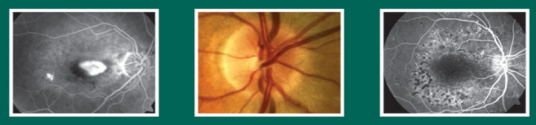
Nutrition & the Eye



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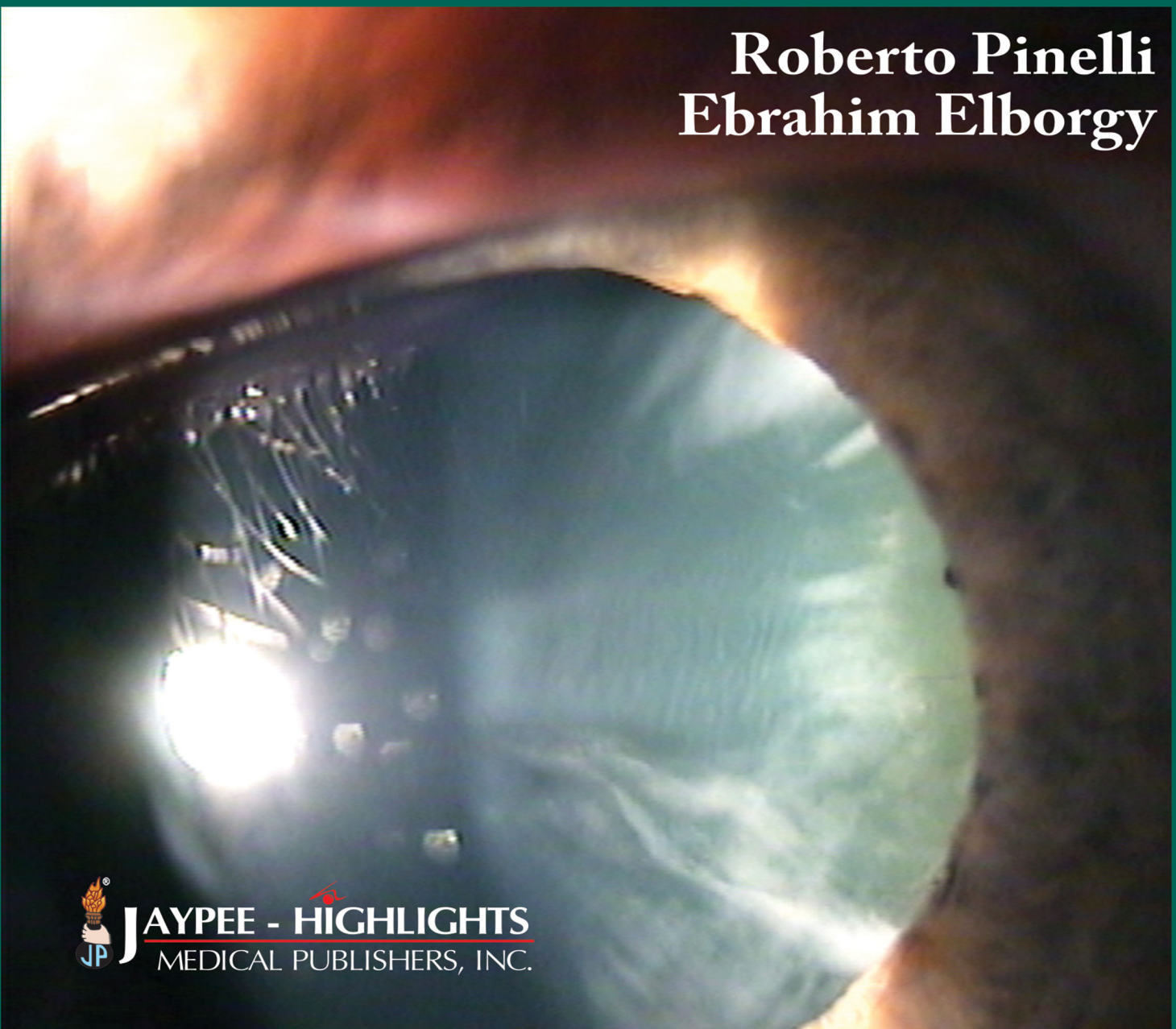

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Contents

SECTION 1: ESSENTIAL NUTRIENTS TO A HEALTHY EYE

1. Vitamins 3
2. Carotenoids 37
3. Proteins 43
4. Fatty Acids 46
5. Carbohydrates 54
6. Glutathione 57
7. Minerals 59

SECTION 2: IMPACT OF NUTRITION ON OCULAR DISORDERS

8. Supplements and the Eye 81
9. Role of Dietary Supplements in the Prevention and Progression of AMD 90
10. Manganese Deficiency and Retina 111
11. Antioxidant Deficiency and Retinitis Pigmentosa 113
12. Can Antioxidants Rescue Photoreceptors in Retinitis Pigmentosa? 116
13. Diet and Diabetic Retinopathy 119
14. Effect of Diet on Cataract Formation 128
15. Glutathione: A Vital Lens Antioxidant 145
16. Dietary Fatty Acids and Dry Eye Syndrome 148
17. Selenium: Correlation with Glaucoma 151
18. Effects of Dietary Fatty Acids and Antioxidants on Glaucoma 154

Bibliography *163*

Index *167*

Chapter

4 Fatty Acids

CLASSIFICATION

Saturated Fatty Acid

A fatty acid with no double bonds between carbon atoms.

Monounsaturated Fatty Acid

A fatty acid with only one double bond between carbon atoms.

Polyunsaturated Fatty Acid

A fatty acid with more than one double bond between carbons.

Omega-3 and omega-6 fatty acids are polyunsaturated fatty acids (PUFA), meaning they contain more than one cis double bond.[1] In all omega-3 fatty acids, the first double bond is located between the third and fourth carbon atom counting from the methyl end of the fatty acid (n-3). Similarly, the first double bond in all omega-6 fatty acids is located between the sixth and seventh carbon atom from the methyl end of the fatty acid (n-6). Although humans and other mammals can synthesize saturated fatty acids and some monounsaturated fatty acids from carbon groups in carbohydrates and proteins, they lack the enzymes necessary to insert a cis double bond at the n-6 or the n-3 position of a fatty acid.[1] Consequently, omega-6 and omega-3 fatty acids are essential nutrients (Fig. 4.1).

Linoleic acid (LA; 18:2n-6) is the parent fatty acid of the omega-6 series from which humans can synthesize long-chain (20 carbons or more) omega-6 fatty acids, such as dihomo-gamma-linolenic acid (DGLA; 20:3n-6) and arachidonic acid (AA; 20:4n-6).

Alpha-linolenic acid (ALA; 18:3n-3) is the parent fatty acid of the omega-3 series from which humans can synthesize long-chain omega-

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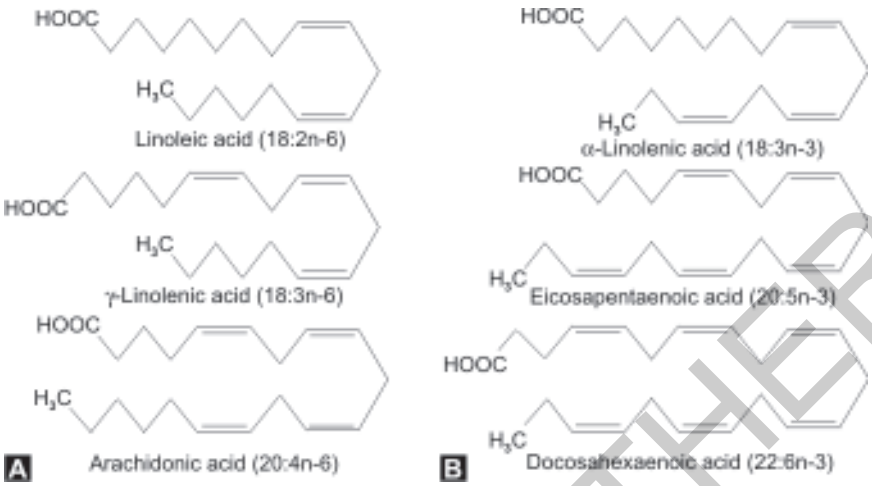

Figs 4.1A and B: (A) Omega-6 fatty acids, (B) Omega-3 fatty acids

3 fatty acids, such as eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3).

Both ALA and LA are called "essential" FAs because they cannot be synthesized by mammals and must be supplied in diet.

A large body of scientific research suggests that increasing the relative abundance of dietary omega-3 fatty acids may have a number of health benefits.

METABOLISM

Prior to absorption in the small intestine, fatty acids must be hydrolyzed from dietary fats (triglycerides, phospholipids, and cholesterol) by pancreatic enzymes.[2] Bile salts must also be present in the small intestine. Fat absorption occurs throughout the small intestine and is 85-95% efficient under normal conditions. Humans can synthesize longer omega-6 and omega-3 fatty acids from the essential fatty acids LA and ALA, respectively, through a series of desaturation (addition of a double bond) and elongation (addition of two carbon atoms) reactions.[3]

LA and ALA compete for the same elongase and desaturase enzymes in the synthesis of longer polyunsaturated fatty acids, such as AA and EPA. Although ALA is the preferred substrate of the delta-6 desaturase enzyme, the excess of dietary LA compared to ALA results in greater net formation of AA than EPA.[4]

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The capacity for conversion of ALA to DHA is higher in women than men. Studies of ALA metabolism in healthy young men indicate that approximately 8% of dietary ALA is converted to EPA and 0-4% is converted to DHA (5). In healthy young women, approximately 21% of dietary ALA is converted to EPA and 9% is converted to DHA.[6] The better conversion efficiency of young women compared to men appears to be related to the effects of estrogen.[4, 7] Although ALA is considered the essential omega-3 fatty acid because it cannot be synthesized by humans, evidence that human conversion of EPA and, particularly, DHA is relatively inefficient suggests that EPA and DHA may also be essential under some conditions.[8, 9]

SOURCES

Food Sources

Omega-6 Fatty Acids

- *Linoleic acid*: Food sources of LA include vegetable oils, such as soybean, safflower, and corn oil, nuts, seeds, and some vegetables. Dietary surveys in the US indicate that the average adult intake of LA ranges from 12-17 g/day for men and 9-11 g/day for women.[1] Some foods that are rich in LA are listed in Table 4.1.

Table 4.1: Some food sources of linoleic acid (18:2n-6)[10]

Foods	*Serving*	*Linoleic acid (g)*
Safflower oil	1 tablespoon	10.1
Sunflower seeds, oil roasted	1 oz	9.7
Pine nuts	1 oz	9.4
Sunflower oil	1 tablespoon	8.9
Corn oil	1 tablespoon	7.3
Soybean oil	1 tablespoon	6.9
Pecans, oil roasted	1 oz	6.4
Brazil nuts	1 oz	5.8
Sesame oil	1 tablespoon	5.6

- *Arachidonic Acid:* Animals, but not plants, can convert LA to AA. Therefore, AA is present in small amounts in meat, poultry, and eggs.

Omega-3 Fatty Acids

- *Alpha-Linolenic Acid (ALA)*: Flaxseeds, walnuts, and their oils are among the richest dietary sources of ALA. Canola oil is also an excellent source of ALA. Dietary surveys in the US indicate that

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average adult intakes for ALA range from 1.2-1.6 g/day for men and from 0.9-1.1 g/day for women.[1] Some foods that are rich in ALA are listed in Table 4.2.

Table 4.2: Some food sources of alpha-linolenic acid (18:3n-3)[10]

Foods	*Serving*	*Alpha-linolenic acid (g)*
Flaxseed oil	1 tablespoon	7.3
Walnuts, English	1 oz	2.6
Flaxseeds, ground	1 tablespoon	0.6
Walnut oil	1 tablespoon	1.4
Canola oil	1 tablespoon	1.3
Mustard oil	1 tablespoon	0.8
Soybean oil	1 tablespoon	0.9
Walnuts, black	1 oz	0.6
Tofu, firm	½ cup	0.7

Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA)

Oily fish are the major dietary source of EPA and DHA. Dietary surveys in the US indicate that average adult intakes of EPA range from 0.04-0.07 g/day and average adult intakes of DHA range from 0.05-0.09 g/day.[1] Omega-3 fatty acid-enriched eggs are also available in the US. Some foods that are rich in EPA and DHA are listed in Table 4.3.

Table 4.3: Some food sources of EPA (20:5n-3) and DHA (22:6n-3)[11]

Foods	*Serving*	*EPA (g)*	*DHA (g)*	*Amount providing1 g of EPA + DHA*
Herring, pacific	3 oz*	1.06	0.75	1.5 oz
Salmon, chinook	3 oz	0.86	0.62	2 oz
Sardines, pacific	3 oz	0.45	0.74	2.5 oz
Salmon, atlantic	3 oz	0.28	0.95	2.5 oz
Oysters, pacific	3 oz	0.75	0.43	2.5 oz
Salmon, sockeye	3 oz	0.45	0.60	3 oz
Trout, rainbow	3 oz	0.40	0.44	3.5 oz
Tuna, canned, white	3 oz	0.20	0.54	4 oz
Crab, dungeness	3 oz	0.24	0.10	9 oz
Tuna, canned, light	3 oz	0.04	0.19	12 oz

Supplements

Omega-6 Fatty Acids

Borage seed oil, evening primrose oil, and black currant seed oil are rich in gamma-linolenic acid (GLA) and are often marketed as GLA or essential fatty acid (EFA) supplements.[12]

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Omega-3 Fatty Acids

Flaxseed oil (also known as flax oil or linseed oil) is available as an ALA supplement. A number of fish oils are marketed as omega-3 fatty acid supplements. Ethyl esters of EPA and DHA (ethyl-EPA and ethyl-DHA) are concentrated sources of long-chain omega-3 fatty acids. Since EPA and DHA content will vary in fish oil and ethyl ester preparations, it is necessary to read the label to determine the EPA and DHA content of a particular supplement. DHA supplements derived from algal and fungal sources are also available. All omega-3 fatty acid supplements are absorbed more efficiently with meals. Dividing one's daily dose into two or three smaller doses throughout the day will decrease the risk of gastrointestinal side effects (see Safety below). Cod liver oil is a rich source of EPA and DHA, but some cod liver oil preparations may contain excessive amounts of preformed vitamin A (retinol).[12]

FATTY ACIDS AND THE EYE

Docosahexaenoic acid in particular is an essential structural component of the retinal membranes[13] and is found in the highest concentration per unit area in the retina.[14] The outer photoreceptor-cell segments of the retina are constantly shed in the normal visual cycle and deficiency of this ω-3 fatty acid may initiate AMD.[15] There is also evidence that such long-chain ω-3 fatty acids protect against oxygenic, inflammatory, and age-associated pathology of the vascular and neural retina,[16-18] which are possible pathogenic factors for AMD development.[19-21]

Long-chain polyunsaturated fatty acids are effected by and influence processes implicated in the pathogenesis of vascular and neural retinal diseases. Docosahexaenoic acid and EPA may serve as protective agents in the retina because of their influence on gene expression,[22-25] retinal cell differentiation,[26-28] and survival.[26-30] Free LCPUFAs, liberated when phospholipase A2 hydrolyzes DHA and AA from their primary storage forms in retinal tissue, are the precursors and substrates to families of bioactive molecules (eicosanoids,[31-34] endocannabinoids,[35,36] and LCPUFA-based autocoids[37,38]) that act as potent regulators of retinal vascular function, cell survival, inflammation, and energy balance. Long-chain polyunsaturated fatty acids also affect factors and processes driving key events in the angiogenic cascade.[16,39] Docosahexaenoic acid may also be involved in rhodopsin regeneration[40] and work in signaling cascades to enhance activation of membrane-bound retinal proteins.[41-44]

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Nutrition & the Eye

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