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THE ROLE OF LIPIDS IN THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM: STRUCTURE, FUNCTIONS, AND CLINICAL SIGNIFICANCE

Палванова Матлюбахон Сатвалдиевна
Ферганский медицинский институт
общественного здоровья

Abstract. This article examines the role of lipids in the central and peripheral nervous system from the perspective of their structure, functions, and clinical significance. Lipids are essential components of nervous tissue, forming part of cell membranes and myelin sheaths, thereby ensuring their structural integrity and functional activity. Particular attention is given to lipid types such as phospholipids, cholesterol, and sphingolipids, which are involved in nerve impulse transmission and the formation of synaptic connections. Their participation in cellular signaling processes and energy metabolism in neurons is also discussed. Special consideration is given to disorders of lipid metabolism, which may lead to the development of various neurological diseases, including demyelinating and neurodegenerative processes. The importance of lipids in maintaining the normal functioning of the nervous system and their role in clinical practice is emphasized. Thus, lipids act as one of the key factors ensuring the structural and functional integrity of the nervous system.

Keywords: phospholipids, sphingolipids, triglycerides, axons, autism, cholesterol, astrocytes, synapse, myelin sheath.

Аннотация. В статье рассматривается роль липидов в центральной и периферической нервной системе с точки зрения их строения, функций и клинического значения. Липиды являются важнейшими компонентами нервной ткани, входя в состав клеточных мембран и миелиновых оболочек, обеспечивая их прочность и функциональную активность. Особое внимание уделено таким видам липидов, как фосфолипиды, холестерин и сфинголипиды, которые участвуют в передаче нервных импульсов и формировании синаптических связей. Также освещается их участие в процессах клеточной сигнализации и энергетического обмена в нейронах. Отдельно рассматриваются нарушения липидного обмена, которые могут приводить к развитию различных неврологических заболеваний, включая демиелинизирующие и нейродегенеративные процессы. Подчёркивается значение липидов в поддержании нормального функционирования нервной системы и их роль в клинической практике. Таким образом, липиды выступают как один из ключевых факторов, обеспечивающих структурную и функциональную целостность нервной системы.

Ключевые слова: фосфолипиды, сфинголипиды, триглицериды, аксоны, аутизм, холестерин, астроциты, синапс, миелиновая оболочка.

Annotatsiya. Ushbu maqolada lipidlarning markaziy va periferik nerv tizimidagi roli ularning tuzilishi, funksiyalari hamda klinik ahamiyati nuqtai nazaridan ko‘rib chiqiladi. Lipidlar nerv to‘qimasining eng muhim tarkibiy qismlaridan biri bo‘lib, hujayra membranalari va miyelin qobiqlari tarkibiga kiradi hamda ularning mustahkamligi va funksional faolligini ta’minlaydi. Fosfolipidlar, xolesterin va sfingolipidlar kabi lipid turlariga alohida e’tibor qaratilgan bo‘lib, ular nerv impulslarini uzatish va sinaptik bog‘lanishlarning shakllanishida ishtirok etadi. Shuningdek, ularning neyronlarda hujayraviy signal uzatish jarayonlari va energetik almashinuvdagi ishtiroki ham yoritilgan. Lipid almashinuvi buzilishlari alohida ko‘rib chiqilib, ular demiyelinizatsion va neyrodegenerativ jarayonlarni o‘z ichiga olgan turli nevrologik kasalliklarning rivojlanishiga olib

kelishi mumkinligi ta’kidlangan. Lipidlarning nerv tizimining normal faoliyatini saqlab turishdagi ahamiyati va klinik amaliyotdagi roli alohida qayd etilgan. Shunday qilib, lipidlar nerv tizimining strukturaviy va funksional yaxlitligini ta’minlovchi asosiy omillardan biri hisoblanadi.

Kalit so‘zlar: fosfolipidlar, sfingolipidlar, triglitseridlar, aksonlar, autizm, xolesterin, astrositlar, sinaps, miyelin qobig‘i.

Introduction

Lipids represent an extensive group of compounds, which include, among others, fats, and they play a key role in the structure of the brain. In the bodies of neurons forming the gray matter, their proportion составляет about 35–40%, whereas in the myelin sheath of nerve fibers of the white matter, the lipid content reaches approximately 78%. The lipid composition of nervous tissue is characterized by diversity and includes phospholipids, sphingolipids, cholesterol, and other components. These substances participate in metabolic processes, ensure the development and functioning of neurons, contribute to the transmission of nerve impulses, and regulate inflammatory reactions. Changes in the lipid composition of the brain may be associated with the development of cognitive disorders, including autism, schizophrenia, and Alzheimer’s disease. Nevertheless, the relationship between lipid distribution and the structural organization of nervous tissue until recently remained insufficiently studied, which limited their use as diagnostic molecular markers. Within the framework of modern research, scientists from the Skolkovo Institute of Science and Technology together with international colleagues created a detailed map of the lipid composition of the human brain. Samples of brain tissue from four healthy individuals were analyzed with assessment of the lipid profile in 75 different anatomical zones. For the identification of molecules, mass spectrometry was applied — a method that makes it possible to determine the structure of a substance based on the ratio of its mass to charge, as well as its behavior in a magnetic field. As a result of the study, 419 different lipid compounds were identified, and about 93% of them were distributed unevenly in different regions of the brain. For example, an increased content of cholesterol was observed in subcortical structures, as well as in the motor and visual cortex, whereas in the prefrontal cortex, which is responsible for complex cognitive functions and decision-making, its level was relatively lower.

Purpose of the Study

The purpose of this study is a comprehensive investigation of the role of lipids in the central and peripheral nervous system, taking into account their anatomical features of distribution and structural organization. Special attention is given to the analysis of the contribution of lipids to the formation and maintenance of the integrity of neuronal membranes and myelin sheaths. From a scientific point of view, the work is aimed at identifying patterns of lipid participation in neuronal signaling and metabolic processes of nervous tissue. From a clinical perspective, the study is focused on establishing the relationship between disorders of lipid metabolism and the development of neurological diseases. The obtained data may contribute to the improvement of methods for diagnosis and prevention of pathologies of the nervous system.

Materials and Methods

Lipids play a key role in the functioning of the nervous system, acting not only as structural components of neuronal membranes, but also as active participants in intracellular signaling. One of the most important representatives is phosphatidylinositol — a phospholipid that ensures the transmission of signaling molecules, including inositol-1,4,5-triphosphate, which regulates calcium processes in the cell. Disruption of its transport, for example in deficiency of the PITP protein, leads to pronounced defects in the development of the nervous system, including slowed axonal growth and neuronal death, which has been confirmed by experimental animal models. Lipid metabolism in the brain has a number of fundamental features that distinguish it from other tissues. Neurons practically do not use fatty acids as the main source of energy, which is associated with low β-oxidation activity and increased sensitivity to oxidative stress. The main energy role is performed by glucose; however, under extreme conditions such as hypoglycemia, the brain is capable of switching to the use of ketone bodies, which are formed in the liver and metabolized with the

participation of astrocytes. At the same time, astrocytes play the leading role in lipid metabolism, providing neurons with energy substrates and participating in the transport and redistribution of lipids. A special place among lipids is occupied by cholesterol, about 95% of which is synthesized directly in nervous tissue. Its formation occurs predominantly in astrocytes, from where it is transported to neurons with the participation of apolipoproteins and used for membrane construction and synapse formation. An important feature is the presence of different pathways of its biosynthesis in neurons and astrocytes, which ensures the diversity of intermediate metabolites with different biological activity. Disorders of cholesterol metabolism, including congenital enzyme defects, can lead to severe clinical consequences such as developmental delay, neurodegeneration, and cognitive disorders. Additional importance belongs to lipid droplets of astrocytes, which perform the function of lipid storage and protect neurons from the damaging effects of oxidized fatty acids. Disorders of lipid and carbohydrate metabolism affect not only the structural state of the nervous system, but also its functional activity, including the psycho-emotional sphere. A relationship has been established between increased levels of triglycerides and glucose, decreased high-density lipoproteins, and the risk of developing depression, anxiety, and stress disorders. Clinically, this may manifest as cognitive and motor impairments, as well as changes in behavior and emotional state, which emphasizes the importance of lipids in maintaining both the anatomical and functional integrity of the nervous system.

Results and Discussion

The results of the conducted analysis confirm that lipids play a multilevel role in ensuring the normal functioning of the nervous system, starting from the structural organization of membranes and ending with the regulation of intracellular signals. It was established that disturbances in phosphatidylinositol transport and deficiency of the PITP protein lead to suppression of axonal growth and increased neuronal death, which affects the development of the organism and the state of motor function. Additionally, it was found that the metabolic load between neurons and astrocytes is distributed unevenly: astrocytes take on the key role in lipid processing, energy supply, and protection of neurons from oxidative stress. During the discussion, it was also noted that cholesterol imbalance, especially during developmental stages, can cause severe neurological and cognitive disorders, whereas its physiological level is necessary for normal synaptogenesis. Along with this, the relationship between metabolic disorders (hyperglycemia, hypertriglyceridemia, decreased HDL) and an increased risk of mental disorders was demonstrated, which indicates the systemic nature of the influence of lipid metabolism on the nervous system. From a clinical point of view, this opens prospects for early diagnosis of diseases through biochemical blood markers and lipid profile analysis. Treatment of such conditions should be comprehensive and include correction of metabolic disorders, the use of neuroprotective therapy, normalization of lipid metabolism, as well as monitoring of glucose and lipoprotein levels. Prevention is based on rational nutrition, maintaining a normal lipid profile, reducing risk factors for metabolic syndrome, and timely detection of metabolic disorders. Thus, the obtained data emphasize the importance of lipids as a key link connecting biochemical processes and clinical manifestations of nervous system diseases.

Conclusion

In conclusion, it should be noted that lipids are an integral component that ensures both the structural organization and functional activity of the nervous system. Their participation covers a wide range of processes — from the formation of cell membranes to the fine regulation of intercellular interactions. Modern studies demonstrate that even minor changes in lipid balance can have a pronounced effect on the state of neurons and intercellular connections. This emphasizes the need for a deeper study of lipid metabolism in the context of neurobiology and medicine. The practical significance of this knowledge lies in the possibility of developing new approaches to the diagnosis and therapy of nervous system diseases. Prospects for further research are associated with the search for precise molecular mechanisms and targets for targeted intervention.

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