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BRAIN BIOPHYSICS: MECHANISMS OF SIGNAL TRANSMISSION BETWEEN NEURONS

Ilhom Hamidov,
Sanjar Mamatmurodov,
Furqat Kholmurodov
Tashkent State Medical University

Shavkat Kholmedov
Assistant at the Department of Biomedical Engineering, Informatics, and Biophysics Tashkent State Medical University

Abstract
This article explores the biophysical foundations of brain activity. It focuses on interneuronal signal transmission and explains mechanisms such as action potentials, ion channels, and information transfer via neurotransmitters at synapses. In addition, it examines the relationship between electrical and chemical processes, biophysical research methods, and their applications in understanding brain signal transmission in health and disease. The article provides students with a scientific basis for understanding neuronal activity and highlights opportunities for applying biophysics in practice.

Keywords: Brain biophysics, neuronal action potential, synapse, membrane signaling, ion channels, neurotransmitter, electrical and chemical processes.

INTRODUCTION:

The brain is the central organ of the human body. Its activity is closely linked to the biophysical processes of the nervous system. Neurons are the fundamental cells of the brain and the entire nervous system, enabling rapid and efficient information transmission. Signal transmission in neurons is based on electrical and chemical mechanisms involving action potentials, ion channels, neurotransmitter activity, and synapses. Cellular biophysics encompasses structural, functional, mechanical, and energetic characteristics of cells. Studying

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the biophysical foundations of interneuronal signal transmission is not only of scientific interest but also of practical importance in neurology, medicine, and neurotechnology.

MAIN PART:

1. Structure and Functions of Neurons

A neuron is a specialized cell responsible for receiving, transmitting, and processing information. It consists of three main parts: the soma (cell body), dendrites, and the axon. Dendrites receive external signals, the soma integrates and processes them, and the axon transmits signals to other neurons or muscle cells.

The neuronal membrane acts as an electrical insulator; however, ions can pass through it. This ion movement alters the membrane potential and generates an action potential. In addition, neurons are equipped with various receptors and protein channels that respond to different biophysical and chemical stimuli.

2. Action Potential and Ion Currents

The action potential is the primary electrical signal of neurons, ensuring rapid information transmission. Changes in membrane potential are associated with the flow of sodium (Na^+) and potassium (K^+) ions.

Depolarization: sodium channels open, Na^+ enters the cell, and the inner membrane becomes positively charged.

Repolarization: potassium channels open, K^+ exits the cell, and the membrane potential returns to a negative state.

Refractory period: the neuron cannot generate a new action potential, ensuring one-directional signal propagation.

The speed of action potential propagation depends on the axon diameter, myelin sheath, and the density of ion channels. In myelinated axons, signal transmission occurs in a saltatory manner, significantly increasing conduction velocity.

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3. Signal Transmission at Synapses

Communication between neurons occurs through synapses, which are classified into two types:

- Electrical synapses: signals are transmitted via direct electrical connections.
- Chemical synapses: neurotransmitters are released from the presynaptic terminal and act on postsynaptic receptors.

Neurotransmitters (such as glutamate, GABA, and dopamine) determine the type and duration of the signal. In chemical synapses, signal transmission is governed by biochemical and biophysical principles, including molecular diffusion, ion flow, and changes in membrane potential.

4. Integration of Electrical and Chemical Processes

Neuronal activity depends on the interaction of both electrical and chemical processes. Electrical impulses propagate as action potentials, while chemical mediators regulate synaptic transmission. Together, these processes ensure:

• Rapid and precise information transfer
• Adaptive responses of the nervous system
• Functioning of memory and learning mechanisms

The strength, speed, and efficiency of signal transmission are modeled and analyzed using biophysical approaches.

5. Biophysical Methods and Research Technologies

Various biophysical techniques are used to study neuronal activity:

• Patch-clamp technique: allows precise measurement of ion channel activity
• Microscopic methods: visualize the structure of neurons and synapses
• Electrophysiological methods: measure signals such as ECG, EEG, and EMG
• Mathematical models and computer simulations: analyze and predict signal transmission processes

These methods enable biophysically grounded scientific research and are highly significant in the study of neurological disorders such as Parkinson's disease, Alzheimer's disease, and epilepsy.

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Conclusion:

Brain biophysics is a crucial field that investigates the functioning of the brain, the most complex organ of the human body. Interneuronal signaling is mediated through action potentials, ion channels, and neurotransmitters at synapses. Electrical and chemical mechanisms are closely interconnected, ensuring rapid and efficient information transfer. Biophysical research methods—including electrophysiological measurements, microscopic observations, and mathematical modeling—provide deep insights into neuronal activity. This knowledge has significant applications in neurology, medicine, and neurotechnology, contributing to the understanding of normal brain function and the treatment of various neurological diseases.

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