Omega-3 polyunsaturated fatty acids and vegetarian diets

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Summary

- While intakes of the omega-3 fatty acid α-linolenic acid (ALA) are similar in vegetarians and non-vegetarians, intakes of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are low in vegetarians and virtually absent in vegans.
- Plasma, blood and tissue levels of EPA and DHA are lower in vegetarians than in non-vegetarians, although the clinical significance of this is unknown. Vegetarians do not exhibit clinical signs of DHA deficiency, but further research is required to ascertain whether levels observed in vegetarians are sufficient to support optimal health.
- ALA is endogenously converted to EPA and DHA, but the process is slow and inefficient and is affected by genetics, sex, age and dietary composition. Vegetarians can take practical steps to optimise conversion of ALA to EPA and DHA, including reducing intake of linoleic acid.
- There are no official separate recommendations for intake of fatty acids by vegetarians. However, we suggest that vegetarians double the current adequate intake of ALA if no direct sources of EPA and DHA are consumed.
- Vegetarians with increased needs or reduced conversion ability may receive some advantage from DHA and EPA supplements derived from microalgae. A supplement of 200–300 mg/day of DHA and EPA is suggested for those with increased needs, such as pregnant and lactating women, and those with reduced conversion ability, such as older people or those who have chronic disease (eg, diabetes).

Vegetarians have a lower overall risk of common chronic diseases, possibly due to a lower saturated fat and cholesterol intake than non-vegetarians.[1] However, vegetarians (and those who eat minimal amounts of oily fish) may be at a disadvantage where intake of essential fatty acids (EFAs) is concerned, and this could potentially counteract some health benefits of the vegetarian diet. In this article, we review EFA intake and status of vegetarians and consider whether current intakes in this population are sufficient to achieve and maintain optimal health. We also explore the potential benefits of adding supplemental sources of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) derived from microalgae, and make practical suggestions for optimising EFA status in vegetarians.

Functional and biological aspects of EFAs

Fats in foods and the body contain saturated, monounsaturated and polyunsaturated fatty acids (PUFAs), the latter comprising omega-6 (n-6) and omega-3 (n-3) families. There are two EFAs: linoleic acid (LA), the parent of the n-6 fatty acid family; and α-linolenic acid (ALA), the parent of the n-3 fatty acid family. EFAs cannot be synthesised by the body and therefore must be supplied by the diet. LA and ALA can be converted by enzymes into long-chain PUFAs.[2] LA is a precursor of arachidonic acid (AA), and ALA is a precursor of EPA, DHA and docosapentaenoic acid (DPA), with stearidonic acid (SDA) an intermediate in the pathway. The long-chain PUFAs are not technically "essential" because they can be produced endogenously, but they can become essential if insufficient precursor is available for their production.

AA and EPA act as substrates for eicosanoids (prostaglandins, thromboxanes, leukotrienes and prostacyclins) that regulate inflammation, platelet aggregation and blood clotting, blood vessel contraction and dilation, muscle contraction and relaxation, immune responses and regulation of hormone secretion. Eicosanoids from n-3 PUFA (3-series) have opposing effects to those from n-6 PUFA (2-series). Eicosanoids from AA are very potent and overproduction is associated with increased risk of disease (heart disease, cancer, diabetes, osteoporosis, and immune and inflammatory disorders).[2-4] Eicosanoids from EPA are less potent and have anti-inflammatory properties that assist in preventing coronary heart disease, hypertension, autoimmune diseases, arthritis and several cancers.[2-4] Extremely powerful mediators called protectins (derived from DHA) and resolvins (derived from DHA and EPA) help protect against and resolve inflammation.[5] Long-chain n-3 PUFAs also favourably affect cell membranes, enhancing intracellular signalling processes and gene expression. DHA is particularly abundant in the cerebral cortex, retina, testes and semen.[2,6,7]

LA and ALA share the same pathway and enzymes for conversion to long-chain PUFAs. An excess of LA, common in Western diets, can suppress conversion of ALA to EPA and DHA and increase production of AA. This in

Abbreviations

AA	arachidonic acid
AI	adequate intake
ALA	α-linolenic acid
DHA	docosahexaenoic acid
DPA	docosapentaenoic acid
EFA	essential fatty acid
EPA	eicosapentaenoic acid
LA	linoleic acid
n-3	omega-3
n-6	omega-6
PUFA	polyunsaturated fatty acid
SDA	stearidonic acid

turn can have significant adverse consequences for health.[2,8,9] The balance of LA and ALA can be even more precarious in vegetarian diets, as vegetarians largely rely on conversion for the production of long-chain n-3 PUFAs and their metabolites.[10,11] Other dietary factors associated with reduced conversion are *trans* fatty acids and excesses of alcohol and caffeine. Nutritional inadequacies such as protein deficiency or lack of vitamin and mineral cofactors, especially zinc, magnesium, niacin, pyridoxine and vitamin C, can diminish the activity of conversion enzymes.[12] Non-dietary factors that negatively affect conversion are genetics, sex (young males convert less efficiently than young females), advancing age, chronic disease (eg, diabetes, metabolic syndrome, hypertension and hyperlipidaemia) and smoking.[12,13]

Dietary sources of PUFAs

The n-3 PUFAs ALA and SDA originate from land plants, whereas EPA, DHA and DPA that occur in fish or other seafood originate from marine plants (eg, microalgae). The n-6 fatty acid LA originates from land plants, and AA originates from animal-based foods. Box 1 shows important dietary sources of PUFAs.

1 Dietary sources of omega-3 and omega-6 polyunsaturated fatty acids

Omega-3 polyunsaturated fatty acids

α-linolenic acid (ALA)
- Chia seed, chia oil
- Flaxseed, flaxseed oil
- Canola oil
- Walnut, walnut oil
- Hempseed, hempseed oil*
- Soybean, soybean oil
- Wheatgerm, wheatgerm oil
- Green leafy vegetables

Stearidonic acid (SDA)
- Echium oil
- Blackcurrant oil
- Genetically modified soybean oil†
- Genetically modified canola oil†

Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and docosapentaenoic acid (DPA)
- Microalgae (plant DHA and EPA), **not** blue-green algae
- Fish and other seafood, particularly oily fish
- Meat (from grass-fed animals)
- Eggs
- Breast milk
- Sea vegetables

Omega-6 polyunsaturated fatty acids

Linoleic acid (LA)
- Safflower seed, safflower oil
- Sunflower seed, sunflower oil
- Sesame seed, sesame seed oil
- Walnut, walnut oil‡
- Corn kernel, corn oil
- Wheatgerm, wheatgerm oil‡
- Soybean, soybean oil‡

Arachidonic acid
- Poultry and red meats
- Eggs
- Milk

* Not currently available in Australia as a food. † Regular soybean and canola oils are **not** sources of SDA. ‡ Walnuts, wheatgerm and soybeans are sources of both ALA and LA. ◆

EFA intake and status of vegetarians

While ALA intakes are similar among vegetarians, vegans and non-vegetarians, LA intakes tend to be somewhat higher among vegetarians and vegans.[14-18] In one study, vegetarians and vegans averaged 19.4 g/day of LA and 1.34 g/day of ALA compared with 13.1 g/day of LA and 1.43 g/day of ALA for meat eaters.[17] These findings are consistent with other research studies.[19] By excluding fish and other seafood, intakes of EPA and DHA are low in vegetarian diets and virtually absent in the vegan diet.

Plasma, blood and tissue concentrations of EPA and DHA are about 30% lower in vegetarians and 40%–50% lower in vegans than in non-vegetarians.[6,14,17,20] A large prospective study in the United Kingdom (196 meat-eaters, 231 vegetarians and 232 vegans) reported no change in long-chain n-3 PUFA status in vegetarians and vegans over time (< 1 year to > 20 years), suggesting that endogenous synthesis of EPA and DHA from ALA was sufficient to keep levels stable over many years.[6]

It is unknown whether the lower DHA levels reported in vegetarian and vegan populations have adverse consequences for health,[19] although increased platelet aggregation has been reported and is thought to be linked to poor n-3 status and high n-6 intake.[21] However, vegetarians tend to have more favourable results for other clotting factors, including factor VII and fibrinogen, and for fibrinolysis.[22-24] Regardless, low plasma levels of DHA are a potential concern, due to the importance of DHA for the development and maintenance of retinal and neural tissue, and its role as an indirect substrate for eicosanoids, resolvins and protectins.[14]

EFA requirements and adequate intakes

The minimum intake of EFAs to prevent deficiency is estimated to be 2.5% of daily energy intake as LA, plus 0.5% as ALA.[25] The World Health Organization recommends that 5%–8% of calories consumed be from n-6 PUFA and 1%–2% from n-3 PUFA.[26] Health authorities worldwide recommend daily intakes ranging from 250 to 550 mg/day for EPA and DHA.[27-29] In Australia, adequate intakes (AIs) for ALA have been set at 1.3 g/day for men and 0.8 g/day for women, and AIs for long-chain n-3 PUFAs are 160 mg/day for men and 90 mg/day for women (115 mg/day during pregnancy, and 145 mg/day during lactation) (Box 2).[30]

Suggested dietary targets for long-chain n-3 PUFAs, aimed at reducing chronic disease risk, are 610 mg/day for men and 430 mg/day for women.[30] Consumption values as high as 3000 mg/day reduce other cardiovascular risk factors and have not had adverse effects in short- and intermediate-term randomised trials.[25] The upper level of intake of combined EPA, DHA and DPA is 3000 mg/day.[4,30]

Adapting recommendations for vegetarian populations

There are no official separate recommendations for n-3 PUFA intake in vegetarians or vegans. Current intakes of ALA and LA in vegetarian populations are not consistent

2 Recommended adequate intake (AI)* of omega-3 polyunsaturated fatty acids (n-3 PUFAs) per day[30]

Sex and age group	AI: Combined EPA + DHA + DPA	AI: ALA	AI: Suggested ALA for vegetarians[20]
Men	160 mg	1.3 g	2.6 g
Women	90 mg	0.8 g	1.6 g
Pregnant	115 mg	1.0 g	2.0 g
Lactating	145 mg	1.2 g	2.4 g
Children			
1–3 years	40 mg	0.5 g	1.0 g
4–8 years	55 mg	0.8 g	1.6 g
Boys 9–13 years	70 mg	1.0 g	2.0 g
Boys 14–18 years	125 mg	1.2 g	2.4 g
Girls 9–13 years	70 mg	0.8 g	1.6 g
Girls 14–18 years	85 mg	0.8 g	1.6 g
Infants	n-3 PUFA		
0–6 months	0.5 g		
7–12 months	0.5 g		

EPA = eicosapentaenoic acid. DHA = docosahexaenoic acid. DPA = docosapentaenoic acid. ALA = α-linolenic acid. * The AI is the average daily nutrient intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that is assumed to be adequate. ◆

with optimal conversion to EPA and DHA,[6,14,20] and the predictable result is reduced EFA status. While the health consequences of this are not known, there is a clear inverse association between EPA and DHA intake and risk of cardiovascular disease, as well as limited evidence for cognitive decline, depression and age-related macular degeneration.[29,31-33] There is also some evidence for improvements in visual acuity, growth, development and cognition with higher maternal DHA intake during pregnancy and lactation, and during the first 2 years of life.[34] Thus, while vegetarians do enjoy certain health advantages, improving their EFA status might afford further protection.

There are two possible means of achieving improved EFA status — by adjusting intakes of LA and ALA to improve conversion, and by adding DHA and EPA supplements derived from microalgae. Although increasing ALA intake can boost its conversion to EPA and DHA, capacity for conversion is limited and genetic variations in metabolism can compromise conversion in some people.[35,36] If microalgae-derived DHA and EPA are used, no adjustment in ALA intake is suggested. If the diet does not provide sufficient DHA and EPA, we suggest that the current AI for ALA be doubled to help shift the balance of LA : ALA towards more efficient conversion.[20] This would mean a minimum ALA intake of 2.6 g/day for vegetarian men and 1.6 g/day for vegetarian women (Box 2). Studies consistently show improved conversion with higher intakes of ALA and lower intakes of LA. Some evidence suggests optimal conversion may be achieved at an n-6 : n-3 ratio of 4 : 1 or less.[12,37,38] Practical suggestions for optimising conversion are provided in Box 3.

3 Dietary strategies for maximising ALA conversion to EPA, DHA and DPA[12,20]

- Regularly include good sources of ALA in the diet: ground flaxseed,* flaxseed oil, chia seeds, canola oil, hempseeds,† hempseed oil† and walnuts. Smaller amounts come from soybeans, green leafy vegetables and sea vegetables. Suggested ALA intakes for vegetarians are at least 2.6 g/day for men and 1.6 g/day for women.
- Limit intake of omega-6 (n-6) oils and margarines (sunflower, safflower, corn, sesame, grapeseed oil). Consume whole food sources of n-6 (sunflower seeds, pumpkin seeds, sesame seeds, walnuts, wheatgerm, soybeans), as they contribute smaller amounts of n-6 and supply other valuable nutrients.
- Use monounsaturated fats (olive oil, canola oil, avocado, olives and nuts) in place of n-6 oils and margarines.
- Limit alcohol and caffeine intake and avoid smoking.
- Ensure a nutritionally adequate diet with due attention to nutrients that are important in the conversion process: vitamins B_3 (niacin), B_6 (pyridoxine) and C, and the minerals zinc and magnesium.

ALA = α-linolenic acid. EPA = eicosapentaenoic acid. DHA = docosahexaenoic acid. DPA = docosapentaenoic acid.
* It is important to grind flaxseeds before use, as whole flaxseeds are not well digested. † Hempseeds and hempseed oil are not currently available in Australia as a food, although they are in countries such as Canada. Food Standards Australia New Zealand is currently reviewing this. ◆

Supplementation for vegetarians

While evidence suggests that dietary n-3 PUFA needs can be met with ALA alone,[14] there may be advantages to adding DHA and possibly EPA supplements derived from microalgae, particularly for people with increased needs (eg, pregnant and lactating women) or reduced conversion ability (eg, people with diabetes, metabolic syndrome or hypertension, and older people). Although women have a greater capacity to convert ALA,[39] demand for DHA may exceed production during pregnancy and lactation, even with relatively efficient conversion rates.[18,20] For those with increased needs or reduced conversion ability, an intake of 200–300 mg/day of DHA and EPA microalgae-derived supplements is recommended. For other vegetarians and vegans, meeting the AI for long-chain n-3 PUFA (Box 2) from foods (including fortified foods) or supplements is suggested, although including supplementation of 100–300 mg/day (or 2–3 times per week) would be a reasonable choice.

Another option is direct consumption of SDA, which bypasses the first step in ALA conversion (desaturation by Δ^6desaturase) to EPA and DHA. In humans, SDA is a better substrate than ALA for formation of EPA and, compared with ALA, SDA supplementation results in greater accumulation of EPA in the erythrocyte membranes.[40] Although SDA is not found in commonly eaten foods, rich sources of preformed SDA include echium oils, genetically modified soybean oil, and blackcurrant oil. Regular soybean oil is not a source of SDA.

Box 4 shows a sample vegetarian meal plan for a 19–50-year-old woman, which easily meets the suggested ALA intake of 1.6 g as well as requirements for other key nutrients (except vitamin D and long-chain n-3 PUFA).[25] For more details, and other sample meal plans, see *page 33*.

Conclusion

Although vegetarians consume minimal EPA and DHA, studies show plasma levels of n-3 PUFA are typically low but apparently stable. An adequate amount of ALA can be consumed from plant sources, and vegetarians can take steps to optimise conversion of ALA to EPA and DHA. The diet must be well supplied with dietary sources of ALA, and there is some evidence that a direct source of microalgae-derived DHA and EPA may be beneficial, particularly for those with increased needs or difficulty converting ALA. There is no convincing evidence that vegetarians or vegans experience adverse effects as a result of a low dietary intake of EPA and DHA. Finally, further research is required to understand if ALA and SDA can be substituted for marine EPA and DHA, or if direct sources of EPA and DHA are essential for optimal health.

4 A sample vegetarian meal plan designed to meet the suggested intake of α-linolenic acid (ALA) for a 19–50-year-old woman, showing ALA content of the foods*

Meal	ALA content
Breakfast	
Bowl of cereal with fruit, and poached egg on toast	
2 wholegrain wheat biscuits	0.02 g
4 strawberries	0.0 g
10 g chia seeds	1.9 g
1/2 cup low-fat soy milk	0.02 g
1 slice multigrain toast	0.08 g
1 poached egg (omega-rich egg)	0.1 g
Snack	
Nuts and dried fruit	
30 g cashews	0.0 g
6 dried apricot halves	0.0 g
Lunch	
Chickpea falafel wrap	
1 wholemeal pita flatbread	0.06 g
1 chickpea falafel	0.0 g
30 g hummus	0.0 g
1/2 cup tabouli	0.0 g
Salad	0.0 g
Snack	
Banana and wheatgerm smoothie	
3/4 cup low-fat soy milk	0.03 g
2 teaspoons wheatgerm	0.04 g
1 banana	0.0 g
Dinner	
Stir-fry greens with tofu and rice	
100 g tofu	0.5 g
2 spears asparagus, 1/3 cup bok choy and 25 g snow peas	0.0 g
12 g cashews	0.0 g
1 cup cooked brown rice	0.0 g
Snack	
Fortified malted chocolate beverage	
1 cup low-fat soy milk	0.05 g
10 g fortified malted chocolate powder	0.0 g
Total ALA	**2.8g**

* Source: FoodWorks 2009 (incorporating Food Standards Australia New Zealand's AUSNUT [Australian Food and Nutrient Database] 1999), Xyris Software, Brisbane, Qld. ◆

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