

Essential fatty acid requirements of vegetarians in pregnancy, lactation, and infancy^{1,2}

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ABSTRACT Long-chain polyunsaturated fatty acids (LCPUFAs) derived from linoleic (18:2n-6) and α -linolenic (18:3n-3) acids are required for the normal development of the retina and central nervous system, but the extent to which they can be synthesized from the parent fatty acids is debated. Consuming LCPUFAs markedly increases their proportions in tissue lipids compared with their parent fatty acids. Thus, it has been argued that LCPUFAs must be supplied in the diet. LCPUFAs are generally absent from plant foods, thus it is important find out how essential fatty acid requirements are met by vegetarians. A developing fetus obtains LCPUFAs via selective uptake from its mother's plasma and LCPUFAs are present in the breast milk of vegetarians. There is no evidence that the capacity to synthesize LCPUFAs is limited in vegetarians. However, there are greater proportions of n-6 LCPUFAs and lower proportions of n-3 LCPUFAs in vegetarians compared with omnivores. This difference is probably a consequence of the selection of foods by vegetarians with high amounts of linoleic acid. Although lower concentrations of docosahexaenoic acid (22:6n-3; DHA) have been observed in blood and artery phospholipids of infants of vegetarians, it is uncertain whether their brain lipids contain lower proportions of DHA than do those of infants of omnivores. On the basis of experiments in primates that showed altered visual function with a high ratio of linoleic acid to α -linolenic acid, it would be prudent to recommend diets with a ratio between 4:1 and 10:1 in vegetarians and that excessive intakes of linoleic acid be avoided. *Am J Clin Nutr* 1999;70(suppl):555S-9S.

KEY WORDS Docosahexaenoic acid, vegetarians, lipids, pregnancy, lactation, essential fatty acids, retinal development, central nervous system development

INTRODUCTION

There are 2 series of essential fatty acids derived from linoleic acid (18:2n-6) and α -linolenic acid (18:3n-3). Both fatty acids are supplied primarily by foods of plant origin but they undergo further desaturation and chain elongation in animal tissues, giving rise to long-chain polyunsaturated fatty acids (LCPUFAs; **Figure 1**). Linoleic acid deficiency results in the failure of several physiologic systems but is characterized particularly by scaly dermatitis, increased susceptibility to infection, and poor growth (1). Linoleic acid itself plays a role in maintaining the barrier to permeability of the skin, and its long-chain metabolite, arachidonic acid (20:4n-6; AA), is the major precursor of phys-

iologically active eicosanoids, which regulate a variety of physiologic systems. Dietary deficiency of linoleic acid is rare because even the most meager diet is likely to provide sufficient linoleic acid to meet the requirement, which is estimated to be 1-2% of dietary energy. On the other hand, iatrogenic deficiency of linoleic acid can arise in infants fed breast-milk substitutes that contain insufficient quantities of linoleic acid, during enteral and total parenteral nutrition, and in conditions that cause fat malabsorption (1). It is now recognized that α -linolenic acid is a dietary essential (2) because its metabolite, docosahexaenoic acid (22:6n-3; DHA), plays important roles in brain and retinal function (1, 3). The final metabolic step in the conversion of α -linolenic acid to DHA is peroxisomal β -oxidation, which shortens 24:6n-3 to 22:6n-3.

The preterm human infant probably needs DHA, and possibly AA, in the diet because they may not be synthesized from their precursors at a rate commensurate with needs (4, 5). DHA and AA are found in breast milk and it has been proposed that breast-milk substitutes should have LCPUFA concentrations comparable with those found in breast milk (2). However, the essential fatty acid requirements of preterm infants are complex owing to their immaturity and rapid rate of brain growth. The controversy over whether term infants require a dietary source of LCPUFAs has not been resolved (6). Some studies showed improvement in visual function (7, 8) in term infants fed formula fortified with DHA, but others found no differences between the visual function between term infants fed formula with or without DHA and AA and those fed breastmilk (9, 10). Furthermore, Jensen et al (11) were unable to show differences in the latency or amplitude component of the visual evoked response between groups of term infants fed formulas with 0.4%, 1.0%, 1.8% and 3.24% α -linolenic acid from birth to 4 mo compared with breast-fed infants. Heird et al (6) concluded that visual function is unlikely to be compromised in term infants who receive no exogenous DHA if exogenous α -linolenic acid comprises \approx 1% of energy intake.

It has also been suggested that pregnant and lactating women may need to supplement their diets with DHA to meet the needs

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| n—6 Series | | n—3 Series |
|-------------------------|--------------|------------------------|
| Linoleic acid | | α-Linolenic acid |
| 18:2n-6 | | 18:3n-3 |
| ↓① | | ↓① |
| γ-Linolenic acid | | |
| 18:3n-6 | | 18:4n-3 |
| ↓ | | ↓ |
| Dihomo-γ-linolenic acid | | |
| 20:3n-6 | ↘ | 20:4n-3 |
| ↓② | | ↓② |
| Arachidonic acid | →Eicosanoids | ←Eicosapentaenoic acid |
| 20:4n-6 | | 20:5n-3 |
| ↓ | | ↓ |
| 22:4n-6 | | 22:5n-3 |
| ↓ | | ↓ |
| 24:4n-6 | | 24:5n-3 |
| ↓① | | ↓① |
| 24:5n-6 | | 24:6n-3 |
| ↓③ | | ↓③ |
| Docosapentaenoic acid | | Docosahexaenoic acid |
| 22:5n-6 | | 22:6n-3 |

FIGURE 1. Metabolism of essential fatty acids. ①, Δ⁶ desaturation; ②, Δ⁵ desaturation; ③, peroxysomal chain-shortening reaction.

of their growing children (12). The major dietary sources of LCPUFAs are fish, meat (especially organ meats, ie, liver and brain), and eggs. Consequently, vegetarian diets are often devoid of LCPUFAs. This article reviews the evidence concerning the essential fatty acid status of vegetarians during pregnancy, lactation, and infancy and makes some recommendations with regard to dietary intake and further research.

DIETARY SOURCES OF ESSENTIAL FATTY ACIDS AVAILABLE TO VEGETARIANS

Seed oils tend to be high in linoleic acid and low in α-linolenic acid, with the exceptions of flaxseed (linseed), canola (rapeseed), and soybean oils. Certain oils, such as evening primrose, black-current seed, and borage (starflower) contain γ-linolenic acid (18:3n-6), which is derived from linoleic acid. α-Linolenic acid is found in relatively high concentrations in chloroplasts, but dark-green vegetables tend to be so low in fat that they probably make very little contribution to dietary intake in the amounts normally

consumed. Egg yolks contain small amounts of AA and DHA; butterfat contains trace amounts. Certain marine algae, eg, *Cryptocodinium cohnii*, are able to synthesize DHA, and AA is found in some fungi such as *Mortierella alpina*. Oils from these sources are being proposed as suitable food sources of LCPUFAs for vegetarians (13). Because there is no history of prior use of fungal and algal oils, more information concerning their safety is needed. The typical dietary intakes of essential fatty acids in British vegan, vegetarian, and omnivorous women (14) are shown in **Table 1**. Intake of linoleic acid was greater, and intake of α-linolenic acid was similar or slightly greater, in vegetarians (particularly vegans) than in omnivores. This appears to be because the vegetarians chose to eat seeds rich in linoleic acid more often than did the omnivores. The ratio of linoleic acid to α-linolenic acid, however, tends to be greater, ≈15:1–20:1, in vegetarians. LCPUFA intake in vegetarians tends to be negligible, whereas the diets of omnivores contain small amounts of AA, eicosapentaenoic acid (20:5n-3), and DHA. Intake of α-linolenic acid is largely from cooking oil, with intakes being greater when canola and soybean oil are used.

MATERNAL AND FETAL SUPPLY OF ESSENTIAL FATTY ACIDS

There is little evidence to suggest that fat intake changes during pregnancy, but fat storage does increase in early pregnancy, probably because of increased energy metabolism efficiency. A typical pregnancy results in the accumulation of 4 kg body fat; the composition of the body fat stored tends to reflect that of the diet because there is little de novo synthesis of fatty acids from carbohydrates when the diet is relatively high in fat. The mother is able to convert both linoleic and α-linolenic acid to AA and DHA, respectively. These LCPUFAs appear to be taken up preferentially by the placenta and undergo further chain elongation and desaturation in fetal tissues, including the brain. This is evident from the relatively higher amounts of AA and DHA and lower amounts of parent fatty acids in fetal plasma phospholipids compared with the maternal circulation.

Analyses of the fetal plasma and cord artery phospholipids show similar proportions of total LCPUFAs in infants of vegetarian mothers and in infants of omnivorous mothers (**Figure 2**; 15). However, the proportion of DHA was lower and the proportions of n-6 LCPUFAs such as AA and docosapentaenoic acid (22:5n-6) were higher in vegetarians than in those of omnivorous control subjects. The consumption of n-3 LCPUFAs in

TABLE 1
Polyunsaturated fatty acid intakes of vegan, vegetarian, and omnivorous women¹

| Subjects | 18:2n-6 | 18:3n-3 | 18:4n-6 | 18:5n-6 | 18:6n-3 |
|---|-------------|------------|-------------|-------------|-------------|
| | <i>g/d</i> | | | | |
| Vegans | | | | | |
| Nonlactating ² (n = 10) | 21.4 ± 3.23 | 1.2 ± 0.22 | 0 | 0 | 0 |
| Lactating ³ (n = 19) | 20.4 ± 2.49 | 1.2 ± 0.28 | 0 | 0 | 0 |
| Vegetarians | | | | | |
| Nonlactating UK whites ² (n = 18) | 14.6 ± 1.69 | 1.5 ± 0.17 | Trace | Trace | Trace |
| Nonlactating UK Indians ² (n = 21) | 14.2 ± 1.25 | 0.9 ± 0.10 | Trace | Trace | Trace |
| Omnivores | | | | | |
| Nonlactating ³ (n = 10) | 9.1 ± 1.07 | 1.1 ± 0.15 | 0.15 ± 0.02 | 0.09 ± 0.02 | 0.04 ± 0.02 |
| Nonlactating ² (n = 22) | 11.8 ± 1.22 | 1.0 ± 0.08 | 0.13 ± 0.04 | 0.08 ± 0.02 | 0.10 ± 0.02 |

¹ $\bar{x} \pm$ SEM. Data from reference 14.

^{2,3} Measurements were taken in: ² 1988, ³ 1980.

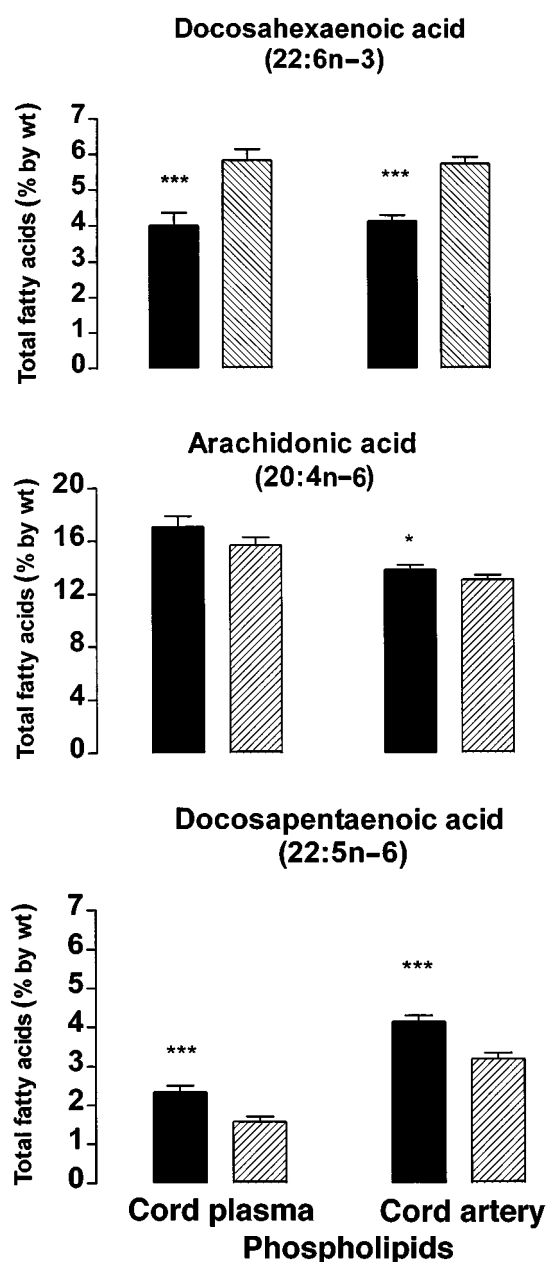


FIGURE 2. Mean proportions of docosahexaenoic, arachidonic, and docosapentaenoic acids in cord plasma and cord artery phospholipids of vegetarian (filled bars) and omnivore (hatched bars) term infants. Error bars indicate SE. * $P < 0.05$ compared with omnivores; *** $P < 0.001$ compared with omnivores. Data from reference 15.

pregnancy results in an increase in the proportion of DHA (12) but this may also be accompanied by a reduction in the proportion of LCPUFAs derived from n-6 fatty acids.

RELATION BETWEEN ESSENTIAL FATTY ACIDS STATUS AND PREGNANCY OUTCOME

It has been hypothesized that essential fatty acid intake affects the duration of pregnancy. It is well known that linoleic acid

deficiency in rats leads to impaired parturition due to insufficient synthesis of AA, which is needed for the formation of biologically active prostaglandins that are required for normal uterine contraction. Prolonged gestation has been observed in women in the Faeroe Islands who consume whale oil during pregnancy, and a controlled trial found that fish oil consumption during pregnancy increased its duration by 2-3 d (16). Birth weight, on the other hand, was not affected. However, concerns were raised over the increased risk of maternal hemorrhage. A slightly shorter duration of pregnancy in vegetarian than in omnivorous women has been reported (15, 17). Birth weights adjusted for gestational age have also been reported to be lower in British vegetarians of Indian origin than in omnivores (15). However, there is little evidence from animal studies to suggest that high intakes of linoleic acid or an altered ratio of linoleic acid to α -linolenic acid affects birth weight (3).

COMPARISON OF THE BREAST-MILK COMPOSITIONS OF VEGETARIANS AND OMNIVORES

As a rule, the proportion of linoleic acid in breast milk tends to be greater in vegetarians, especially vegans, than in omnivores (Table 2; 14, 18, 19). The UK studies (14) have consistently found lower proportions of DHA in the breast milk of vegetarians, especially in vegans compared with omnivores. Studies of vegetarians in the United States (18, 19) have not found lower proportions of DHA in breast-milk lipids. This may be related to higher intakes of α -linolenic acid from soybean oil or preformed DHA in the case of macrobiotic vegetarians. However, the proportion of AA in breast milk is similar among vegetarians, vegans, and omnivores. The proportion of α -linolenic acid is more variable. The proportion of DHA in breast milk can be increased by consuming preformed DHA (20). To date, no studies have investigated the influence of increased intake of α -linolenic acid on breast-milk DHA concentrations.

COMPARISON OF THE ESSENTIAL FATTY ACID STATUS AMONG BREAST-FED INFANTS OF VEGETARIAN AND OMNIVOROUS MOTHERS AND FORMULA-FED INFANTS

To date, only 1 study has compared the essential fatty acid status of infants of vegans and infants of omnivores who were breast-fed exclusively (21). This study reported lower proportions of DHA in erythrocyte lipids and slightly higher proportions of docosatetraenoic acid (22:4n-6) and AA in vegans and omnivores, respectively.

The same authors performed similar analyses in infants who had been fed modified cow-milk formula exclusively for the same amount of time (22). The infants fed cow-milk formula had a lower proportion of AA than did both groups of breast-fed infants (Figure 3). Furthermore, their proportion of DHA was higher than that of the breast-fed infants of vegans but lower than that of the breast-fed infants of omnivores. The cow-milk formula used provided $\approx 0.5\%$ of energy as linoleic acid and 0.5% energy as α -linolenic acid as well as small amounts of longer-chain n-3 fatty acids, and was typical of the fatty acid composition of breast-milk substitutes that were in use up to about the mid-1970s. Manufacturers of infant formulas subsequently increased the amount of linoleic acid substantially to such an extent that linoleic acid typically provides $\approx 10\%$ of energy in modern formulas.

TABLE 2
Polyunsaturated fatty acids in breast-milk lipids in vegans, vegetarians, and omnivores¹

| Fatty acid | Percentage by weight | | | P |
|-----------------|--------------------------|------------------------|-----------------------|-------|
| | Vegans (n = 19) | Vegetarians (n = 5) | Omnivores (n = 21) | |
| | | % | | |
| 18:2n-6 | 23.8 ± 1.40 ² | 19.5 ± 3.62 | 10.9 ± 0.96 | <0.01 |
| 18:3n-3 | 1.36 ± 0.184 | 1.25 ± 0.22 | 0.49 ± 0.055 | <0.01 |
| 20:3n-6 | 0.44 ± 0.034 | 0.42 ± 0.07 | 0.40 ± 0.078 | NS |
| 20:4n-6 | 0.32 ± 0.024 | 0.38 ± 0.045 | 0.35 ± 0.032 | NS |
| 22:6n-3 | 0.14 ± 0.059 | 0.30 ± 0.050 | 0.37 ± 0.065 | <0.01 |
| Ratio | | | | |
| 18:2n-6:18:3n-3 | 17.5 | 15.6 | 22.2 | |
| n-6:n-3 | 16.4 | 13.0 | 13.5 | |

¹Data from reference 14.

² $\bar{x} \pm \text{SEM}$.

CONCLUSIONS

There are differences in the essential fatty acid status of vegetarians and omnivores, the most notable being the higher intakes of linoleic acid by vegetarians and, to a lesser degree, the differences in intake of LCPUFAs. Because the proportion of AA in the blood and tissue lipids of vegetarians and vegans is similar to or greater than that of omnivores, the implication is that vegans and vegetarians do not require AA in their diets because they can synthesize adequate amounts from linoleic acid. It has been suggested that the capacity to synthesize AA from linoleic acid may be limited in neonates. However, the breast milk of vegetarian mothers supplies additional AA to neonates.

The lower proportion of DHA in the blood and tissue lipids of vegans and vegetarians is of some concern because it may adversely affect brain and cardiac function (1). Evidence that the enzymes necessary for the conversion of α -linolenic acid to DHA are functional in term infants (23) suggests that LCPUFAs are not absolutely required in the diet. However, if the intake of linoleic acid is excessive or the rate of synthesis of DHA is not commensurate with needs, as is the case with preterm infants, consumption of DHA may be necessary. Vegetarians who breast-feed their infants will supply them with both α -linolenic acid and DHA. Vegetarian and vegan diets are unlikely to be lacking in α -linolenic acid because it is derived mainly from plant sources. Whether there would be any benefit from the mother consuming preformed DHA is uncertain. Animals studies suggest that the ratio of linoleic acid to α -linolenic acid in the maternal diet is important in determining the proportion of DHA in brain lipids. For example, in rats fed adequate intakes of α -linolenic acid, it is possible to decrease the proportion of DHA in fetal brain with high intakes of linoleic acid (24). This is probably because linoleic acid competitively inhibits the $\Delta 6$ desaturation of 24:5n-3 to 24:6n-3. It has been shown that altering the ratio of linoleic acid to α -linolenic acid in infant milks can change the proportion of DHA in the erythrocyte lipids of term infants (25). Furthermore, lower proportions of DHA and higher proportions of 22:5n-6 have been observed in the brain lipids of formula-fed infants compared with control subjects (26, 27). Although no studies have examined the brain lipids of infants of vegetarians, it is likely that they will reflect the balance of n-6 to n-3 in the maternal diet. Because visual and cognitive function might be influenced by differences in the balance of n-6 and n-3 fatty acids, there is a case for conducting a randomized, controlled trial in vegetarians of supple-

mentation with an acceptable source of DHA or an altered ratio of linoleic acid to α -linolenic acid with pregnancy outcome (maternal and fetal) and measurements of the visual and cognitive function of infants as the measured endpoints.

It is of some concern that the amount of n-6 fatty acids has been increased and that of n-3 fatty acids has been reduced in the food supply by modern agricultural and food processing practices. Vegetable oils, such as sunflower and corn oil, with high ratios of linoleic acid to α -linolenic acid are now widely used. Feeding cattle with feed concentrates rather than grass leads to lower concentrations of α -linolenic acid in dairy products. The process of partial hydrogenation of soybean and canola oils leads to the selective destruction of α -linolenic acid. There has been emphasis on increasing the intake of linoleic acid in the diet because of its putative cholesterol-lowering properties. The consequence of these changes in the food supply is an increase in the proportion of linoleic acid in breast-milk lipids in both the United Kingdom and the United States and probably a decline in the proportion of DHA. For example, in the late 1970s, linoleic acid typically accounted for 8–10% of the total fatty acids consumed; typical values observed in omnivores in the mid-1990s were $\approx 15\%$ (10, 28), which is similar

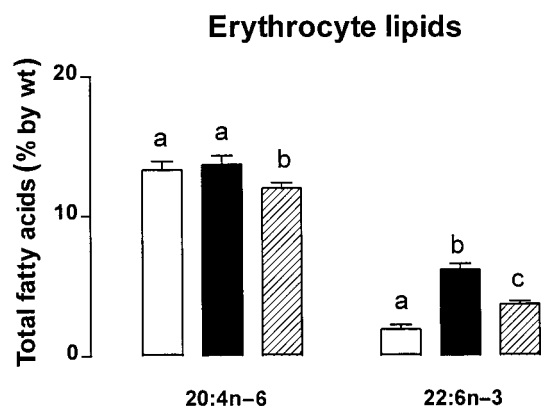



FIGURE 3. Mean proportions of arachidonic and docosahexaenoic acids in erythrocyte lipids from 14-wk-old infants who were breast-fed by vegans (open bars), breast-fed by omnivores (filled bars), and fed cow-milk formula (hatched bars). Error bars indicate SEM. Data with different letters are significantly different from each other, $P < 0.05$. Data from references 21 and 22.

to the proportions found in vegetarians. There is no apparent advantage of consuming >6% of energy from linoleic acid; a high intake has the disadvantage of inhibiting the synthesis of DHA from α -linolenic acid. Whereas further research is needed to quantify the optimum ratio of n-6 to n-3 fatty acids in the diet, it would be prudent to ensure that vegetarian diets do not contain excessive amounts of linoleic acid and that the ratio of linoleic acid to α -linolenic acid is between 4:1 and 10:1, as suggested by Food and Agriculture Organization/World Health Organization (2). 

REFERENCES

1. British Nutrition Foundation. Task Force on Unsaturated Fatty Acids. London: Chapman and Hall, 1992.
2. FAO/WHO. Fats and oils in human nutrition (report of a joint expert consultation). Rome: FAO, 1994. (Food and Nutrition paper 57.)
3. Neuringer M, Anderson GJ, Connor WE. The essentiality of n-3 fatty acids for the development and function of the retina and brain. *Annu Rev Nutr* 1988;8:517-41.
4. Uauy RD, Birch DG, Birch EE, Tyson JE, Hoffman DR. Effect of dietary omega-3 fatty acids on retinal function of very low birth weight neonates. *Pediatr Res* 1990;28:485-92.
5. Carlson SE, Werkman SH, Tolley EA. Effect of long-chain n-3 fatty acid supplementation on visual acuity and growth of preterm infants with and without bronchopulmonary dysplasia. *Am J Clin Nutr* 1996;63:687-97.
6. Heird WC, Prager TC, Anderson RE. Docosahexaenoic acid and the development and function of the infant retina. *Curr Opin Lipidol* 1997;8:12-6.
7. Makrides M, Neumann MA, Simmer K, Pater J, Gibson RA. Are long-chain polyunsaturated fatty acids essential nutrients in infancy? *Lancet* 1995;345:1463-8.
8. Carlson SE, Ford AJ, Werkman SH, Peeples JM, Koo WWK. Visual acuity and fatty acid status of term infants fed human milk and formulas with and without docosahexaenoate and arachidonate from egg yolk lecithin. *Pediatr Res* 1996;39:882-8.
9. Innis SM, Nelson CM, Lwanga D, Rioux FM, Waslen P. Feeding formula without arachidonic acid and docosahexaenoic acid has no effect on preferential looking acuity or recognition memory in healthy full-term infants at 9 mo of age. *Am J Clin Nutr* 1996;64:40-6.
10. Auestad N, Montalto MB, Hall RT, et al. Visual acuity, erythrocyte fatty acid composition and growth in term infants fed formulas with long chain polyunsaturated fatty acids for one year. *Pediatr Res* 1997;41:1-10.
11. Jensen CL, Prager TC, Fraley JK, Anderson RE, Heird WC. Effect of dietary linoleic/ α -linolenic acid ratio growth and visual function of term infants. *J Pediatr* 1997;131:200-9.
12. Connor WE, Lowensohn R, Hatcher L. Increased docosahexaenoic acid levels in human newborn infants by administration of sardines and fish oil during pregnancy. *Lipids* 1996;31:S183-7.
13. Conquer JA, Holub BJ. Supplementation with an algae source of docosahexaenoic acid increases (n-3) fatty acid status and alters selected risk factors for heart disease in vegetarian subjects. *J Nutr* 1996;126:3032-9.
14. Sanders TA, Reddy S. The influence of a vegetarian diet on the fatty acid composition of human milk and the essential fatty acid status of the infant. *J Pediatr* 1992;120:S71-7.
15. Reddy S, Sanders TA, Obeid O. The influence of maternal vegetarian diet on essential fatty acid status of the newborn. *Eur J Clin Nutr* 1994;48:358-68.
16. Olsen SF, Sørensen JD, Secher NJ, et al. Randomised controlled trial of effect of fish-oil supplementation on pregnancy duration. *Lancet* 1992;339:1003-7.
17. McFadyen IR, Campbell-Brown M, Abraham R, North WRS, Haines AP. Factors affecting birthweight in Hindus, Moslems and Europeans. *Br J Obstet Gynaecol* 1984;91:968-72.
18. Finley DA, Lønnerdal B, Dewey KG, Grivetti LE. Breast milk composition: fat content and fatty acid composition in vegetarians and non-vegetarians. *Am J Clin Nutr* 1985;41:787-800.
19. Specker BL, Wey HE, Miller D. Differences in fatty acid composition of human milk in vegetarian and nonvegetarian women: long-term effect of diet. *J Pediatr Gastroenterol Nutr* 1987;6:764-8.
20. Makrides M, Neumann MA, Gibson RA. Effect of maternal docosahexaenoic acid (DHA) supplementation on breast milk composition. *Eur J Clin Nutr* 1996;50:352-7.
21. Sanders TA, Ellis FR, Dickerson JW. Studies of vegans: the fatty acid composition of plasma choline phosphoglycerides, erythrocytes, adipose tissue, and breast milk, and some indicators of susceptibility to ischemic heart disease in vegans and omnivore controls. *Am J Clin Nutr* 1978;31:805-13.
22. Sanders TA, Naismith DJ. A comparison of the influence of breast-feeding and bottle-feeding on the fatty acid composition of the erythrocytes. *Br J Nutr* 1979;41:619-23.
23. Sauerwald TU, Hachey DL, Jensen CL, Chen H, Anderson RE, Heird WC. Intermediates in endogenous synthesis of C22:6 ω 3 and C20:4 ω 6 by term and preterm infants. *Pediatr Res* 1997;41:183-7.
24. Sanders TAB, Mistry M, Naismith DJ. The influence of a maternal diet rich in linoleic acid on brain and retinal docosahexaenoic acid in the rat. *Br J Nutr* 1984;51:57-66.
25. Gibson RA, Makrides M, Neumann MA, Simmer K, Mantzioris E, James MJ. Ratios of linoleic acid to alpha-linolenic acid in formulas for term infants. *J Pediatr* 1994;125:S48-55.
26. Farquarson J, Cockburn F, Patrick WA, Jamieson EC, Logan RW. Infant cerebral cortex phospholipid fatty-acid composition and diet. *Lancet* 1992;340:810-3.
27. Makrides M, Neumann MA, Byard RW, Simmer K, Gibson RA. Fatty acid composition of brain, retina, and erythrocytes in breast- and formula-fed infants. *Am J Clin Nutr* 1994;60:189-94.
28. Sanders TA, Reddy S. Infant brain lipids and diet. *Lancet* 1992;340:1093-4.