

Figure 8. Dependence of membrane model time constants at the pulse front and trail from transmembrane potential.

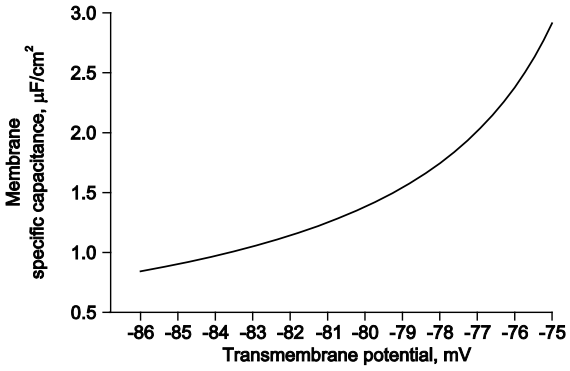

Figure 9. Dependence of membrane specific capacitance from transmembrane potential.

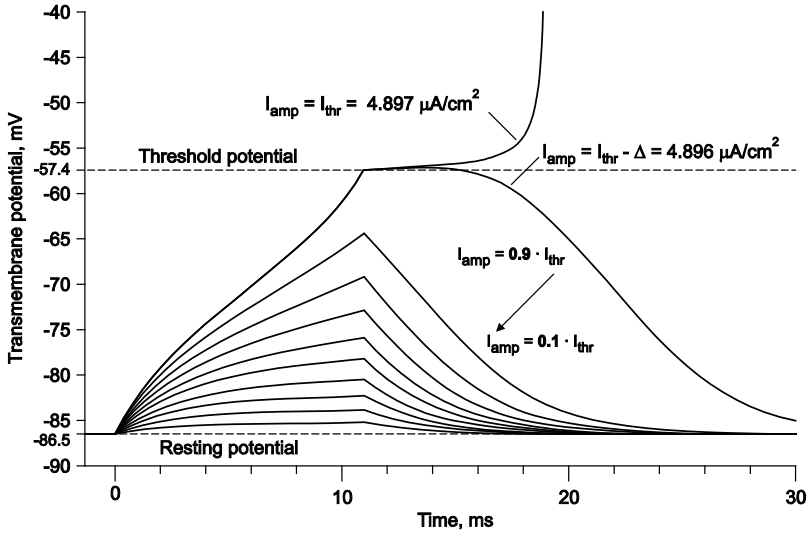

Figure 10. Response of membrane model to current pulses of a duration 11 ms with various amplitude.

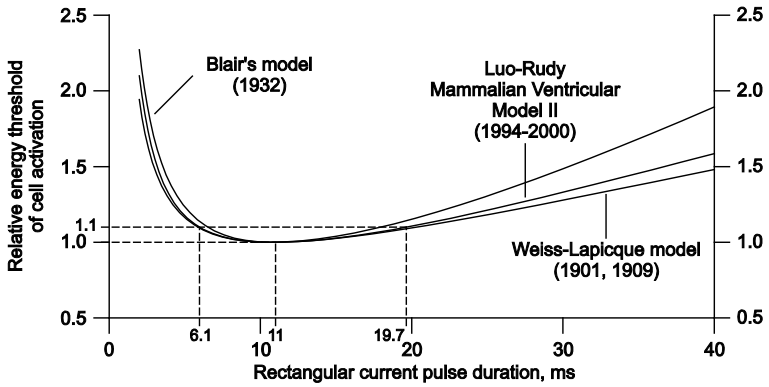

Figure 11. Dependence of relative energy threshold of cell activation on rectangular current pulse duration.