Rocz Panstw Zakl Hig 2018;69(1):15-21

http://wydawnictwa.pzh.gov.pl/roczniki_pzh/

REVIEW ARTICLE

INFLUENCE OF SELECTED DIETARY COMPONENTS ON THE FUNCTIONING OF THE HUMAN NERVOUS SYSTEM

Agnieszka Wendołowicz, Ewa Stefańska, Lucyna Ostrowska

Medical University of Białystok, Department of Dietetics and Clinical Nutrition, Bialystok, Poland

ABSTRACT

The diet is directly connected not only with the physical status but also with the functioning of the brain and the mental status. The potentially beneficial nutrients with a protective effect on the nervous system function include amino acids (tryptophan, phenylalanine, tyrosine, taurine), glucose and vitamins C, E, D and *beta*-carotene, B group vitamins (vitamin B_{12}, vitamin B_6, vitamin B_4, vitamin B_1) and minerals (selenium, zinc, magnesium, sodium, iron, copper, manganese, iodine). The presence of antioxidants in the diet protects against oxidative damage to nervous system cells. Biochemical data indicate that polyunsaturated fatty acids such as arachidonic acid (AA), docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and gamma-linolenic acid (GLA) as structural components of the nervous system play a key role in its function. The nutrition of the entire body also influences the production of neurotransmitters in the brain. A diet without an appropriate supply of protein, mineral nutrients or vitamins may result in a failure to form appropriately balanced numbers of neurotransmitters, which, as a result, may lead to neurotransmission dysfunction. This is the reason why proper nutrition is based on vegetables, fruits, whole-grain cereal products supplemented with products providing full-value protein (dairy products, fish, lean meat) and high-quality fat products (vegetable oils, fish fats).

Key words: *nutrition, central nervous system*

STRESZCZENIE

Sposób żywienia ma bezpośredni związek nie tylko ze stanem fizycznym ale również z funkcjonowaniem mózgu i kondycją psychiczną. Wśród potencjalnie dobroczynnych składników pożywienia działających protekcyjnie na funkcjonowanie układu nerwowego wymienia się między innymi aminokwasy (tryptofan, fenyloalanina, tyrozyna, tauryna), glukozę oraz witaminy C, E, D i *beta*-karoten, witaminy z grupy B (witamina B_{12}, witamina B_6, witamin B_4, witaminaB_1) oraz składniki mineralne (selen, cynk, magnez, sód, żelazo, miedź, mangan, jod). Obecność w diecie przeciwutleniaczy chroni przed oksydacyjnym uszkodzeniem komórek układu nerwowego. Dane biochemiczne wskazują, że wielonienasycone kwasy tłuszczowe takie jak kwas arachidonowy (AA), kwas dokozaheksaenowy (DHA), kwas eikozapentaenowy (EPA) oraz gamma-linolenowy (GLA) jako składniki strukturalne układu nerwowego odgrywają kluczową rolę w jego funkcjonowaniu. Odżywienie całego organizmu wpływa na wytwarzanie w mózgu neurotransmiterów. Brak w diecie odpowiedniej podaży energii, białka, związków mineralnych czy witamin może spowodować niewykształcenie odpowiednio zbilansowanych ilości neurotransmiterów, co w efekcie może prowadzić do dysfunkcji neurotransmisyjnej czego konsekwencją mogą być różne zaburzenia stanu psychicznego. Dlatego, tak ważne jest prawidłowe żywienie opierające się na warzywach, owocach, produktach zbożowych z pełnego przemiału uzupełnione produktami dostarczającymi pełnowartościowego białka (produkty mlecze, ryby, chude mięso) oraz produktami tłuszczowymi o wysokiej jakości (oleje roślinne, tłuszcze pochodzące z ryb).

Słowa kluczowe: *żywienie, centralny układ nerwowy*

INTRODUCTION

The diet influences human health to a large extent. Proper functioning of the central and peripheral nervous system depends on the diet [8, 9]. The function of the nervous system depends on the proper supply of the necessary nutrients. The brain does not have the ability to store nutrients, so it requires a continuous supply of easily accessible sources of energy, carbohydrates, protein and fats. Nervous system cells need nutrients to build and keep their structure and also to maintain their function and avoid premature

Corresponding author: Agnieszka Wendołowicz, Department of Dietetics and Clinical Nutrition, Medical University of Bialystok, Mieszka I-go 4B, 15-054 Bialystok, Poland, Tel. +48 85 7328225, Fax +48 85 6865302; e-mail: agnieszka.wendolowicz@umb.edu.pl

ageing [5, 17]. The brain is a priority organ in the body and necessary nutrients are delivered to it first, before other organs, and, if necessary, the brain can use the reserves of other organs, thus weakening them. The consumption of too low or too high amounts of food may have an enormous influence on the human mental condition as individual nutrients cause significant changes in the biochemistry of the brain which has an effect on thinking processes and behaviour [17]. The potentially beneficial nutrients with a protective effect on central nervous system function include amino acids (tryptophan, phenylalanine, tyrosine, taurine), glucose, polyunsaturated fatty acids and vitamins C, E, D and *beta*-carotene, B group vitamins (vitamin B_{12}, vitamin B_6, vitamin B_4, vitamin B_1) and minerals (selenium, zinc, magnesium, sodium, iron, copper, manganese, iodine). An appropriate supply of these nutrients or their deficiencies can influence nervous system function. All that we feel, our emotions, desires and awareness of our existence depends on our brain and the neurotransmitters functioning in it. Deviations from their proper function influence all systems and organs in the human body, but the nervous system is the main victim. Diseases such as schizophrenia, recurrent mood disorders, *Parkinson's* disease, *Alzheimer's* disease, epilepsy, anxiety result from incorrect neurotransmitter function [17].

MACRONUTRIENTS AND THE NERVOUS SYSTEM

The human brain is a very "costly" organ in terms of energy. It constitutes approx. 2% of body weight but, under resting conditions, it uses as much as 20-23% of basic metabolism [5]. As opposed to other tissues, glucose is almost exclusively an energy substrate for neurons. It is transported through the blood-brain barrier with the participation of insulin-independent glucose transporters GLUT1 with high density and medium affinity to glucose. The transport to neurons, on the other hand, takes place by means of GLUT3 transporters, which show high affinity to glucose. These transporters are always saturated with glucose, even in mild hypoglycaemia conditions, which ensures the supply of an appropriate amount of substrates to neurons. Glucose uptake does not only depend on GLUT transporters but also on glucose concentrations on both sides of the blood-brain barrier [23, 31]. Brain activation leads to a reduction in intracellular glucose and ATP concentrations, which stimulates glucose uptake by neurons. Glucose concentrations in cerebrospinal fluid constitute 2/3 of its concentration in general circulation. Glucose transformation occurs in the process of glycolysis of pyruvate, which is the key precursor of acetyl-CoA. A higher amount of this substrate (acetyl-CoA) causes an increase in acetylcholine production, which is a neurotransmitter with a proven effect on the memory, amongst other things [5, 10, 31]. In ketone acidosis or hypoxia conditions, the brain may use alternative sources of energy such as beta hydroxybutyrate or lactate. Lactate can be a source of energy in states of increased energy production with lower glucose availability [10, 31]. However, these sources of energy are not capable of fully replacing glucose. Neurons constitute 10% of all brain cells and use approx. 80% of the total glucose and oxygen supplied. As neural cells of the brain are not capable of storing high-energy compounds, their proper function depends on the supply and use of equivalent quantities of oxygen and glucose. Energy reserves accumulated in the CNS are very low, and it is estimated that they are enough for only 10 minutes of brain functioning [13, 23]. In numerous in vitro and in vivo studies, it was found that the majority of energy produced by neurons (60-70%) is used to keep and restore appropriate resting potentials on their pre- and post-synaptic membranes after functional depolarization. Appropriate gradients of $Na^+/K^+/Ca^+$ ion concentrations between inter-neuron and extracellular spaces as well as in their intracellular partitions are kept. It is necessary to keep these gradients for proper neurotransmitter activity both in glutamatergic neurons as well as in the neurons of other neurotransmitter systems (GABA-ergic, cholinergic, serotoninergic) [13, 19].

Foodstuffs that provide carbohydrates (including cereal products, fruits) are willingly eaten when one is in a depressed mood as they increase endorphin secretion and have a calming effect. In numerous studies, carbohydrates were proven to increase tryptophan and serotonin synthesis in the CNS, which may contribute to mood improvement [8, 10, 31].

Fats contained in food — apart from proteins and carbohydrates — belong to basic nutrients. Depending on their source, they contain a lot of other ingredients, especially vitamins A, D, E, K and the necessary unsaturated fatty acids. In the past, fats were thought to be unhealthy so they were not desirable in the human diet. At present, they are considered to be necessary for the proper function of the human body and especially the nervous system [19].

Polyunsaturated fatty acids are compounds of proven importance for proper development and function of the brain and the peripheral nervous system. The central nervous system contains several necessary fatty acids including arachidonic acid (AA), docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and gamma-linolenic acid (GLA) [25]. Biochemical data show that Omega-3 fatty acids (EPA and DHA) and Omega-6 fatty acids play a key role in the function of the nervous system as its structural components [1]. Necessary unsaturated fatty acids constitute approx. 15-20% of the dry mass of the brain and over 30% of all fatty acids in the nervous system. EPA is part of phospholipids of cell membranes in which it is the precursor of eicosanoids necessary for ongoing regulation of the function of the central nervous system and transfer of information between brain cells [30]. Elevated EPA concentrations reduce the activity of phospholipase A2 (PLA2), the enzyme responsible for releasing DHA from nerve cell membranes [22, 25]. *Omega*-3 DHA is a structural fatty acid and a building material for neurons. DHA acid is metabolized to compounds with neuroprotective action such as docosahexaenoylethanolanid (DEA) and neuroprotectins 1 (NPD1). *Omega*-6 GLA is metabolized to dihomo-gamma-linolenic acid (DGLA) and arachidonic acid (AA) [11]. The former fulfils an anti-inflammatory function while the latter plays a role in the function of the central nervous system, including processes responsible for memory. Arachidonic acid is also a substrate for the production of eicosanoids, physiologically and pharmacologically active compounds known as prostaglandins (PG), thromboxanes (TX), leukotrienes (LT) and lipoxins (LX) [16, 22, 26]. In recent years, it has been found in a large number of studies that reduced DHA and AA concentrations occur in the blood serum and erythrocyte membranes in some people. This applied to patients suffering from depression, schizophrenia and also dyslexia, dyspraxia, ADHD and autism [1, 27, 30]. *Omega*-3 EPA and DHA acids influence the reduction in the production of inflammatory cytokines from arachidonic acid. This is caused by the competition of these acids with arachidonic acid for incorporation into phospholipid membranes, as a result of which the level of arachidonic acid is reduced both in the cells and in the plasma. EPA, on the other hand, competes with arachidonic acid in the cyclooxygenase pathway by inhibiting the production of proinflammatory eicosanoids, including prostaglandines E2 and thromboxane B2. DHA and EPA inhibit the secretion of proinflammatory cytokines such as interleukins 1 (IL-1), IL-2, IL-6, interferon gamma (IFN) and the tumour necrosis factor (TNF alpha) [3, 16, 19]. A lot of data show that fatty acids are related to the activity of the serotoninergic system [15, 19, 22]. Research conducted on people and animals has shown the influence of *omega*-3 acids on the receptor function, the neurotrasmitter level and its metabolism [15]. The relationship between a low concentration of *omega*-3 DHA and a low concentration of 5-hydroxyindolacetic acid (5-HIAA) in the cerebrospinal fluid, which is the main metabolite of serotonin. Low concentrations of 5-HIAA in the cerebrospinal fluid are observed with people after violent suicide attempts, in the state of aggression, weakened impulse control, especially in people suffering from depression, schizophrenia, alcohol addiction and adjustment disorders. This may imply that low concentrations of *omega*-3 DHA acids is related to impaired serotonergic neurotransmission [25]. Fatty acids influence intracellular transmission related to secondary transmitters such as cyclic adenozynomonophosphate (cAMP) and the phosphatidylinositol. The influence of *omega*-3 on mood stabilization can occur through mechanisms of inhibiting the phosphatidylinositol system [16]. Research on animals also shows that *omega*-3 acids have a modulatory and inhibitory influence on ion channels depending on calcium [19]. EPA and DHA have an inhibitory effect on the activity of protein kinase C (PKC), which is dependent on calcium and phosopholipids. PKC plays an important role in pre- and postsynaptic regulation of signal transmission by releasing neurotransmitters, receptor function, ion channels, neuronal excitation and gene expression [16, 25]. Docosahexaenoic acid induces the synthesis of neurotrophic factor (BDNF), thus extending the life of neurons. Antidepressants may increase BDNF concentrations, while a diet rich in saturated fatty acids and stress inhibit the production of this neurotrophin [16]. Quantitative changes of this acid in cell membranes of neurons may impair the function of ion and receptor channels such as dopaminergic, GABA-ergic and cholinergic ones [1, 18, 30]. Polyunsaturated fatty acids in nervous system cells influence the release and uptake of neurotransmitters and enzymatic processes. Their deficiency may contribute to the development of depression, anxiety, aggression [30, 31].

The only real source of necessary *omega*-3 polyunsaturated fatty acids is fat from fish and seafood. The EPA and DHA content and their mutual proportions depend on the fish species, season, physiological condition of fish and the fishing area. Fish from cold northern seas contain more EPA while those from southern seas - more DHA. Also, some species of freshwater fish contain high levels of *omega*-3 acids - mostly salmon. Various types of seafood (oysters, shrimps, crabs) and algae also contain *omega*-3 acids, however, oil extracted from the liver of sharks living near New Zealand and Tasmania is still considered to be the most valuable source these acids [22]. More cases of depression are observed in countries with low consumption of fish that are a source of *omega*-3 acids [17]. Research shows that the consumption of *omega*-3 fatty acids is recommended in *Alzheimer's* disease prevention [21]. Eating fish once a week reduces the risk of *Alzheimer's* disease by 60% [18, 25]. Necessary *omega*-6 fatty acids are present in oilseeds. *Gamma*-linolenic acid occurs in primrose oil and arachidic acid is present in the bodies of various animals [21].

A high content of saturated fatty acids and trans fatty acids in the diet may reduce the flexibility and elasticity of nerve cells. Excessive amounts of these ingredients reduce the oxygen supply and the ability to remove metabolites from the brain. The main source of saturated fatty acids are milk and meat products; they also occur in large amounts in coconut oil and in palm oil. A source of trans isomers are hardened vegetable oils and products in which they are used, mostly solid margarines, confectionery and frying fat and, as a result, confectionery products, candy bars, cookies and fast foods [8, 17, 21].

A diet containing an appropriate amount of protein, which is a source of exogenous amino acids for our body, is necessary for proper function of the nervous system [8, 17]. Meat, fish, eggs and dairy products contain protein that contains exogenous amino acids that are necessary for the proper function of the brain, which is the basis of mental performance [19]. A protein-rich diet stimulates the brain function. High-quality protein that provides sulphur amino acids stimulates a higher uptake of tryptophan and also branched-chain amino acids [8, 19, 21]. In the digestive process, proteins are transformed into peptides, amino acids and biogenic amines, which fulfil the function of neurotransmitters. Peptides formed from milk proteins, such as endorphins, encephalin and dynorphins are important for the brain function. These are neurotransmitters with opioid action (similar to morphine and codeine), which stimulate brain activity in adults and have a sedative effect in small children [29]. Another protein that is very precious for the function of the nervous system is glutathione - a tripeptide containing cysteine, glutamic acid and glycine. Together with superoxide dismutase and catalase, it is the main detoxication factor of the brain that captures and neutralizes free radicals [13, 21, 29]. The glutathione level depends on the quantity of sulphur amino acids in the diet and the degree of saturation of the body with vitamins B_6, B_{12} and B_9 (folic acid). Amino acids released from food proteins in enzymatic digestion processes in the gastrointestinal tract show a stimulating effect on the function of the central nervous system [4]. Glutamate is the main neurotransmitter from which g-aminobutyric acid - GABA is formed in the brain. GABA-ergic synapses constitute approx. 20% of all synapses in the brain. Through glutamatergic pathways, visual, auditory and sensory information reaches the brain cortex from the peripheral nervous system. Glutamatergic pathways also participate in remembering and forgetting information in learning processes. Taurine also plays an important role in neurotransmission and neuromodulation in the central nervous system [18], which is confirmed by its high concentrations in the cortex, hippocampus and hypothalamus. Moreover, taurine also shows antioxidative and anti-inflammatory action protects nuclear DNA from free radicals, which is very important, in particular, for long-living cells of the brain, heart and skeletal muscles. A lot of research shows that taurine may limit the development of neurodegenerative diseases and its best sources within the human diet include tuna, beef and poultry. A broad spectrum of biological action of taurine also makes daily consumption of milk and dairy products advantageous to health, especially if sulphur amino acids are absent from the diet (methionine and cysteine) [32]. Endogenous synthesis of taurine does not fully meet the demand of the human body [29]. Catecholamines: adrenaline and noradrenaline are formed from tyrosine, which intensify mental activity, i.e. shorten the reaction time and also dopamine, the so-called 'happiness hormone' whose deficiencies may cause schizophrenia, *Parkinson's* disease and *Tourette syndrome.* Serotonin is formed from tryptophan, which has a pain-killing, relaxing and slowing-down action. When tryptophan concentrations go down in the brain, serotonin synthesis also decreases [12, 13, 26]. Phenylalanine is particularly valuable for the brain amongst amino acids. It is a chemical carrier of impulses between the peripheral nerve cells and the brain. It is present in soy, dairy products, legumes, sesame seeds [17].

NERVOUS SYSTEM AND ANTIOXIDANTS

The nervous system is particularly exposed and sensitive to free radicals, hence, at present particular attention is paid to a proper supply of antioxidants. Antioxidants are collected together with food and they include vitamins C, E and β-carotene, zinc, copper, manganese, glutathione, co-enzyme Q10, selenium, which are active in cells and prevent oxidative stress, damaging a large number of cell components including DNA [15, 18]. The best sources of antioxidants include vegetables (onion, broccoli, spinach, carrot, cabbage) and fruit (oranges, grapes, strawberries, cherries, black currants, avocado) [9]. In numerous biochemical and psychological studies, it was found that oxidative molecules may contribute to the development of neurodegeneration diseases such as *Parkinson's* disease and *Alzheimer's* disease and oxidative modification of lipoproteins from the LDL fraction is an important factor in the atherosclerosis process. It results from literature data that regular consumption of fruits and vegetables is the best protection against oxidative stress. It has been found that enriching the diet with vegetables and fruits for 14 days improves the DNA and lipid condition in the human body [15]. The human brain contains high levels of oxidized lipids, which should be protected against oxidative stress. The accumulation of antioxidants in the brain and in the nervous tissue is much slower than in other tissues [2, 10]. Low vitamin E concentrations in the cerebrospinal fluid are often observed in patients suffering from *Alzheimer's* disease. It has also been found that the rate of formation of peroxidation products is correlated with vitamin E levels, which is related to daily magnesium consumption. Vitamin E, apart from its antioxidative function, may additionally inhibit the development of atherosclerosis by influencing the immune system function [9, 10]. In direct epidemiological research, a relationship was found between the level of antioxidants in the plasma and metal activity. A correlation was observed between low vitamin C consumption and a simultaneous low level of this vitamin in the plasma and an increased risk of ischaemia and reduced mental performance [2]. In other studies, a significant correlation was shown between components of the diet and mental performance. From among the variables, tested, the consumption of vitamin C, β-carotene, folic acid and iron was positively correlated and the consumption of monounsaturated fatty acids, saturated fatty acids and cholesterol - negatively [2].

Over the past decade, there has been a growing interest in vitamin D, which allowed for discovering new action of calcitriol within the central nervous system. On the basis of epidemiological and molecular research, calcitriol was recognized as neurosteroid whose deficiency plays a key role in etiopathogenesis of dementia, depression, schizophrenia, epilepsy and autism [28, 29].

Proper function of the central and peripheral nervous system depends directly on the mechanism of action of group B vitamins B. Vitamin B_1 in the active form of thiamine triphosphate plays an important role in the nervous tissue function [9, 23]. This compound influences the serotonin- and adrenergic system and participates in impulse transmission [13, 23]. Vitamin B_2 is necessary to keep glutathione in its reduced form as it protects against harmful action of free radicals [24]. The deficiency of vitamin B_6 may cause catecholamine synthesis disorders, reduced quantities of g-aminobutyric acid (GABA) and changes in the amino acid composition in certain areas of the brain. Disorders caused as a result of vitamin B_6 deficiency can, as a result, cause premature ageing of neurons [16, 24]. Niacin takes part in the synthesis of cortisol, thyroxine, as a result of which it is necessary for the proper function of the brain and the peripheral nervous system. The cobalamin content influences the amount of reduced glutathione in erythrocytes and in the liver and, as a result, its deficiency may weaken the antioxidant system. Choline, which is called vitamin B_4, takes part in the transport of important nutrients in the body and in the function of all cells. As a precursor of acetylcholine, a neurotransmitter in the cholinergic system, choline takes part in the control of the function of muscles, the respiratory system and the heart action and also in brain functions connected with memory. It is very important in the diet of pregnant and breastfeeding women as it influences the prenatal and postnatal development of the brain and the spinal cord (the central nervous system) [24]. It was found that choline uptake improves long-term memory and learning functions. Research on animals has shown that ageing-related memory deterioration can be delayed if the mother's diet is supplemented with choline during pregnancy. There are also reports that claim that a diet containing large quantities of easily assimilable choline can reduce the risk of dementia that is characteristic of Alzheimer's disease. Deficiencies of group B vitamins in the body, such as B_1, B_2, B_6, B_{12} and folic acid, may result in the development of depression and myelin degeneration and the lack of vitamins B_6 and B_{12} to peripheral neuropathy [17, 20, 24]. The deficiency of these vitamins may also cause disorders in homocysteine metabolism. The level of synthesized homocysteine in the plasma is negatively correlated with the level of vitamins B_{12}, B_6, and folic acid. Vitamin B_6, as a co-factor of cystathionine β-synthetase catalyses the process of cystathionine formation from homocysteine and serine, while vitamin B_{12} and folic acid participate in the process of changing homocysteine back to methionine. Homocysteine, which is a precursor of cysteine and homocystein acid, takes part in neurodegeneration, regardless of atherosclerosis. In studies involving older people with depression, the homocysteine level was higher among those with vascular diseases, but a significant correlation between homocysteine concentrations and the impaired function was only obtained among people in whom no vascular diseases were found [21]. A relationship was shown between a very low level of folic acid and depression that may, to a certain extent, be explained by changes in the level of S-Adenosyl methionine and serotonin in the brain. S-Adenosyl methionine is formed as a result of homocystein transformation to methionine in the presence of folic acid. In the acetylation process, serotonin is transformed into acetyl-5-hydroxytryptamine from which, with the participation of hydroxy-indolo-O-methyltransferase and S-adenosyl methionine, N-acetyl-5-metoxytryptamine, i.e. melatonin is formed [20]. Melatonin neutralizes free radicals, thus protecting tissues from damage and premature ageing. Melatonin is also a factor that improves physiological sleep, and a form of S-Adenosyl methionine also participates in the synthesis of catecholamines [2].

Bioelements such as iron, calcium magnesium, copper, manganese, zinc, iodine and selenium are very important for the proper function of the brain and the entire nervous system. Many neurological and mental diseases are caused by changes in the distribution and action of neurotransmitters. Iron, as a component of monooxygenase, participates in the transformation of tryptophan to 5-hydroxy-tryptamine, a serotonin precursor.

Iron, zinc, magnesium and copper are important modulators of glutamatergic transmission related to etiopathogenesis of depression. Physiological concentration of copper and zinc plays an important role in the activation of enzymes dependent on these elements that are involved in catecholamine transmission [7]. Copper participates in the metabolism of biogenic amines participating in myelinogenesis. Magnesium regulates the action of glycoprotein P, which is one of transport proteins responsible for proper permeability of the blood-brain barrier for many substances. Magnesium deficiencies in the daily food ration are frequent nutritional problems of various population groups [6, 19]. The zinc level in the serum is closely related to inflammatory processes that are activated during depression. Zinc absorption is enhanced by the presence of vitamins A and E. Zinc is necessary for the proper development and function of the brain. The important role of this element results from the fact that the transmission of nervous signals is modulated in synapses in the central nervous system [23]. Neurons which contain zinc cations in a complex with glutamate, which are also called glutamatergic, occur in brain areas such as: the cortex, limbic system structures which are responsible for managing emotions, receiving and processing sensory impressions, i.e. smell, taste, hearing, vision or pain and also learning processes and memory formation [7, 10]. Calcium and sodium also take part in the transmission of neural stimuli. Another element that plays a key part in the proper brain function is iodine. It is an element necessary for the production of triiodothyronine T_3 and thyroxine T_4 in the thyroid gland. Appropriate differentiation and maturation of the brain cells and nervous system cells depend on proper concentrations of thyroid hormones in the blood. Iodine deficiencies during the foetal life are particularly dangerous as they may cause congenital defects and the development of neurological cretinism [19].

CONCLUSIONS

Synthesis of neurotransmitters responsible for maintaining well-being in the brain is conditioned by the quantity and quality of the consumed food. Deficiencies, even moderate, especially if they persist for a long time, have a disadvantageous effect on human health, including, in particular, the functioning of the nervous system. Some nutrients such as amino acids, necessary unsaturated fatty acids and carbohydrates take part in neurotransmitter synthesis, which may influence the human mood. The presence of antioxidants in the diets, including vitamin C, E, β-carotene, protects against oxidative damage to nervous system cells. Deficiencies of B group vitamins may result in memory and concentration disorders, emotional balance disorders, symptoms that frequently occur in patients suffering from depression. A properly composed diet, based on vegetables, fruits, whole-grain cereal products supplemented with products providing full-value protein (dairy products, fish, lean meat) and high-quality fat products (vegetable oils, fish fats) may become the key to solving a large number of health problems.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

1. *Astorg P, Couthouis A, Bertrais S, Arnault N, Meneton P, Guesnet P, Alessandri JM, Galan P, Hercberg S.*: Association of fish and long-chain n-3 polyunsaturated fatty acid intakes with the occurrence of depressive episodes in middle-aged French men and women. Prostaglandins. Leukot Essent Fatty Acids 2008; 78(3): 171-82.
2. *Beyer JL, Payne ME.*: Nutrition and Bipolar Depression. Psychiatr. Clin. North Am 2016; 39(1):75-86.
3. *Cardoso C, Afonso C, Bandarra NM.*: Dietary DHA and health: cognitive function ageing. Nutr Res Rev 2016; 29(2): 281-294.
4. *Cichosz G. Czeczot H.*: Kontrowersje wokół białek diety. Pol Merk Lek 2013; 35 (210): 397-401 (in Polish).
5. *Ciok J, Dolna A.*: Węglowodany a sprawność umysłowa – znaczenie indeksu glikemicznego. Pol Merk Lek 2006; 20(117): 367-370 (in Polish).
6. *Flynn A, Hirvonen T, Mensink GB, Ocké MC, Serra-Majem L, Stos K, Szponar L, Tetens I, Turrini A, Fletcher R, Wildemann T.*: Intake of selected nutrients from foods, from fortification and from supplements in various European countries. Food Nutr Res 2009: 53: doi 10.3402/fnr.v53i0.2038.
7. *Gapys B, Raszeja-Specht A, Bielarczyk H.*: Role of zinc in physiological and pathological processes of the body. Journal of Laboratory Diagnostics. 2014; 50 (1): 45-52
8. *Glibowski P, Misztal A.*: Wpływ diety na samopoczucie psychiczne. Bromat Chem Toksykol 2016; 49(1): 1-9 (in Polish) .
9. *Gruber BM.*: Witaminy pamięci. Aktualn Neurol 2009; 9(1): 52-56 (in Polsih).
10. *Hakkarainen R, Partonen T, Haukka J, Virtamo J, Albanes D, Lönnqvist J.*: Food and nutrient intake in relation to mental wellbeing. Nutr J 2004; 3(14) doi: 10.1186/1475-2891-3-14
11. *Hashimoto M, Maekawa M, Katakura M, Hamazaki K, Matsuoka Y.*: Posisibility of Polyunsaturated Fatty Acids for the Prevention and Treatment of Neuropsychiatric Illnesses. J Pharmacol Sci 2014;124(3):294-300.
12. *Hogenelst K, Sarampalis A, Leander NP, Müller BCN, Schoevers RA, Rot M.*: The effects of acute tryptophan depletion on speech and behavioural mimicry in

individuals at familial risk for depression. Journal of Psychopharmacology 2016; 30(3): 303–311.
13. *Jankowska-Kulawy A, Bielarczyk H, Ronowska , Bizon-Zygmańska D, Szutowicz A.:* Zaburzenia metabolizmu energetycznego mózgu w stanach niedoboru tiaminy. Diagn Lab 2014; 50(4): 333-338 (in Polish).
14. *Keller HH, Bocock MA*.: Nutrition and dementia: clinical considerations for identification and intervention. Neurodegenerative Disease Management. 2011; 7(1): 513-522.
15. *Kennedy David O*.: B Vitamins and the Brain: Mechanisms, Dose and Efficacy--A Review. Nutrients 2016; 8(2): 68-98.
16. *Kochman K*.: Key role of omega-3 and omega-6 fatty acids in human biology; crawford`s predictive theory of evolution. Postępy Biologii Komórki 2012; 38(2): 189-198 (in Polish) .
17. *Koszowska A, Ditteld A, Zubelewicz-Szkodziwska B.:* Psychologiczny aspekt odżywiania oraz wpływ wybranych substancji na zachowania i procesy myślowe. Hygeia Public Health 2013; 48(3): 279-284 (in Polish).
18. *Laurin D. Foley DJ. Masaki KH*.: Vitamin E and C supplements and risk of dementia. *JAMA.* 2002;288(18):2266-2268.
19. *Leszczyńska T. Pisulewski PM*.: Wpływ wybranych składników żywności na aktywność psychofizyczną człowieka. Żywność Nauka Technologia Jakość 2004; 1(38): 12-24 (in Polish).
20. *Lizak-Nitsch M*.: Rola noradrenaliny i serotoniny w modulacji funkcji mózgu i ich znaczenie dla snu człowieka. 2011; Sympozja I: Neurokognitywistyka w patologii i zdrowiu 2009-2011. Annales Academiae Medicae Stetinensis 2011(in Polish).
21. *Magierski R, Antczak-Domagała K, Sobów T*.: Dieta jako czynnik protekcyjny otępienia. Aktual Neurol 2014; 14(3): 167-174 (in Polish).
22. *Materac E, Marczyński Z, Bodek KH*.: Rola kwasów tłuszczowych omega -3 i omega -6 w organizmie człowieka. Bromat Chem Toksykol 2013; 46 (2): 225-233 (in Polish).
23. Michalak S. Zaburzenia metabolizmu węglowodanów a układ nerwowy. Pol Przegl Neurol 2009; 5(1): 13-22 (in Polish).
24. *Mitchell ES, Conus N, Kaput J*.: B vitamin polymorphisms and behavior: evidence of associations with neurodevelopment, depression, schizophrenia, bipolar disorder and cognitive decline. Neurosci Biobehav Rev 2014; 47: 307-320.
25. *Morris G, Berk M, Carvalho A, Caso JR, Sanz Y, Walder K, Maes M.:* The Role of the Microbial Metabolites Including Tryptophan Catabolites and Short Chain Fatty Acids in the Pathophysiology of Immune-Inflammatory and Neuroimmune Disease. Mol Neurobiol 2016, DOI: 10.1007 / s12035-016-0004-2.
26. *Morris MC, Evans DA, Bienias JL.:* Consumption of fish and n-3 fatty acids and risk of incident Alzheimer disease. Arch Neurol 2003; 60(7): 940-946.
27. *Murakami K, Miyake Y, Sasaki S, Tanaka K, Arakawa M*.: Fish and n-3 polyunsaturated fatty acid intake and depressive symptoms: Ryukyus Child Health Study. Pediatrics 2010; 126(3): 623-630.
28. *Nowak JK*.: The role vitamin D in disorders of the central nervous system. Neuropsychiatria i Neuropsychologia. 2012; 7(2): 85-96 (in Polish).
29. *Parker G, Brotchie H*.: 'D' for depression: any role for vitamin D? 'Food for Thought' II Acta Psychiatr Scand 2011; 124(4): 243-2499 .
30. *Pawełczyk T*.: The role of omega-3 polyunsaturated fatty acids in the etiopathogenesis and treatment of psychiatric disorders. Farmakoterapia w Psychiatrii i Neurologii. 2010; 26 (2): 71-77(in Polish).
31. *Sathyanarayana Rao TS, Asha MR, Ramesh BN, Jagannatha Rao KS*.: Understanding nutrition, depression and mental illnesses. Indian J Psychiatry 2008; 50(2): 77–82.
32. *Strasser B, Gostner JM, Fuchs D*.: Mood, food, and cognition: role of tryptophan and serotonin. Curr Opin Clin Nutr Metab Care. 2016; 19(1): 55-61.

Received: 04.07.2017
Accepted: 05.11.2017