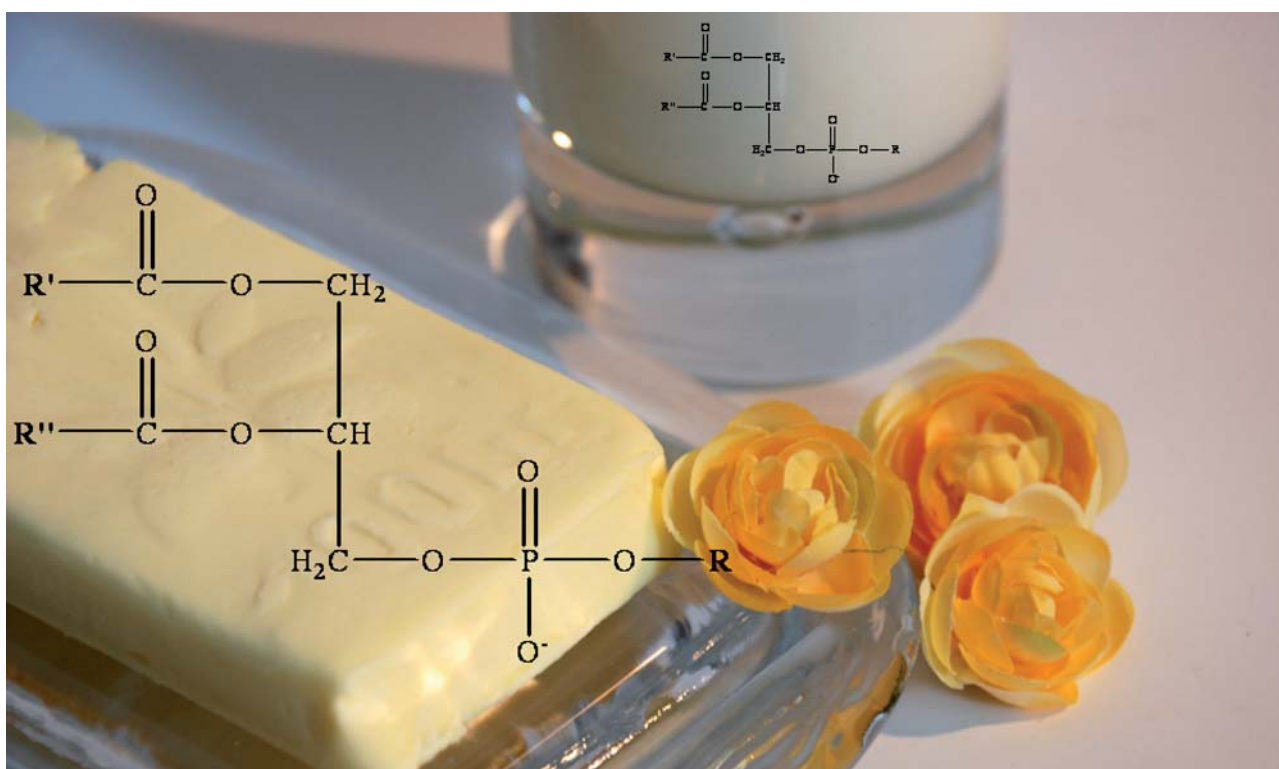


IMPACT OF DIETARY PHOSPHOLIPIDS ON HUMAN HEALTH

Technical-scientific information



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Title

Impact of dietary phospholipids on human health

Picture on cover

Milk and dairy products contribute to the daily intake of the different phospholipids, Photo: Alexandra Schmid, ALP

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Author

Karin Wehrmüller

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Forschungsanstalt Agroscope Liebefeld-Posieux (ALP)

Schwarzenburgstrasse 161

CH-3003 Bern

Phone +41 (0)31 323 84 18

Fax +41 (0)31 323 82 27

http: www.alp.admin.ch

e-mail: science@alp.admin.ch

Contact

Karin Wehrmüller

e-mail karin.wehrmueller@alp.admin.ch

Phone +41 (0)31 325 30 31

Fax +41 (0)31 323 82 27

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IMPACT OF DIETARY PHOSPHOLIPIDS ON HUMAN HEALTH

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1. Abstract

Phospholipids are ubiquitous in nature and are essential for the lipid bilayer of cell membranes. Their structural and functional properties are pivotal for the survival of the cell. Although phospholipids are present in almost all foods, egg, soybeans, milk, and other dairy products are especially good sources. The quantities consumed are not well defined. Though dietary phospholipids may not be essential for the survival of healthy adults, they probably have various impacts on health. The fatty acids consumed as phospholipids are often discussed in the literature. However, the head group and the phospholipid molecules themselves also have different properties, which are sometimes neglected. This review focuses on the effects of phospholipids (with emphasis on phosphatidylcholine and -serine) on the liver, plasma cholesterol, the brain and cognition and the capacity for exercise. In particular, the prevention of dementia and the improvement of exercise capacity are areas where dietary supplements based on phospholipids are heavily marketed. But is it always justified? The aim of this study is to review the scientifically proven impacts of phospholipids on health.

Phospholipids were long assumed to be cholesterol-lowering agents; this was proved to be incorrect, but they may have other anti-atherogenic properties. It was thought that the symptoms of dementia could be ameliorated by enhancing cholinergic precursors such as phosphatidylcholine and choline, and thereby leading to elevated acetylcholine levels in brain. Newer data, however, indicate that the acetylcholine turnover in brain is not affected by phospholipid intake, and therefore no amelioration in cognitive symptoms of dementia occurs. Although some putative influences of phospholipids remain controversial, overall they are likely to have a positive effect on human health.

2. Introduction

In the nineteenth century, the French scientist Maurice Gobley isolated a phosphorus-containing lipid from egg yolk and brain and called it "lekithos" after the Greek word for "egg yolk." He showed that glycerophosphoric acid could be prepared from lecithin and later proposed a structure for the molecule, based on his research [1,2].

Phospholipids are phosphoric, amphiphilic (chemical compounds possessing both a hydrophilic and a hydrophobic nature) lipids and are constituents of membrane lipids. They make up the main component of the lipid bilayer of biomembranes. Many discoveries have shown that phospholipids are not limited only to being structural components of the cell membrane. Phospholipids help carry out the functions of the membranes and regulate biological processes such as signaling, as well as being involved in metabolic and neurologic diseases [3].

As a constituent of all cells, phospholipids are also present at different concentrations in various foods. Phospholipids have been used for a long time in the food industry as emulsifiers or emulsion stabilizers. Recent evidence has found that phospholipids from food have positive effects on human health. Diverse beneficial health effects have been ascribed to the whole phospholipid mixture as well as to individual phospholipids. Defined phospholipids exhibit well-documented nutritional and/or therapeutic benefits [4,5].



The large amounts of phospholipids in eggs indicate that phospholipids are very important for life and development

Abbreviations list

AI	Adequate intake
HDL	High density lipoprotein
IOM	Institute of Medicine and National Academy of Sciences
MFGM	Milk fat globule membrane
PC	Phosphatidylcholine
PE	Phosphatidylethanolamine
PI	Phosphatidylinositol
PS	Phosphatidylserine
SM	Sphingomyelin
TG	Triglyceride
VLDL	Very low density lipoprotein

3. Definition of phospholipids

Phospholipids may be divided into two main groups: glycerophospholipids, which are reviewed in this article and the sphingophospholipid sphingomyelin that is discussed elsewhere [6]. In this review glycerophospholipids will be termed phospholipids.

Phospholipids are complex, polar lipids that are made up of a glycerol backbone, two fatty acids (R' and R'') that are esterified at positions sn-1 and sn-2, and a head group R at position sn-3 (figure 1). Thus, phospholipids are triglycerides in which one fatty acid is substituted by a phosphorus-containing head group, R. The non-polar fatty acids and the polar head group contribute to the amphiphilic character of phospholipids. Depending on their polar head group, phospholipids may be subdivided into different classes [7]. The head group R determines the type of phospholipid as well as its bioactivity. The fatty acids at sn-1 and sn-2 (R' and R'') differ depending on their source (figure 2). The chain length, in particular, and the degree of saturation contribute much to the physicochemical properties of phospholipids and also differ depending on their origin.

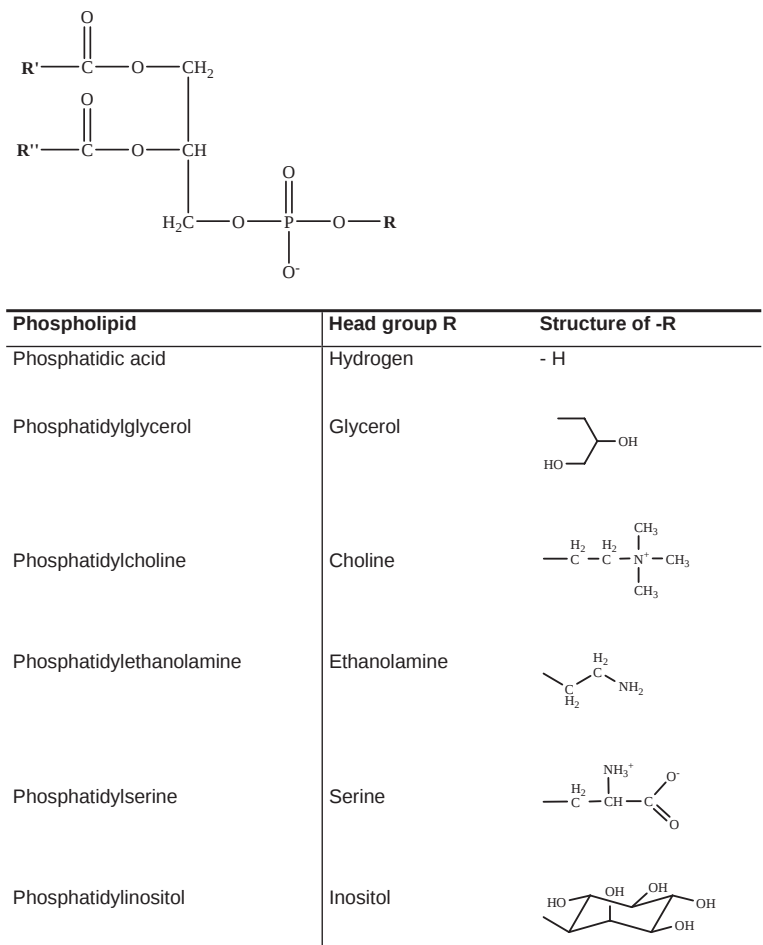


Figure 1: Chemical structure and classification of glycerophospholipids according to their polar head group R (R', R'': esterified fatty acids)

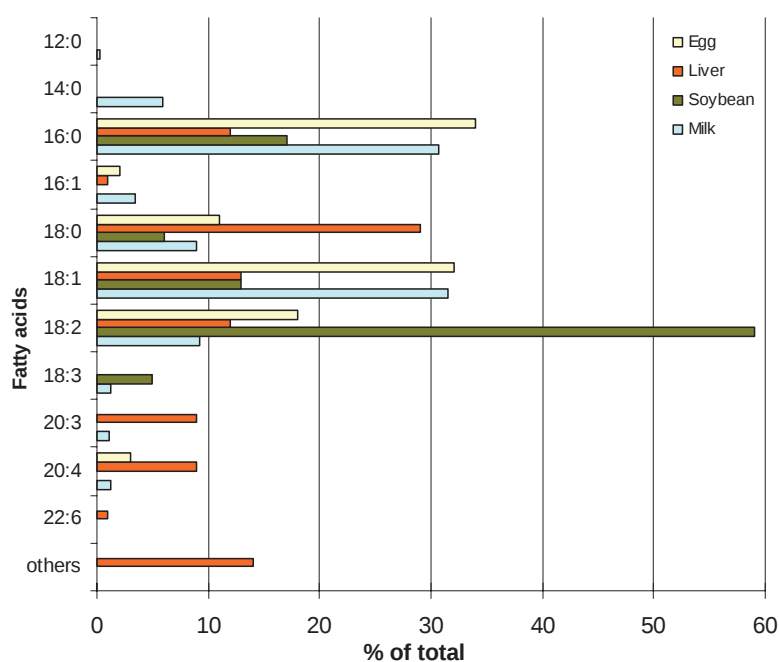


Figure 2: Distribution of fatty acids of phosphatidylcholine from different sources
 Egg, Liver, Soybean: Avanti® Polar Lipids, Inc. Alabaster, Alabama / Milk: Bitman & Wood 1990 [12], average of lactation days 7, 42 and 180.

Phospholipids are ubiquitous in nature and are essential for the lipid bilayer of cells [7]. Their structural and functional properties are pivotal for the survival of the cell. The preferred structure of phospholipids in an aqueous medium is a lipid bilayer, which is also found in cell membranes (figure 3). These bilayers are of great biological importance and assemble spontaneously.

Historically the term “lecithin” was used by Gobley to describe phospholipids from egg yolk and brain. The food additive lecithin E322 is a mixture of phosphoglycerides containing for the most part phosphatidylcholine and is normally isolated from soybean or egg yolk. Chemically, the term lecithin is defined as phosphatidylcholine [8]. Because the term lecithin is not used consistently in the literature, it will be avoided in this article.

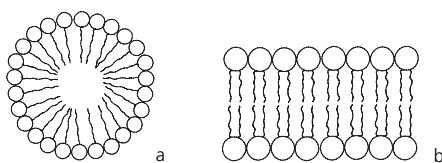


Figure 3: Structure of a micelle (a) and a lipid bilayer (b)

4. Sources of phospholipids

Phospholipids are present in almost all foods in human nutrition. They accumulate in cell membranes, so therefore foods with cell membranes contain phospholipids [9]. Soybean is an excellent source of phospholipids; other high-quality sources are eggs, offal, milk and other dairy products, and some vegetables. When lecithin is used as an additive (emulsifier), the quantities in food products are too low to play any role in nutrition [5].

4.1 Phospholipids in eggs

Eggs are the first stage of a bird's life and therefore must provide all the nutrients for the developing and growing embryo. Despite their poor reputation with respect to their fatty acid composition and high cholesterol level, eggs are a very nutritious food. The large amounts of phospholipids in eggs indicate that phospholipids are very important for life and development.

One chicken egg (50 g) contains approximately 1.75 g phospholipids. This is about one third of the total lipids in an egg. It is mostly the egg yolk that provides these phospholipids: 100 g of egg yolk contains 10.3 g phospholipids [10]. This is also the reason why egg yolk has excellent emulsifying properties and is regularly used as an adjuvant in home cooking or commercial food production. The distribution of egg phospholipids is given in figure 4.

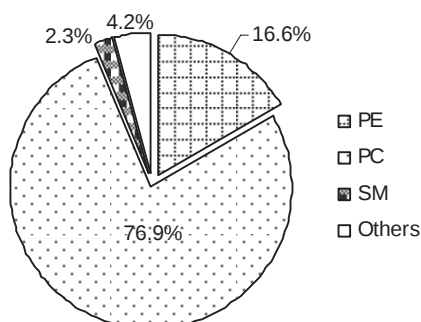


Figure 4: Distribution of phospholipids in whole, fresh chicken eggs [11]. Abbreviation: PE Phosphatidylethanolamine, PC Phosphatidylcholine, SM Sphingomyelin

4.2 Phospholipids in soybean

Because of the high content of phospholipids in soybeans, which are readily available, they are often used as raw material to produce dietary supplements as well as emulsifiers for food processing. Soybean phospholipids are extracted from the sludge left after crude soy oil goes through a degumming process. Compared with eggs, soybeans contain more fat (18.3 g per 100 g), but less phospholipids (1.8 g per 100 g food or 9.7 g per 100 g fat) [10]. Yet, it is the best vegetarian source of phospholipids and the amounts are higher than in most other foods (figure 5).

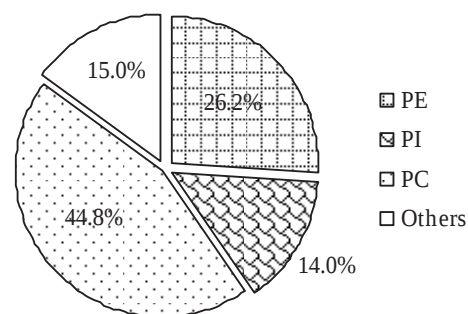


Figure 5: Distribution of phospholipids in dried soybean seed [11]. Abbreviation: PE Phosphatidylethanolamine, PI Phosphatidylinositol, PC Phosphatidylcholine

4.3 Phospholipids in milk

Milk and dairy products are described as examples of foods that contain phospholipids as an important functional ingredient. Phospholipids in milk are enriched in the milk fat globule membrane, in which approximately 60 % of the total phospholipids are embedded [11]. The hydrophobic components of the fatty acids face towards the centre of the milk fat globule, which contains triglycerides, whereas the hydrophilic part faces the aqueous phase. Being amphiphilic molecules, phospholipids act as natural emulsifiers and stabilize milk as an emulsion of two phases. There are also free phospholipids in the aqueous phase of the milk.

The concentration of phospholipids in milk varies, but not only as a result of analytical differences. Natural factors influencing the phospholipid concentration in milk are the stage of lactation, feeding, season and breed. Triglycerides are relatively constant during lactation. By contrast, the level of phospholipids declines with advancing lactation [12].

The distribution of the phospholipids in whole milk is given in figure 6. The amount of polar lipids in whole milk ranges between 13 and 40 mg polar lipids per 100 g milk. If calculated as a proportion of total fat, it ranges between 320 and 1000 mg polar lipids per 100 g fat (table 1). When polar lipids are expressed as mg per 100 g fat, the polar lipids present in the aqueous phase are ignored. Recent research has shown, however, that there is no correlation between the fat content and the sphingolipid content of dairy products [17]. Because phospholipids have similar amphiphilic properties to sphingolipids, the phospholipid content of dairy products is also unlikely to be correlated with the fat content of the product.

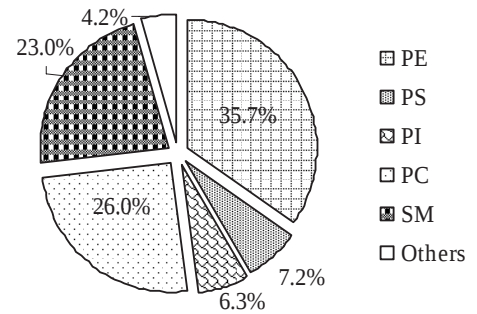


Figure 6: Distribution of phospholipids in milk as measured by HPLC-ELSD (average of Avalli and Contarini 2005 [13], Christie et al. 1987 [14], Fagan and Wijesundera 2004 [15], Rombaut et al. 2005 [16] and Rombaut et al. 2006 [17]. Abbreviation: PE Phosphatidylethanolamine, PS Phosphatidylserine, PI Phosphatidylinositol, PC Phosphatidylcholine, SM Sphingomyelin

Table 1: Comparison of the total polar lipid (phospho- and sphingolipids) content of milk

Author	mg PL/ 100 g milk 2)	mg PL/ 100 g fat
Avalli & Contarini 2005 [13]	9.4 ¹⁾	359 ³⁾
Bitman & Wood, 1990 [12]	35.4 ⁴⁾	888 ¹⁾
Bitman & Wood, 1990 [7]	12.8 ⁵⁾	320 ¹⁾
Christie et al. 1987 [14]	22.8	575 ¹⁾
Fagan & Wijesundera, 2004 [15]	24.2	605 ¹⁾
Rombaut et al. 2005 [16]	29.4	725 ¹⁾
Rombaut et al. 2006 [16]	40.0	1000 ¹⁾
Souci et al. 2000 [10]	32.2	875 ¹⁾

¹⁾ Calculated on the assumption that whole milk contained 4 % fat per 100 mg milk and PL were only present in the fat fraction

²⁾ A conversion factor of 1 g per ml was used

³⁾ Milk in vat with a fat content of 2.6%

⁴⁾ At lactation day 7

⁵⁾ At lactation day 180

5. Phospholipids in the human diet

The quantities of phospholipids in the human diet are not fully known. The total phospholipid intake of eight healthy Swedish women ranged from 1.5 to 2.5 mmol per day. Of the total dietary fatty acids, 13 to 33 mg/g were consumed as phospholipids [18].

Further research has been carried out on the consumption of phosphatidylcholine and its head group choline. Zeisel et al. [19] estimated that the adult population in the United States consumes about 6 g of phosphatidylcholine per day. Phosphatidylcholine consists of approximately 13 % choline by weight [20], and this corresponds to 0.6 to 1.0 g choline per day. According to Fischer et al., the total daily choline intake in the United States amounts to 8.4 ± 2.1 mg/kg bodyweight in men and 6.7 ± 1.3 mg/kg bodyweight in women [21]. Thus men consume more than the adequate intake (AI) (table 2), whereas women consume slightly below the AI [21]. The current intake is, however, likely to be lower, because many people have reduced their consumption of high-cholesterol and fatty foods such as eggs, meat, and dairy products that are rich sources of phosphatidylcholine and choline [20].

The levels of dietary choline and phosphatidylcholine influence their concentrations in plasma [19]. Consumption of a choline-deficient diet for three weeks resulted in a decrease in plasma phosphatidylcholine and choline levels of approximately 30 % [22]. Whether a decreased plasma level has any impact on the corresponding level in the brain is controversial (see section 5.4).

Because there is an endogenous pathway for the de novo biosynthesis of choline via methylation of phosphatidylethanolamine, it is considered to be dispensable in the human diet [23]. Humans fed total parenteral nutrition solutions without choline, however, develop fatty liver and liver damage, which reverses when dietary choline is added [24-26]. These results suggest that the de novo synthesis of choline is not always sufficient to meet human requirements and that a dietary source might be essential for humans [22,27]. A true choline deficiency is probably very rare except where it is induced on purpose in a research setting or during total parenteral nutrition. Nevertheless, choline was identified in 1998 as a required nutrient for humans and an adequate intake was recommended by the Institute of Medicine and National Academy of Sciences (IOM) (table 2).

Table 2: Recommended adequate intake (AI) for choline by the institute of medicine and national academy of sciences (IOM) [28]

Population	Age	AI (mg/d)
Infants	0 to 6 months	152 (18 mg/kg)
	6 to 12 months	150
Children	1 – 3 years	200
	4 – 8 years	250
	9 – 13 years	375
Males	14 – 18 years	550
	> 19 years	550
Females	14 – 18 years	400
	> 19 years	425
Pregnancy	All ages	450
Lactation	All ages	550

5.1 Absorption

In the intestinal lumen, phospholipids from food are mixed with those from bile. Usually the biliary contribution is significantly higher than the dietary. However the metabolism of both dietary and biliary phosphatidylcholine is probably similar [29,30].

Luminal phosphatidylcholine is cleaved by the enzyme phospholipase A2 from the pancreatic juice into fatty acids and lyso-phosphatidylcholine [29-32]. The two breakdown products are absorbed across the intestinal mucosa.

Early studies in rats suggested that about half of the orally administered phosphatidylcholine is absorbed as lysophosphatidylcholine, whereas the other half is degraded to glycerophosphatidylcholine or phosphorylcholine and is taken up via the portal vein [33]. Other studies in animals have shown that up to 20 % of intact phosphatidylcholine may be absorbed [31]. A survey that used labeled 3H in choline and 14C in the two fatty acid residues demonstrated over 90 % absorption from the intestine for both isotopes; a large portion of the radio-activity from labeled oral phosphatidylcholine appeared in the phosphatidylcholine of plasma lipoproteins and red blood cells. The largest contribution was from lysophosphatidylcholine, which is produced by hydrolyzation of dietary phosphatidylcholine in the gut lumen and then resynthesized into phosphatidylcholine in the mucosa. It is also possible that a small part was derived from intact absorption [31].

Although phosphatidylserine is present in the diet and can be synthesized in the liver and intestinal cells, only trace amounts or none at all are recovered in plasma lipoproteins. Its contact with plasma is prevented by the distribution of this phospholipid in the inner layer of the plasma membrane. In line with current knowledge of the intestinal absorption of other phospholipids, it can be assumed that phosphatidylserine is hydrolyzed in the intestinal lumen to give lysophosphatidylserine. This phospholipid is absorbed and converted back to phosphatidylserine in the mucosal cells [34].

Decarboxylation in the mucosal intestinal cells and translocation into the inner layer of the erythrocyte plasma membrane prevent the contact of phosphatidylserine with plasma constituents. The appearance of phosphatidylserine in the plasma is followed by pharmacological effects due to the activation of cells participating in immune and inflammatory reactions. This may occur when phosphatidylserine is exposed on the surface of damaged cells, when lysophosphatidylserine is produced, or when this phospholipid is administered from exogenous sources. Lysoderivative generation may be required for absorption by the oral route, for transfer across the blood–brain barrier and for transient enrichments of phosphatidylserine in target cells [34].

6. Health impacts of phospholipids

Even though they may not be essential, phospholipids in food can have several health implications, for instance in liver disease, cholesterol control, cognition and brain development, or exercise capacity.

6.1 Phospholipids and liver diseases

Two important preventable causes of liver diseases are hepatitis viruses and excessive alcohol consumption. Fatty liver, alcoholic hepatitis and alcoholic cirrhosis are the three main types of alcohol-induced liver disease. Excessive accumulation of fat inside the liver cells leads to a fatty liver. Acute inflammation of the liver combined with the destruction of individual liver cells and scarring is called alcoholic hepatitis. Cirrhosis (fibrosis of the liver) results from damage to normal liver tissue, which leaves scar tissue and is often preceded by hepatitis and fatty liver (steatosis), independent of the inciting cause. Several viruses cause hepatitis; however, not all of these viruses cause severe disease. Some viruses, such as hepatitis B and C, may lead to outbreaks of hepatitis and sometimes necessitate liver transplantation.

There is evidence that phospholipids influence the course of liver disease that occurs in connection with excessive alcohol consumption. Phosphatidylcholine is effective in ameliorating or even curing liver disease. Several studies have been conducted to learn more about the effect of phosphatidylcholine on alcoholic liver disease. The first and most established study was that of Lieber et al. [35], which involved a 10-year trial using baboons. One group of baboons was fed a liquid diet supplemented with a soybean phospholipid extract (4.1 mg/kcal) that was high in polyunsaturated phosphatidylcholine plus either ethanol (50 % of total energy) or isocaloric carbohydrates. The control group was fed an equivalent amount of the same liquid diet (with ethanol or with carbohydrates) but devoid of the phospholipid extract. The two groups that received ethanol developed a comparable increase in plasma lipids; however, a significant difference was seen in the degree of cirrhosis. In a subsequent study it was determined that phosphatidylcholine was the active agent in the protection against alcohol induced liver disease. Again, baboons fed ethanol without phosphatidylcholine developed cirrhosis whereas those with phosphatidylcholine supplementation did not. Phosphatidylethanolamine, free fatty acids, or choline had no positive effect [36]. Dietary supplementation with polyunsaturated phosphatidylcholine in ethanol-fed rats also prevented alcohol-induced impairment of mitochondrial respiration and significantly attenuated the ethanol-induced increases in triglycerides and cholesterol esters, whereas it had no effect on the control animals [37]. A likely mechanism for the preventive effects of polyunsaturated phosphatidylcholine on fatty liver and hyperlipidemia is the inhibition of the ethanol-induced impairment of the capacity of the hepatic mitochondria to oxidize fatty acids. A decrease in mitochondrial fatty acid oxidation, and also

cytochrome oxidase activity, has been demonstrated in ethanol-fed animals [37,38]. Dietary phosphatidylcholine supplementation not only alleviates ethanol-induced liver damage, but a comparable impact has been achieved in hepatic steatosis induced by orotic acid [39] and in liver fibrosis caused by tetrachlormethane (CCl₄) but not that caused by iron [40].

One explanation of this effect is that phosphatidylcholine is an essential component of very low density lipoproteins (VLDL) [41]. Furthermore, triglycerides must be packaged as VLDL to be exported from the liver otherwise a fatty liver may develop.

6.2 Phospholipids and cholesterol management

The outcome of early studies that investigated the serum cholesterol lowering activity of phospholipids is controversial. Trials with animals showed a decrease in total cholesterol [42-46]. The addition of 3.4 % soybean phospholipids to the diet (as recommended by the American Heart Association) led to a greater decrease in non-high density lipoprotein (non-HDL) cholesterol, total cholesterol and triglycerides in the plasma, as well as a smaller aortic fatty streak area, than the same diet without the addition of phospholipids. The levels of fatty acids, choline, ethanolamine, inositol and glycerol were adjusted to balance the level of phospholipids.

The influence of different dietary sources of phospholipids on human serum lipoproteins was investigated by O'Brien and Andrews [47]. Treatment with the relatively saturated dietary egg phospholipids (given as capsules) did not lead to any improvement in blood lipid profiles. Phospholipids from soybean lowered total serum cholesterol in contrast to egg phospholipids; but so did a triacylglycerol mixture with a fatty acid composition similar to soybean phospholipids. Jiang et al. [42] also examined the effects of phosphatidylcholine from different origins on intestinal cholesterol absorption in rats with a lymph cannula. The cholesterol absorption in rats given egg phosphatidylcholine was lower than those given soybean phosphatidylcholine. The more saturated the fatty acids of phosphatidylcholine, the lower was the lymphatic absorption of cholesterol. Both trials indicate that the composition of the fatty acids is responsible for the cholesterol lowering effect. Studies that adjusted for linoleic acid in phospholipids demonstrated no additional cholesterol-lowering benefits from the phospholipid complex, which confirms the results of O'Brien and Andrews [47] and Jiang et al. [42]. Little or no further decrease in plasma cholesterol was found when trial diets were adjusted for the fatty acids in phospholipids [48,49]. The outcome of a cross-over study on healthy, normolipidemic men consuming moderate quantities of phosphatidylcholine was not promising [50]. The doubt whether phospholipids have any

significant influence on postprandial plasma lipoprotein levels in the context of a normal Swedish diet was confirmed. However, the dose of phospholipids administered exceeded the average daily amount of phosphatidylcholine in a normal Swedish diet [18]. It was concluded that, with a normal diet, no changes in postprandial plasma lipoprotein levels probably occur.

Thus phospholipids might not be of use as cholesterol-lowering agents, but they possibly have other anti-atherogenic properties. There are other important risk factors for cardiovascular disease in addition to total serum cholesterol level. Phospholipids decrease another risk factor that influences the progression of atherosclerosis in a beneficial manner: the ratio of total cholesterol to HDL cholesterol. Data suggest that soybean phospholipids selectively increase the levels of cardio-protective serum HDL cholesterol and serum phospholipids. The mechanism by which phospholipids increase HDL cholesterol is, however, not well understood. According to Childs et al., the effect on serum HDL cholesterol is independent of polyunsaturated fatty acids [48]. On the other hand, Oosthuyzen et al. did not find any effect on serum lipids, or on HDL [51].

6.3 Phospholipids and brain development

Choline is an important nutrient for the normal development of the brain [52]. During pregnancy and lactation requirements increase, thus an adequate intake is essential. Early dietary choline supplementation can cause long-term changes in brain function that lead to an improvement in cognitive processes in adulthood [53]. Rat pups born to mothers fed a choline deficient diet during the prenatal period had diminished memory function [54].

6.4 Phospholipids and cognition

Aging often entails impaired health. Age-associated cognitive decline is often even more distressing than the physical problems associated with aging. If the progressive decline in cognitive function goes beyond what is expected during normal aging, it is called dementia. With the growth in size of the elderly population, more and more people are at risk of developing dementia. Measuring cognitive function is a complex task. Parameters such as well-being are difficult to compare because of the patient's individuality and the subjectivity of many parameters. The same problem also occurs for the detection of nutrition-induced improvements in cognitive function.

Phospholipids account for approximately 20–25 % of the dry weight of an adult brain. Besides forming the backbone of the biomembrane, they also provide the dynamic membrane with a suitable environment, fluidity, and ion permeability that affect cognition positively [55].

Phosphatidylcholine and Choline

In patients with Alzheimer's disease there is decreased activity of the enzyme choline acetyltransferase in the hippocampus of the brain. As a consequence, the neurotransmitter acetylcholine is markedly reduced. This decrease is greater than that in normal aging [55,56]. It was long thought that the symptoms of Alzheimer's disease could be ameliorated by enhancing cholinergic precursors such as phosphatidylcholine and choline and therefore elevating the acetylcholine levels in the brain. However, dietary treatment with phosphatidylcholine or choline supplementation gave inconsistent results [53,55,57-59]. Although treatment with dietary phosphatidylcholine or choline supplementation increases plasma choline levels, recent results indicate that the acetylcholine level and turnover in the brain are not affected, and therefore no amelioration of the cognitive symptoms of dementia occurs [60,61].

Phosphatidylserine

There is better evidence that phosphatidylserine influences cognition. Phosphatidylserine plays an important role in the function and homeostasis of neuronal cell membranes. Phosphatidylserine is able to improve age-associated behavioral alterations in animal models, so it was thought that it may also have a positive impact on cognition in humans, particularly on those functions that are impaired during aging, such as memory and language achievement, as well as learning and concentration [62,63]. Therefore it was assumed that phosphatidylserine may be useful in the prevention and treatment of age-associated cognitive decline such as Alzheimer's disease, and in depression and other cognitive disorders [64].

Over the years, several trials have been conducted on human patients with Alzheimer's disease or other cognitive impairment, with inconsistent results [65-71]. Conclusions from clinical trials indicate that phosphatidylserine could possibly reduce the cognitive decline related to aging; however, to date there are no convincing data to prove its clinical effectiveness.

The cognition-enhancing properties of phosphatidylserine from bovine brain cortex, egg or soybean were compared in rats [72]. On the basis of this study, it was concluded that phosphatidylserine from soybean may have similar positive effects on cognition to that from bovine brain cortex. Phosphatidylserine from egg, conversely, led to no improvement in cognition. No data are available concerning the bioactivity of phosphatidylserine from milk or buttermilk.

Phosphatidylserine shows no known negative side effects and is well tolerated by the elderly population. There are no known interactions of phosphatidylserine from soybean with drugs, which is an important concern in elderly patients [73]. Gastrointestinal distress or insomnia are reported to occur, rarely, if phosphatidylserine is taken in a large dose (600 mg) just before going to bed [64,73,74].

6.5 Phospholipids and exercise capacity

There are different hypotheses to explain how decreases in phospholipids, in particular phosphatidylcholine and -serine, could be associated with fatigue and therefore limit the performance of long-lasting and exhausting physical exercise and mental tasks [75].

Phosphatidylcholine and choline

It appears, theoretically, that choline depletion, which occurs during prolonged exercise, could be involved in the progress of physical and mental fatigue as experienced by participants of stressful and exhausting training. Only a limited number of studies on the effects of choline supplementation on physical performance have been carried out. Phosphatidylcholine and choline supplementation have been shown to counteract a decrease in circulating choline levels during exercise. There are, however, very few data from well-controlled studies to support the beneficial effect of phosphatidylcholine or choline supplementation on performance or recovery [75]. The literature reports are also controversial regarding the observation that prolonged physical stress reduces plasma choline. Therefore, it is possible that there is no benefit in supplementing choline during strenuous exercise [76,77]. The combination of type, duration, and intensity of exercise might be an important determinant in this respect.

Phosphatidylserine

Two placebo-controlled trials have investigated the effect of a daily dose of 750 mg phosphatidylserine (from soybean) over 10 days [78,79]. In the first study [78], the cortisol response, perceived soreness, and markers of muscle damage and lipid peroxidation following exhausting running were not attenuated. The running time to exhaustion, however, tended to increase following supplementation. In ensuing further study Kingsley et al. [79] investigated the ergogenic properties of phosphatidylserine (ergogenic aids are external influences that can positively affect sporting performance). The supplementation had a significant effect on exercise time to exhaustion at 85 % of maximal oxygen intake (VO₂max). This was the first study to show increased exercise capacity with phosphatidylserine supplementation.

7. Conclusions

Phospholipids have several impacts on human health. As an integral component of cell membranes they are involved in cell signaling and are therefore indispensable for the communication and interaction between body cells. Although some influences of phospholipids on health are controversial, overall dietary phospholipids are most likely to have a positive effect on health. The technological properties of phospholipids as emulsifying agents and their isolation from natural sources such as soybeans, eggs and milk lead to their application as adjuvants in different food production processes.



Soybeans are the best vegetarian source of phospholipids.

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