MATHEMATICAL MODELING IN MEDICINE

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Summary

The present article considers mainly the complex mathematical models describing the basic physiological systems in human beings. At first, the main features of the physiological processes will be examined. Then approaches to mathematical modeling of blood circulation, respiration and heat regulation systems will be considered. A relatively simple system of blood sugar regulation will serve as an example of application of the mathematical modeling methods. Some particular mathematical models of medicine phenomena and their application in the modern practice will be also illustrated.

Many issues of mathematical applications in the modern medicine can not be included in the pre sent article. A part of them is considered in other articles. They are mathematical modeling of immune processes, mathematical modeling in biophysics and mathematical modeling in oncology. Other issues such as the differential diagnostics of diseases, the automation of the maintenance of the patients' personal records and the medical care organization are now related mainly to the field of computer technology.

1. Introduction

Mathematics application to medicine research has a long time history. Even in the ancient world scientists and philosophers tried to find harmony in the structure of the human body. For example, the golden section was used to describe relationships between different parts of the body. Moreover, in the network of ideas generally accepted at that time any disease was considered as lack of balance in the principal body components. Later on this idea became transformed into modern concept of homeostatic equilibrium of human body under health condition and its disturbance during illness.

Today two main approaches to mathematical description of medicine phenomena can be distinguished. The first approach is to find regularities in quantitative analysis of medicine data. Such investigations are usually attributed to the field of biometrics. Modern statistical methods and computer systems are widely used for treatment of huge amount of biometrical data. In turn, the intensive data analysis leads to rapid development of the proper mathematical methods. For example, the term "regression" was introduced in the 19th century as an result of investigation on inheritance of physiological characteristics of human beings. The mathematical models suggested using this approach have a descriptive design and may be applied to deduce the mechanisms of phenomena under research.

The second approach is to predict the system behavior using the data on mechanisms underlying the described processes. This type of mathematical models may have a generalized character and describe the biological processes on any level of complexity. Moreover, these models may use the information obtained by the first approach. It should be noted that the mathematical models make a compromise between the two extremes. A very simple model can be easily constructed and analyzed mathematically. But it can describe adequately the problem only in a short range of conditions. In contrast, very complex model can take into account much more real processes, but it is hard to tune and operate.

2. Physiological systems and processes

Almost all fields of today's physiology use mathematical and computer methods to a certain extent. There exists a tendency towards the transition from modeling the isolated systems and processes to construction of complex models of interrelated systems controlling the regulation of a fair number of living functions.

The modern approach to describe the functioning of physiological systems is based on the principle of unstable equilibrium of biological systems. This principle is especially evident considering the interaction of these systems with the environment. The living systems are never in equilibrium and permanently work against the equilibrium required by the laws of physics and chemistry under the corresponding environment. The dynamic stability of the living systems is the result of a delicate balance between the processes of anabolism and catabolism, and it allows the organism to interact with its environment.

Physiological systems may be represented as the feedback systems. From the viewpoint of physiological systems identification, the influence of feedback on the system characteristics is of special importance. It is because the influence allows elucidating the nature and the mechanisms underlying the system functioning. The feedback in living systems may become apparent as the homeostasis mechanisms. These mechanisms participate in regulation of such living functions as temperature, breathing, hormones' level and others. The feedback may also appear in the form of the perception mechanisms of environmental stimuli.

Surely the feedback is intrinsic to living systems and is necessary for theirs survival and subsistence. Furthermore, the feedback mechanism allows accounting for some features of physiological systems. The features include the presence of fuzzy elements but the reliability of signal processing, high intensity of noise but the good quality of work, higher bandwidth than that of individual components, a significant number of different inherent oscillators called as biological clocks.

The mathematical models describing the physiological systems should have proper features. Usually they have stationary solutions corresponding to the homeostatic state of the described system. Besides, the models should include the mechanisms controlling the relaxation. It means return of the physiological system to a homeostatic state at a certain range of external actions or internal system characteristics. It should be noted that the relaxation mechanisms might differ depending on the scale of changes. In the case of significant changes the system may even transit to a new homeostatic equilibrium.

3. System of blood circulation

This system has attracted the attention of mathematicians since the 17^{th} century. But attempts to describe blood circulation by hydrodynamics theory have been seen only in 19^{th} century. Now there are robust mathematical models describing the system functioning under both normal and pathological conditions. These models are widely used in clinical practice, sportsmen training and space medicine research.

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Bibliography

Bauernschmitt R., Naujokat E., Mehmanesh H., Schulz S., Vahl C.F., Hagl S, and Lange R. (1999).Mathematical modeling of extracorporeal circulation: simulation of different perfusion regimens. *Perfusion*, Vol. 14, N. 5, pp. 321-330. [A mathematical model has been proposed for simulating haemodynamics during pulsatile perfusion. This model was then modified to allow it to simulate the effects of different perfusion regimens on arterial haemodynamics and whole body oxygen consumption.]

Beneken I. E. W.,(1965). A mathematical approach to cardiovascular function. The uncontrolled human system. Utrecht, Inst. Med. Phys. [A mathematical model of cardiovascular functioning has been constructed using hydrodynamics theory. The model has been proved by experimental data.]

N. M. Amosov (Ed.), (1977).Theoretical investigations of physiological systems. Mathematical modeling. Kiev, Naukova Dumka [in Russian] [A complex mathematical model describing vital organism functions under normal and pathological conditions has been formulated. The model incorporates particular models of different physiological systems.]

West J. B. , (1985).Respiratory physiology – the essentials. Baltimore, London, Los Angeles, Sydney – Williams & Wilkins. [The monograph represents a concise presentation of the basic principles underlining the modern concepts of respiratory physiology.]

Zacek M., Krause E. (1996). Numerical simulation of the blood flow in the human cardiovascular system. *J. Biomech.* , Vol. 29, N. 1, p. 13-20. [A numerical model of the human cardiovascular system has been described. The results of the simulation agree with the physiological data given in the literature.]