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REVIEW ARTICLE / ПРЕГЛЕДНИ РАД

# Lipids in the diet of children and adolescents

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**SUMMARY**
Lipids are macronutrients with multiple roles in adequate growth and development, as well as in maintaining health in other phases of life. In addition to being, along with carbohydrates, the main source of calories, lipids are indispensable structural and functional constituents of the human body. Their intake must be complete and adjusted to optimal needs, which differ in quantitative terms during different phases of growth and development. Of particular importance are meeting the needs for essential and semi-essential fatty acids and strictly adhering to the upper limits of permissible intake of saturated fatty acids, cholesterol, and trans fatty acids.
**Keywords:** lipids; physiological role; optimal needs; children and adolescents

## INTRODUCTION

Lipids, along with proteins and carbohydrates, are among the macronutrients of the human diet. In addition to being an important source and reservoir of energy, lipids are essential structural and functional factors of the human body and, as such, are responsible for numerous physiological processes [1–5]. Inadequate fat balance during the developmental period has numerous consequences, such as energy deprivation and essential fatty acid deficiency in celiac disease, cystic fibrosis, and cholestatic syndrome, or obesity, secondary hyperlipidemia, and a tendency to cholelithiasis in conditions of excessive intake [6–13].

This article, along with a review of the dietary content, digestion, absorption, and basic physiological roles of lipids, provides current guidelines for their optimal intake in childhood and adolescence.

## LIPIDS IN THE HUMAN DIET

About 90–95% of the lipids present in the standard human diet are triglycerides, with the remainder being phospholipids and cholesterol [1]. Triglycerides are esters of glycerol and fatty acids. According to chain length, fatty acids are classified as short-chain (≤ C6), medium-chain (C8–14), or long-chain (≥ C16); they may also be classified according to whether they contain an even or odd number of carbon atoms [1, 14]. The human diet is dominated by long-chain fatty acids with an even number of carbon atoms. Long-chain fatty acids are further differentiated into saturated and mono- and polyunsaturated. The monounsaturated fatty acids palmitoleic (C16:1, ω-7) and oleic (C18:1, ω-9) can be synthesized in the human body, while the essential fatty acids linoleic (C18:2, ω-6) and alpha-linolenic (C18:3, ω-3) must be ingested through food [15]. The main sources of essential fatty acids are foods of plant origin, because plants, unlike animals, possess Δ12-desaturase in their chloroplasts, which converts oleic acid into linoleic acid, as well as Δ15-desaturase, which transforms linoleic acid into alpha-linolenic acid [16, 17]. Although plant foods are, in general, low in fat, there are certain plant varieties from which oils rich in linoleic and alpha-linolenic acids, as well as other unsaturated fatty acids, are obtained by appropriate technological procedures. During the process of successive elongation and desaturation of essential fatty acids, which is almost completely carried out in the liver, long-chain polyunsaturated fatty acids (LCPUFA) are formed, which have ≥ 20 carbon atoms and ≥ 2 double bonds [1]. However, the capacity for endogenous synthesis of the final components of ω-3 LCPUFA, i.e., docosahexaenoic acid (DHA, C22:6, ω-3) and eicosapentaenoic acid (EPA, C20:5, ω-3), is insufficient not only in infants but also at other ages, so the intake of preformed EPA and DHA with food or in the form of supplements is necessary to meet physiological needs [15, 18–22]. This also applies to arachidonic acid (C20:4, ω-6), which is also a semi-essential nutrient within the first few months after birth [23]. According to the spatial arrangement of hydrogen atoms around the double bond of the carbon chain, cis and trans unsaturated fatty acids are further distinguished. Trans fatty acids, identically to

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saturated ones, are characterized by a rigid linear structure, a high melting point, and high atherogenic potential [24–27]. In addition, some studies suggest that excessive intake of trans fatty acids (> 1% of total energy intake) is a risk factor for developing insulin resistance and breast, prostate, and colon cancers [24, 25]. In milk, dairy products, and ruminant meat, trans fatty acids make up 4–6% of all fatty acids [28]. However, during the thermal processing of food, and especially during the hydrogenation of vegetable oils into margarine, a large part of cis fatty acids, sometimes as much as 60%, is converted to trans isomers [28]. Due to transplacental and transmammary transfer and possible damage to the developing brain, intake of trans fatty acids should be minimized among pregnant and breastfeeding women, as well as children, especially during the first 2–3 years of life [24, 28].

Phospholipids are complexes of diacylglycerol and inositol, choline, serine, or ethanolamine linked by a phosphate group. The exception is sphingomyelin, which contains sphingosine instead of glycerol. As key components of the cell and subcellular membranes of all eukaryotes, phospholipids are present in foods of plant and animal origin.

Cholesterol is the main animal sterol, while the main sterol in fungi is ergosterol, and in plants sitosterol. Cholesterol is synthesized in the body from acetyl-CoA, primarily in the liver, and is partly ingested with animal food. Dietary cholesterol is primarily (85–90%) absorbed in free form and, to a lesser extent, as esters with fatty acids.

Tables 1–3 show the quantitative and qualitative fat content of some foods [29–34].

Plant foods are characterized by the absence of cholesterol, with the exception of palm and coconut oil, the predominant content of unsaturated fatty acids and, except for algal oil, a complete lack of LCPUFA. Also, the level of EPA and DHA in animal food from land is much lower than in food of the same species from water, especially marine [35].

**Table 1.** Triglyceride and cholesterol content in certain types of food [29, 30]

| Type of food | Triglycerides (g/100 g) | Ratio of saturated to unsaturated fatty acids | Cholesterol (mg/100 g) |
|---|---|---|---|
| Human milk* | 3.5–4.5 | 0.34–0.47:1 | 9–15 |
| Cow's milk | 3.6–3.88 | 1.7–2.3:1 | 5–15 |
| Cheese (full-fat) | 23–32 | 1.8–2.1:1 | 70–100 |
| Chicken egg yolks | 31–33 | 1.8–1.1:1 | 1070–1700 |
| Chicken liver | 4–6.2 | 0.93:1 | 429–555 |
| Chicken meat (with skin) | 6.2–11.2 | 0.55–0.62:1 | 60–91 |
| Beef (brisket) | 1.55–3 | 2.32:1 | 70 |
| Pork (lean) | 1–2.8 | 0.34:1 | 65–77 |
| Sardine | 1.2–9.81 | 0.43:1 | 142 |
| Salmon | 12.5–16.5 | 0.28:1 | 35–52 |
| Catfish | 1.58–4.3 | 0.1:1 | 33 |

*According to reference [29]

**Table 2.** Linoleic and α-linolenic acid content in vegetable and animal fats (mg/100 g) [31, 32]

| Dietary source | Linoleic acid | α-linolenic acid | Ratio |
|---|---|---|---|
| Linseed oil | 24,000 | 47,000 | 1:2 |
| Soybean oil | 53,400 | 7600 | 7:1 |
| Olive oil | 8000 | 950 | 8:1 |
| Corn oil | 50,000 | 900 | 55:1 |
| Sunflower oil | 60,200 | 500 | 120:1 |
| Pork fat | 8600 | 1000 | 8.6:1 |
| Tallow | 2580 | 190 | 13.6:1 |

**Table 3.** Content of basic ω-3 long-chain polyunsaturated fatty acids in food (mg/100 g) [33, 34]

| Dietary source | EPA | DHA |
|---|---|---|
| Sardine | 763 | 1292 |
| Herring | 909 | 1105 |
| Salmon | 862 | 1104 |
| Tuna | 91 | 328 |
| Catfish | 20 | 69 |
| Fish oil | 27,050 | 900 |
| Microalgae oil | 15,000 | 30,000 |
| Human milk | 0.47–0.53 | 3.51–5.52 |
| Infant formula | 0.45–0.55 | 6.81–6.88 |
| Egg | 0 | 58 |
| Chicken | 10 | 20 |
| Beef | 2 | 3 |
| Pork | 0 | 2 |

DHA – docosahexaenoic acid; EPA – eicosapentaenoic acid

## DIGESTION AND ABSORPTION OF LIPIDS

Digestion and absorption of fat occur primarily in the small intestine. Triglycerides are hydrolyzed by pancreatic lipase, phospholipids by phospholipase 2, and cholesterol esters by cholesterol esterase. Under the action of sublingual and gastric lipase, most of the short- and medium-chain triglycerides are hydrolyzed and absorbed in the stomach [36, 37, 38]. In breastfed infants, milk lipase also makes an important contribution to the digestion of triglycerides [36]. After hydrolysis, fatty acids and cholesterol are absorbed and transported into the bloodstream via the lymphatic system as part of chylomicrons [37, 38]. In addition to pancreatic lipase, colipase, and an optimal pH, an optimal amount of bile acids and salts is required for normal digestion and absorption of fats [37, 38]. The exceptions are short-chain and medium-chain triglycerides, which are water-soluble and, independent of bile acids and salts, either in hydrolyzed or intact form, pass directly into the bloodstream [36, 38].

## PHYSIOLOGICAL ROLE OF LIPIDS

Lipids are essential structural and functional factors of the human body. Triglycerides, along with carbohydrates, are the main source of energy. In addition, they are the main reservoir of energy and indispensable carriers of numerous physiological functions. The role of phospholipids and cholesterol lies in their universal presence in the cellular and subcellular membranes of all eukaryotes [39, 40]. Cholesterol is a precursor of steroid hormones and bile acids and a basic component of myelin [41, 42]. Essential fatty acids have multiple important roles. Unlike other fatty acids, their primary role is related to the synthesis of

**Table 4.** Basic guidelines regarding fat intake in the diet of children and adolescents [45, 46, 47]

| Component | Recommended intake |
|---|---|
| Total fat (share of total caloric value of food) | 0–1 year: 40–50%<br>2–3 years: 30–35%<br>4–18 years: 25–35% |
| Essential fatty acids | 7–10% (ω-6:ω-3 ~ 5–10:1) |
| Saturated fatty acids | < 10% |
| Trans fatty acids | < 1% |
| Cholesterol | < 300 mg daily |

**Table 5.** Recommended daily intake of ω-3 long-chain polyunsaturated fatty acids in food (WHO/FAO, 2008) [49]

| Age | DHA | EPA + DHA |
|---|---|---|
| 0–6 months | 0.1–0.18% of total energy intake | |
| 6–24 months | 10–12 mg/kg | |
| 2–4 years | | 100–150 mg |
| 4–6 years | | 150–200 mg |
| > 6 years | | 200–250 mg |

DHA – docosahexaenoic acid; EPA – eicosapentaenoic acid

LCPUFA, mostly DHA and arachidonic acid (C20:4, ω-6), which are part of the membrane phospholipids of cells of the central nervous system and retina [15, 20, 23]. When present in adequate amounts, with the highest concentrations in the neurocytes of the gray matter of the frontal lobe of the brain, photoreceptor cells of the macula, and interneural synapses, these LCPUFA fractions, especially DHA, ensure optimal mental and visual function [22, 23, 43]. In addition, LCPUFA are precursors of tissue hormones (eicosanoids), prostanoids, leukotrienes, lipoxins, and others, which play an irreplaceable role in numerous processes at the cellular and tissue levels [22, 23]. DHA is also a precursor of the anti-inflammatory neuroprotectors, protectins, resolvins, and maresins [20, 44].

## PHYSIOLOGICAL NEED FOR LIPIDS

Recommendations from the Institute of Medicine of the United States, the American Heart Association, and the United States Department of Health and Human Services regarding the proportion of fat in the diet are given in Table 4 [45, 46, 47]. Both the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) recommend that saturated fatty acids and trans fatty acids account for less than 10% and less than 1% of total energy intake, respectively [47, 48, 49]. Considering the limited capacity for endogenous conversion of alpha-linolenic acid into EPA and DHA, recommendations are given regarding their optimal intake (Table 5) [49]. Identical or similar recommendations are followed by other relevant international and national institutions and associations [15, 50].

## CONCLUSION

Lipids are among the three basic components of the human diet. They are an important source of energy and essential structural and functional constituents of the human body. Their intake must be adapted to optimal needs, which differ quantitatively during different stages of growth and development. Of particular importance are meeting the needs for essential and semi-essential fatty acids and strictly adhering to the permitted intake limits of saturated fatty acids, cholesterol, and trans fatty acids.

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**Ethics:** The authors declare that the article was written in accordance with the ethical standards of the Serbian Archives of Medicine as well as those of each author's medical institution.

**Conflict of interest:** None declared.

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**САЖЕТАК**

Липиди су макронутријенти од вишеструког значаја за адекватан раст и развој, као и очување здравља у осталим фазама живота. Сем што су, уз угљене хидрате, основни извор калорија, липиди су неизоставни структурни и функционални конституенти организма. Њихов унос мора бити комплетан и прилагођен оптималним потребама, које се у квантитативном погледу разликују током различитих фаза раста и развоја. Посебан значај има задовољавање потреба за есенцијалним и семиесенцијалним масним киселинама, као и стриктно поштовање горње границе дозвољеног уноса засићених масних киселина, холестерола и трансмасних киселина.

**Кључне речи**: липиди; физиолошка улога; оптималне потребе; деца и адолесценти