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BIOPHYSICAL MODEL OF CARDIAC ACTIVITY

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Abstract

This article analyzes the biophysical model of cardiac activity and its significance in medicine. The pumping function of the heart, bioelectrical processes, and hemodynamic parameters were studied from a biophysical perspective. The research is presented according to the IMRAD structure, and the main parameters used in modeling cardiac activity are presented in tabular form. The results demonstrate that cardiac function can be deeply analyzed using biophysical models.

Keywords: cardiac biophysics, biophysical model, blood circulation, bioelectrical processes, hemodynamics.

INTRODUCTION

The heart is the central organ of the circulatory system in a living organism, and its primary function is to ensure the continuous circulation of blood. Impairment of cardiac function leads to numerous cardiovascular diseases. Therefore, in-depth study and modeling of cardiac activity are among the urgent tasks of modern medicine.

In biophysics, cardiac activity is considered as a complex set of mechanical, hydrodynamic, and bioelectrical processes. Biophysical models represent cardiac function in a simplified form and help optimize diagnostic and treatment processes.

The aim of this article is to scientifically describe the biophysical model of cardiac activity.

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MATERIALS AND METHODS

During the research process, theoretical analysis, literature review, and mathematical modeling methods were used. The heart was considered as a pump, and its activity was evaluated based on the following biophysical parameters:

- heart rate
- stroke volume
- cardiac output
- arterial blood pressure
- electrical activity

Hemodynamic equations and simplified models describing bioelectrical processes were used in modeling cardiac activity.

**Table 1

Main Biophysical Parameters of Cardiac Activity**

Parameter	**Symbol**	**Average Value**	**Unit**
Heart rate	f	60–80	beats/min
Stroke volume	V	60–80	ml
Cardiac output	Q	4–6	L/min
Arterial pressure	P	120/80	mmhg
Electrical potential	U	1–5	mv

RESULTS

Based on the biophysical model of cardiac activity, the functional relationship between the mechanical (hemodynamic) parameters of the heart and its electrical activity was comprehensively analyzed. In the model, mathematical expressions were assigned to the main parameters of the cardiac cycle: heart rate (HR), stroke volume (SV), cardiac output (CO), arterial pressure, and the excitability properties of the myocardium.

The analysis showed that changes in heart rate and stroke volume directly affect cardiac output. According to the model formula:

CO = HR \times SV

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calculations indicated that when heart rate increased from 70 beats/min to 90 beats/min, while stroke volume remained constant, cardiac output increased on average by **25–30%**. Conversely, a **10–15% decrease in stroke volume** resulted in a significant reduction in cardiac output, indicating the risk of hemodynamic insufficiency.

During the analysis of electrical activity, the model indicators were found to correspond with **electrocardiography (ECG)** data. Changes in the amplitude and duration of the QRS complex were shown to influence myocardial contraction strength. When the propagation speed of electrical impulses decreased, the mechanical response of the myocardium also slowed down. This finding scientifically explains the disruption of hemodynamic parameters during cardiac rhythm disorders.

The biophysical model made it possible to analyze cardiac activity under three functional states:

1. Stable (normal) state – heart rate and stroke volume remain within physiological norms, and cardiac output is maintained at an optimal level. Pressure and volume changes remain balanced.

2. Enhanced (compensatory) state – under physical load or stress, cardiac output increases due to an increase in heart rate. The contraction strength increases; however, prolonged conditions may lead to myocardial overload.

3. Weakened (decompensatory) state – a decrease in stroke volume and impaired electrical conduction lead to reduced cardiac output. This condition is characteristic of the early stages of heart failure and is important for early detection.

The model results demonstrated that the interrelation between the electrical and mechanical activities of the heart becomes particularly evident in pathological conditions. Disruption of electrical excitation reduces mechanical efficiency, which leads to decreased arterial pressure and weakened peripheral circulation.

Additionally, by modifying vascular elasticity and peripheral resistance parameters within the model, the hemodynamic response was evaluated. Reduced vascular elasticity resulted in an increase in systolic pressure and cardiac workload. These findings are important for understanding the pathogenesis of cardiovascular diseases.

Overall, the results indicate that **biophysical modeling enables a deeper understanding of cardiovascular system function, early detection of functional disorders, and improved clinical diagnostics**. The prognostic capabilities of the model may contribute to the development of personalized assessment systems based on individual clinical indicators in the future.

DISCUSSION

The obtained results confirm that biophysical modeling of cardiac activity has significant theoretical and practical importance. Although a biophysical model cannot fully reproduce the complex morphofunctional system of the heart, it helps explain the main phases of the cardiac

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cycle—systole and diastole—as well as the relationships between pressure and volume changes, electrical impulse propagation, and hemodynamic parameters.

Using the model, the interrelationship between myocardial contraction strength, ejection fraction, arterial pressure dynamics, and heart rate can be mathematically expressed. This allows complex biological processes to be analyzed in a simplified yet scientifically grounded form. Particularly, the comparison of electrical activity models with **electrocardiography (ECG)** indicators is essential for understanding the mechanisms of cardiac rhythm disorders.

Biophysical modeling is one of the innovative approaches widely used in modern medicine and is closely connected with computer technologies. For instance, computer software can be used to create three-dimensional heart models and simulate hemodynamic processes, enabling the imitation of real clinical conditions. This provides physicians with an additional source of information for clinical decision-making.

From a practical perspective, the importance of the model is especially high in the following areas:

1. **Clinical diagnostics** – the model can be used to explain the pathogenesis of heart failure, arrhythmias, and ischemic heart diseases. By modifying model parameters, various pathological conditions can be simulated and their effects on cardiac function evaluated.
2. **Educational process** – in medical universities, modeling methods help develop students' abstract thinking when teaching subjects such as biophysics and physiology. Visual representation of mechanical and electrical cardiac processes significantly improves learning efficiency.
3. **Scientific research** – the effects of new pharmaceutical drugs on cardiac activity can be preliminarily evaluated through modeling. This reduces the number of experimental studies and optimizes research processes.

Furthermore, biophysical models allow the analysis of overall hemodynamic parameters of the cardiovascular system, including peripheral resistance, vascular elasticity, and blood flow velocity. Such a systemic approach enables cardiac activity to be studied as an integrated physiological mechanism.

In conclusion, biophysical modeling is an important tool for improving the understanding of cardiac physiology, increasing the accuracy of clinical diagnostics, and enhancing educational and research processes. In the future, the integration of artificial intelligence and digital technologies may enable the creation of individualized models of cardiac activity, contributing to the development of personalized medicine.

CONCLUSION

In conclusion, biophysical modeling plays an important role in deepening the understanding of the fundamental mechanisms of cardiac activity, improving the accuracy of clinical diagnostics, and enhancing educational and research processes. In the future, the integration of artificial intelligence and digital technologies will expand the possibilities for creating individualized cardiac models, contributing to the development of personalized medicine.

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