Nutrition as a Mediator

Nutrition as a Mediator of Visual Health Across the Lifespan

by

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"Of the traditional five senses man is more consciously dependent on sight to make his way in the world than on the other senses. He is predominantly a visual animal. … Most people probably regard sight as their most valued faculty, and would rather lose a limb or become deaf or dumb than to sacrifice vision."[1]

Introduction

For the approximately 314 million people with visual impairment, 12 million of whom are children,[2] the presence of visual dysfunction often leads to reduced quality of life, financial burdens, and even increased mortality. Many forms of visual loss are irreversible and lack efficacious treatment options (e.g., age-related macular degeneration, or "AMD"), and those that are treatable are costly to treat and often require surgical intervention (e.g. age-related cataract, or "ARC"). The World Health Organization has prioritized ten of the most commonly occurring and/or damaging eye diseases into a list of Priority Eye Diseases[3] (see **Table 1**) that should receive special attention from the medical, research, and non-governmental (NGO) communities. Conditions on this list differ in terms of the severity of visual dysfunction produced, the number of people impacted worldwide, and the cost and difficulty of treatment. Some conditions, such as Trachoma and Onchocerciasis, are present largely in the developing world and occur secondarily to a different primary infection, such as Chlamydia or a parasitic infection. Other conditions on the list, such as AMD and ARC, are responsible for a high proportion of blindness world-wide

> **Key messages**
> - The World Health Organization has prioritized ten of the most commonly occurring and/or damaging eye diseases into a list of Priority Eye Diseases. These diseases are known for their high incidence and treatment difficulty.
> - Lifestyle changes can be implemented as a preventive strategy, with the exception of diseases that are caused by gene defects or infection. Nutrition is an extremely promising potential lifestyle intervention, as it plays a major role in all of these diseases.
> - Nutrition influences both development and progression, and can even help manage the symptoms of visual disease.
> - Vitamin A (in the form of retinal), for instance, is involved in the physiology of visual transduction. Polyunsaturated fatty acids and taurine support ocular structures. Multiple antioxidants, such as vitamin E and the carotenoids lutein and zeaxanthin, provide protection against oxidative stress and can slow the development of ocular degenerations.
> - Nutrition can also reduce the symptoms of visual disease. Lutein and zeaxanthin, for instance, improve the optical quality of the eye orbit and have been shown to decrease glare disability and discomfort, speed photostress recovery, and improve chromatic contrast and visual processing speeds.

Table 1: Priority Eye Diseases, listed by condition prevalence, cause and treatment strategy. World Health Organization, 2010.

Condition	Prevalence/Impact	Cause	Treatment
Cataract	Responsible for 48% of worldwide blindness	Opacification of the crystalline lens due to environmental insult, oxidation, advancing age	Emulsification of cataractous region, implantation with an intraocular lens implant
Trachoma	84 million people worldwide affected, and responsible for at least 3% of world blindness	Chlamydia	Antibiotics, surgical intervention
Onchocerciasis (river blindness)	More than 17.7 million affected worldwide, and 90% occurring in Africa	Parasite transmission	Pharmaceutical treatment
Childhood blindness	1.4 million children worldwide	Nutritional deficiencies, heredity, retinopathy of prematurity	Nutritional supplementation (vitamin A), pharmaceuticals, proper medical care throughout the lifespan
Refractive errors and low vision	Refractive errors responsible for blindness in 5 million people, and 124 million people affected by low vision worldwide	Various affecting axial length, degenerative disease	Optical correction and vision devices
Diabetic retinopathy	Cause of 5% of world blindness	Diabetes; result of thickening in retina due to growth of new blood vessels	Glycemic sontrol, photocoagulation of retinal vasculature
Glaucoma	65 million reported cases world wide	Risk factors include age and genetics; however, exact causes are still unknown	Early medical diagnosis, surgical intervention, medication
Age related macular degeneration	Responsible for 8.7% of world blindness	Degenerative lesions and circulatory dysfunctions	No reported efficacious treatment
Corneal opacities	Responsible for 5.1% of world blindness	Corneal scarring due to xerophthalmia, nutritional deficiencies, injury	Surgical grafting of cornea
Genetic eye diseases	No available statistics on extent of genetic diseases worldwide; however, they are a significant cause of blindness in industrialized countries	Genetic	Surgery, gene therapy, grafting of retinal cells

and are difficult or particularly expensive to treat. Consequently, it is not surprising that research has already begun to address the prevention of these latter diseases.

Disease prevention should be a high priority

Disease prevention should undoubtedly be a high priority, but often requires substantial lifestyle modification over many years of life. Consequently, one major challenge has been to identify those specific lifestyle choices that have the highest probability of leading to reductions in disease incidence. This task is made even more difficult by the fact that the etiology of high-impact diseases such as AMD is clearly not uniform across populations. Thus, the importance of a given lifestyle modification probably depends upon the characteristics of the group being studied. For example, a central event in AMD development is the oxidation of polyunsaturated fatty acids in photoreceptor membranes, which probably results from stressors such as high-energy light being focused on the retina over decades of life. The products of this oxidation form adducts that elicit an immune response.[4] Individuals with a certain genotype, such as the CFH Y402H mutation, however, also have altered immune responses. Such alterations make this group even more susceptible to damage due to oxygen when compared to individuals without this specific mutation.[5] Ultimately, determining what changes are significant must be done on an individual level with due consideration of age, genotype, risk exposure, lifestyle habits, etc.

If, however, a single factor could be chosen that linked all of the various risk factors for degenerative disease, a strong argument could be made for choosing oxidative stress. Oxidative stress is central to many theories of both aging and degenerative diseases such as AMD and ARC. Oxidative stressors such as free radicals and reactive oxygen species are produced as a natural byproduct of cellular respiration and immune function, but most humans incur a higher free radical load than would be predicted by endogenous sources alone. Consequently, exogenous sources must be responsible for much of the free radical load. Fortunately, many of the lifestyle changes that can lead to increased or decreased oxidative damage can be identified and implemented. For example, one of the most consistent behavioral risk factors for AMD is smoking tobacco. Smoke contains numerous pro-oxidants, increases lipid oxidation *in vivo* and *in vitro*, and

lowers serum concentrations of antioxidant nutrients, such as vitamin C and carotenoids. According to this oxidative stress model of AMD and ARC development, by making the correct lifestyle choices (not smoking, increasing dietary intake of antioxidants, etc), oxidative stress to the retina and crystalline lens is lowered, and the probability that an individual will suffer age-related diseases such as AMD or ARC is reduced.

Dietary choices are of primary importance

An important implication of the oxidative stress model briefly presented above is the idea that dietary choices are of primary importance. Dietary choices can be classified into those choices that increase risk by promoting oxidative damage, and those choices that decrease risk by reducing or preventing oxidative damage. The purpose of this review is, therefore, to examine the dietary behaviors and dietary substances that influence some of the most impactful diseases on the Priority Eye Disease list, such as ARC, childhood diseases (such as retinopathy of prematurity, ROP), diabetic retinopathy, and AMD.

Age-related cataract

ARC is a condition that affects the crystalline lens (see **Figure 1**). Rarely, individuals are born with a congenital opacity that can be surgically removed at birth or early in childhood. More commonly, the crystalline lens undergoes a series of changes during senescence that results in ARC, the most common cause of blindness worldwide.[2] At birth, the crystalline lens is composed of epithelial cells that then elongate into clear fibers that lack organelles, co-localized with crystalline proteins (see Banh et al, 2006).[6] The cells of the lens do not undergo biological renewal; rather, old cells are compacted toward the nucleus of the lens, and new growth occurs on the lens exterior.[6] Older cells, located near the nucleus, tend to sustain damage over time, both from external sources and from internal sources.[7] As the proteins near the nucleus become oxidized, they tend to lose clarity (see Truscott, 2005).[7] Over years of environmental stress and lens expansion, the nucleus of the lens becomes opaque and the lens loses flexibility and the ability to accommodate, or to change its focal length depending on the size and distance of objects in the environment. In this condition, the individual presents with a nuclear cataract, which is the most common type of ARC.

ARC is one of the few age-related vision diseases that is treatable with high efficacy. The most common method for treating ARC is via emulsification and removal of the cataractous nucleus, followed by replacement of the emulsified region with an intraocular lens implant. This procedure is obviously surgical. In the United States and in many developed countries, cataract surgery is one of the most common surgical procedures performed. On average, for example, the United States spends over $3.5 billion in Medicare benefits on ARC alone.[8] As the world's population continues to age, ARC will likely increase in incidence, and the financial and quality-of-life burden will increase concomitantly.

Childhood blindness

Childhood blindness is a general term used to refer to a variety of conditions that can cause vision impairment in infants, young children and adolescents. Of all of the varied conditions that can cause childhood blindness, the two conditions that seem to be most impactful on a global scale are ROP and vitamin A deficiency.

ROP, formerly known as retrolental fibroplasia, is a condition that affects low birth weight (usually less than about 1,250 grams), premature (less than 31 weeks) infants. The risk of ROP increases proportionally to birth weight and gestational age: the smaller and more premature the infant, the higher the risk of ROP. Retinal development, especially the development of new retinal vasculature, is rapid during the last trimester of pregnancy (see Hellström et al, 2009).[9] Premature infants are often born before the new blood vessels originating from the optic disk can reach the edges of the retina. Premature birth can cause a lack of maternal oxygen and essential nutrients, which can then cause a cascade of pathological changes within the retina. When the normal process of neovascularization stops, this can then cause vasoconstriction, scarring, and retinal detachment. Once the retina is in a hypoxic state and suffering inadequate nutrition, its response is the growth of abnormal blood vessels, which often break and leak. One of the most common treatments for ROP is, consequently, laser and cryotherapy of the aberrant blood vessels. The majority of infants (>90%) with ROP are in the mildest category, which is associated with abnormal vision (e.g., restricted visual field), but not blindness. Premature birth is, however, common enough that the prevalence of severe ROP, which is associated with retinal detachment, severe neovascularization and blindness, is still significant worldwide. As medical technology improves and the survival rates of extremely premature, extremely low birth weight infants increase, severe ROP will also likely increase in incidence.

190 million children are deficient in vitamin A

The World Health Organization has estimated that about 190 million children under the age of five are deficient in vitamin A. 250 to 500,000 of these children will become legally blind from the deficiency and most of those will be dead within a year. Vitamin A is essential for vision because, in the form of retinal, it binds with a protein opsin (in its 11-cis configuration) to form photopigment. Retinal straightens (changes to its all-trans-form) when exposed to
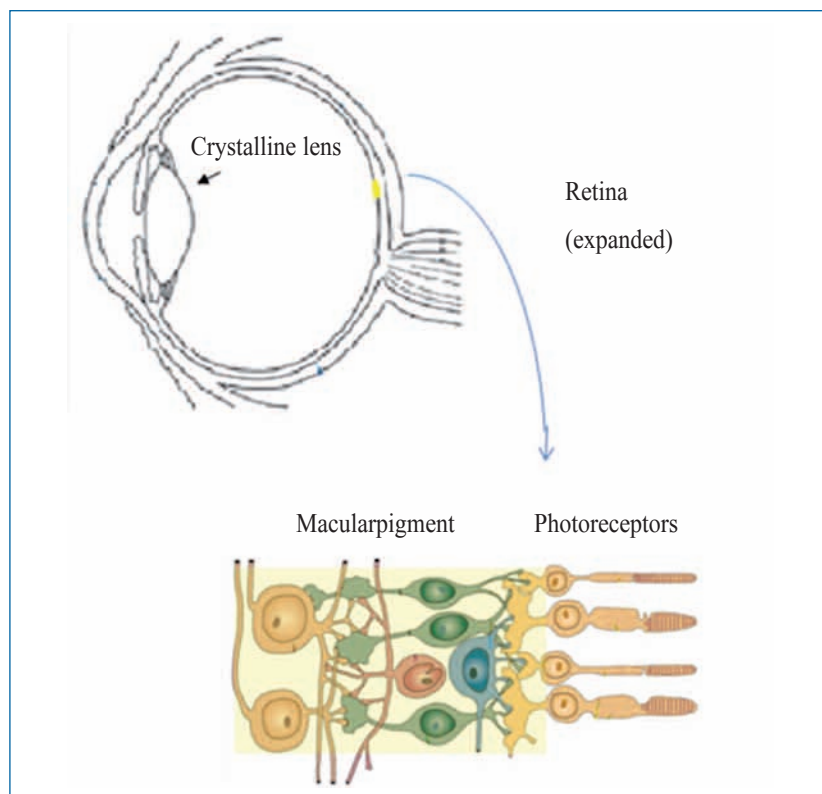
Figure 1: A schematic showing the crystalline lens and the neural retina lining the back of the eye. The expanded retina on the right shows the yellow macular pigments in the inner retinal layers.

(Figure labels: Crystalline lens; Retina (expanded); Macularpigment; Photoreceptors)

light and it is this process that initiates the activation of the photorector. When a child is deficient, the more numerous rods are initially affected and night blindness (nyctalopia) results. The idea that carrots are "good for your eyes" is based on the fact that carrots are rich in β-carotene which is a pro-vitamin A carotenoid that can be coverted to vitamin A. Glycoprotein synthesis and endothelial cell function also require vitamin A (now in the form of retinol). Hence, deficiency can lead to corneal dryness and ulcerations, and eventually blinding, conditions that are common in children from developing countries.

two forms, "dry" and "wet". The "dry" or nonexudative form involves both atrophic and hypertrophic changes in the retinal pigment epithelium (RPE) underlying the central retina (i.e. macula), as well as deposits, called drusen, on the RPE. Patients with nonexudative AMD can and often do progress to the "wet" or exudative form of AMD, in which abnormal blood vessels develop under the retina, leak fluid and blood, and ultimately cause a blinding "disciform" scar in and under the retina in a relatively short amount of time. The exudative form is thought to be responsible for the majority of blindness in patients with AMD.
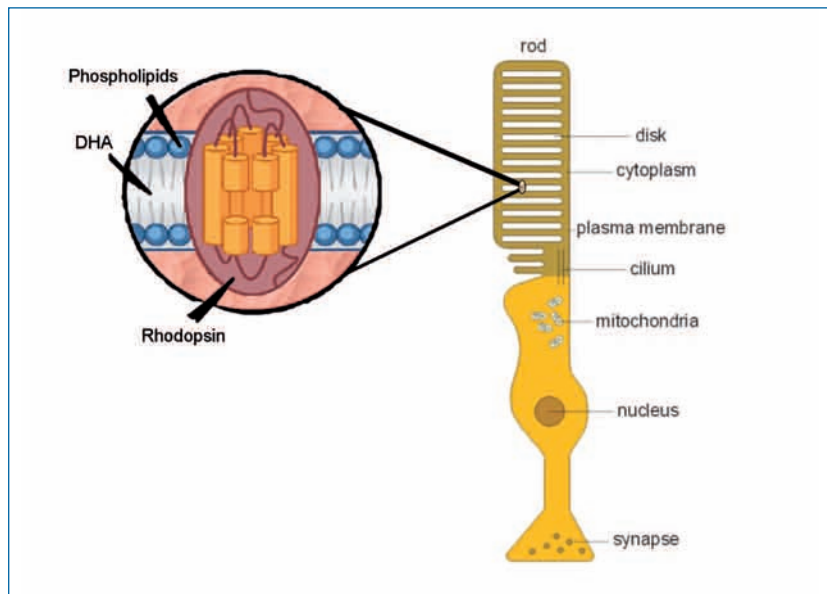
Diabetic retinopathy

Diabetes is pandemic and worsening. The prevalence of diabetes is projected to rise to 366 million people by 2030, an increase of almost 40 percent since the year 2000.[10] The most common form of diabetes (Type II or adult-onset diabetes) is a disease characterized by membrane insensitivity to insulin. This insensitivity is due to multiple factors, including genetic susceptibility and overexposure to insulin caused by excessive sugar intake. In the absence of sufficient glucose, insulin-resistant cells send out angiogenic cytokines that promote neovascularization. Tissues with high metabolic needs, like the retina, are particularly affected.

Structure of a rod cell. Rod cells in the retina can function in less intense light than can cone cells.

The retinopathy resulting from diabetic complications follows a similar pattern to the retinopathy seen after birth in ROP: new, weak blood vessel growth occurs in order increase sugar delivery to retinal tissues with high, unmet metabolic demand. Treatment procedures are also similar to those for ROP: new blood vessels are cauterized with lasers, often with the aid of photosensitizers (photodynamic therapy).

Age-related macular degeneration

AMD is a progressive neural degenerative condition affecting the macular region of the retina and the retinal pigment epithelium (or "RPE"). AMD is the leading cause of blindness in developed countries and is the third leading cause of blindness worldwide.[2] AMD's etiology is complex; the damage that ultimately leads to AMD accrues over a lifetime, and that damage, once incurred, is thought to be irreversible. Traditionally, physicians have classified AMD into

Once AMD becomes exudative, laser photocoagulation and photodynamic therapy are the standard treatments to control the growth of new blood vessels. Treatment efficacy, however, remains low; thus, great interest exists in delaying the progression of AMD and more effectively treating the factors leading to vision loss once AMD is diagnosed.

Although damage within the RPE (the supportive tissue behind the retina) is one of the primary developmental features of AMD, it is the loss of the overlying photoreceptors that ultimately leads to loss of visual function. Losses within the RPE and retina occur throughout life. It is typically only later in life, however, that the declination of visual function is observed. Indeed, older subjects and patients often classified with "early or atrophic AMD" often present with minimal losses in every day visual performance. The fact that visual function loss does not seem to parallel the damage leading to the disease may be due to the fact

that central nervous tissue (including the neural retina) is capable of compensating for this loss. Certainly, it would be advantageous for the brain to compensate for age-related losses in order to maintain optimal visual function as long as possible.

Although damage to the retina accumulates as a monotonic function of age, this effect is probably not linear. Children, for instance, tend to have very clear lenses, which transmit a higher percentage of energetic shorter-wave light. Photochemical damage to the retina and RPE is probably higher at this time (evidenced by increased accumulation of lipofuscin during adolescence) than later in life, when the lens yellows and transmits less actinic light. Such observations have led many scientists to conclude that, although AMD is manifest later in life, it reflects the accumulation of damage that occurs throughout life (e.g., Hammond et al, 2008) .[11] AMD, ultimately, is a disease of aging, where loss accrues over time and at some point is severe enough that the disease process begins.

Disease prevention strategies

The conditions listed on the Priority Eye Diseases list are varied in their etiologies and treatment strategies, which makes drawing a single conclusion about how to handle the problem of increasing incidence of many of these diseases difficult. Nevertheless, one point is clear: these conditions are often difficult to treat, and their treatment often requires expensive surgical intervention, which is impractical on a global scale. Furthermore, no efficacious treatment exists for some of these conditions (e.g., AMD), practical or otherwise. Consequently, as stated previously, emerging research should be focused on prevention of these conditions, rather than treatment alone.

Emerging research should focus on disease prevention

In 2005, the World Health Organization prepared the Vision 2020 Report, which made the striking claim that approximately 80 percent of the world's blindness is preventable. There are many possible strategies for prevention, including renewed focus on controlling vectors that can cause eye disease, such as the black-fly, which carries the *Onchocerca volvulus* parasite responsible for Onchocerciasis. Programs aimed at improving public health, sanitation, and reduction of sexually transmitted infections such as Chlamydia may also reduce sight loss. In the developed world and increasingly in developing countries too, strategies

aimed at combating diabetes and obesity may reduce risk for conditions such as Diabetic Retinopathy, and adequate sun protection may help reduce risk for ARC.

Many of the prevention strategies discussed above are promising. The bulk of the above strategies, however, are single strategies focused on a single condition, despite the fact that many of these conditions have common etiological features. As shown above, oxidative stress is part of the etiology for ARC, AMD, diabetic retinopathy and ROP. It should be noted that oxidative stress is also part of the etiologies of diseases such as cardiovascular disease and Alzheimer's disease and is the major component of aging itself. Inflammation and neovascularization are also common to the bulk of these diseases. Perhaps the best preventive approach is, then, one that targets all of these common issues. Diet is a likely candidate.

Nutrition as a *preventive* strategy

The Age-Related Eye Disease Study (AREDS, 2001)[12] was the first large intervention trial to be sponsored by the National Institutes of Health that examined the question of whether intervention with dietary nutrients could influence the progression of eye disease in elderly, highly susceptible, individuals. The four treatments were placebo, antioxidants, zinc, or antioxidants + zinc. The supplements contained (amount/day): 500 mg vitamin C, 400 IU all-rac-α-tocopherol acetate, 15 mg β-carotene, 80 mg zinc as zinc oxid with 2 mg copper as cupric oxide. This is now a common formulation that is used by ophthalmologists to promote eye health and retard disease progression. There were, however, several concerns about the formulation of these supplements. For example, β-carotene (not found in the eye, but the only carotenoid available at the time) was used in lieu of the xanthophylls which are concentrated in the vulnerable macula and are known to protect ocular tissues. Notwithstanding these limitations, the study yielded strong results. The largest result was that the combination of the antioxidant cocktail and zinc reduced the risk of disease progression by 25 percent for subjects with intermediate drusen or advanced AMD in one eye (from 16 percent risk over five yrs to 12 percent risk). Risk of vision loss was also reduced (around 19 percent) for these subjects. Since that original study, follow-up studies have focused on nutrients that are thought to be even more important to visual health. For example, AREDS II (2007)[13] included L and Z and found that these carotenoids were independently related to risk: those individuals that were in the highest quintile of dietary intake of L and Z had a 27 percent, 35 percent, and 55 percent lower probability of developing large or extensive

intermediate drusen, neovascular AMD, or geographic atrophy, respectively. Another large follow-up (12-year longitudinal design, 2009)[14] focused on omega-fatty acids and found that individuals in the highest quintile of omega-3 intake (e.g., DHA) had 30 percent less change of developing central geographic atrophy and neovascular AMD when compared to those in the lowest quintile. If aggressive nutritional intervention can be so effective at late stages, one can infer that optimal diet, starting in infancy and maintained over a lifespan, could have even more dramatic results.

A full description of all of the nutrients involved in the visual system would, of course, require a set of texts. What follows is simply a short description of the two recent nutrients that were the focus of the latests AREDs trials, polyunsaturated fatty acids such as docosahexaneoic acid (DHA) and the xanthophylls L and Z.

Xanthophylls

L, its isomer Z and a novel carotenoid, *meso*-zeaxanthin (MZ), formed in the retina itself, are found ubiquitously in ocular tissues, such as cornea, crystalline lens and retina. In the retina, they are the exclusive carotenoids located within the macula (here they reach levels that are over 10,000 times higher than those within circulating blood),[5] where they are termed macular pigment (MP). A large confluence of data (see Whitehead, 2006)[16] have consistently shown that L and Z protect the lens, retina and retinal pigment epithelium from the damage that accrues from long-term exposure to actinic light and reactive oxygen. Data from Seddon et al.[17] originally emphasized the importance of this prophylaxis on the prevention

of retinal disease. Seddon et al. found that individuals (n=356 AMD cases, n=520 controls) in the highest quintile of L+Z intake had a 43 percent lower risk of AMD compared with those in the lowest quintile. Direct measures of L and Z in retinal tissue supported this strong link to the disease. For instance, donor eyes with the highest levels of macular pigment are 82 percent less likely to have AMD when compared to donor eyes with the lowest levels of MP.[17,18] Many risk factors for AMD are correlated with low MP, including female gender, smoking, iris color, and body mass index (or "BMI").[19,20] A prospective study of 77,466 female nurses and 36,344 male health workers showed that individuals in the highest quintile of carotenoid intake (namely L and Z) had about a 20 percent less chance of cataract extraction compared to those in the lowest quintile of intake.[21,22]

This protection by L and Z is based on two complementary mechanisms: passive screening of highly energetic short-wave (blue) light and active quenching of reactive oxygen. Actinic blue light easily reaches the retina, is focused on the vulnerable macular area and can convert inert oxygen into its more reactive forms. L and Z strongly absorb this waveband of light (400–500 nm) and can reduce transmission in the central macula by as much as 98 percent. L and Z are found both in the inner retinal layers where they screen the vulnerable outer retina, as well as the lipid membranes of receptoral outer segments. This latter placement is optimal for protection against the peroxidation of membrane lipids. L and Z are known to quench the triplet state of photosensitizers, singlet oxygen[23] and oxygen radicals,[24] react with free radicals,[25,26] and retard the peroxidation of phos-

pholipids.[27] For example, a cell culture study in human lens epithelial cells (where L and Z are also found in the intact eye) showed that L and Z inhibited UVB-induced lipid peroxidation by 47–57 percent.[28] L supplementation reduces total hydroperoxide levels (a marker of oxidative stress) and increases antioxidant activity when measured in the blood of newborns.[29] Since infancy represents a time of special vulnerability,[11] such protection is likely vital.

Docosahexaenoic acid

The fatty acid composition of neuronal cells, including those of the retina, appears to be central to optimal neural function. For instance, DHA is exceptionally dense in the lipid membranes of photoreceptors. This high concentration confers great fluidity to the receptoral membrane. In the absence of a diet sufficient in DHA (a common occurrence with the declining quality of diets), DHA is replaced by docosapentaeonoic acid (or "DPA"). This replacement results in a significant loss in membrane fluidity.[30]

DHA, along with another polyunsaturated fatty acid, eicosapentaenoic acid (or "EPA"), have other important protective effects. They modulate retinal cell gene expression and promote cellular differentiation and survival. They are also effective anti-inflammatory agents.[31] DHA, for instance, is a precursor for neuroprotectin D1 (or "NPD1"). NPD1 promotes RPE cell survival by inhibiting the induction of pro-inflammatory genes and apoptosis in response to oxidative stress.[32,33] Animal modeling[34] has shown that NPD1, RVDI (another DHA derivative), and RVE1 (an EPA derivative) protect against retinal vascular dis-
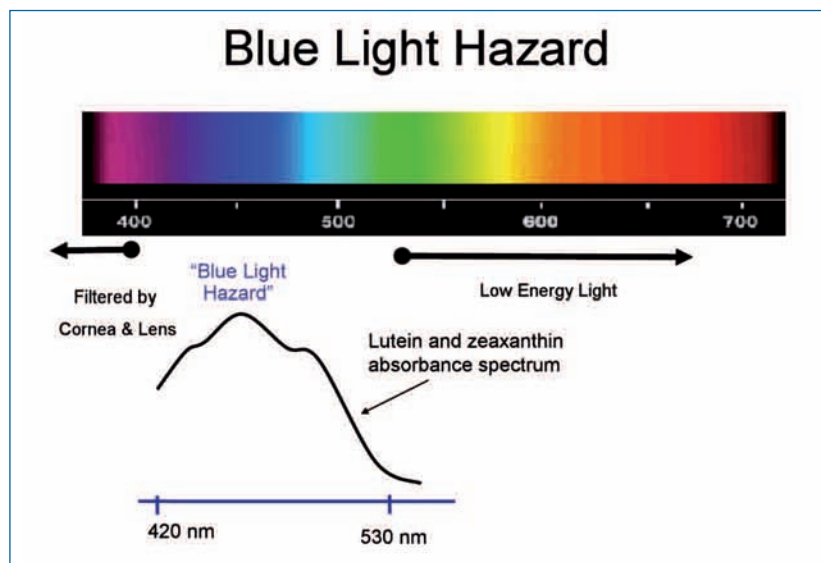
Lutein and zeaxanthin protect the retina by absorbing damaging 'blue' light.

ease.[34] Consistent with these studies, a recent meta-analysis[35] showed that high intake of polyunsaturated fatty acids was related to a 38 percent reduction of AMD. The Blue Mountain Eye study[36] has shown that eating fish (rich in polyunsaturated fatty acids) is associated with a 40 percent reduction in the incidence of early AMD.

Nutrition as a *treatment* strategy

Eye disease is ultimately characterized by sight loss. Recently, it has become quite clear that many nutrients have the potential for ameliorating such loss. For example, Richer et al.[37] tested the effects of L supplementation in a double-masked placebo controlled study of veterans (average age = 65 years) with early stage AMD. They found that the L-treated group showed improvements in visual function, such as Snellen acuity. These palliative improvements were directly related to increases in their MP density. Olmedilla et al.[38] tested the visual effects of L supplementation on ARC patients also using a double-masked placebo controlled design. They also found improvements in visual acuity in only those patients supplemented with L. Similar to Richer et al., the ARC subjects in the Olmedilla et al. study also showed reductions in glare sensitivity after the two-year L supplementation period.

Many nutrients have the potential for ameliorating sight loss

Glare disability and discomfort are common problems for the elderly and individuals with cataracts and

AMD. As the eye ages, lenticular cells become increasingly disordered and scatter light towards the back of the eye (about 70 percent of the scatter comes from the lens, most of the rest comes from the cornea). Stringham and Hammond,[39] studying young, healthy subjects, found a direct relationship ($r = 0.76$) between retinal L and Z levels and the ability to withstand scattered light in the eye and recover from a blinding light exposure. In a follow-up study, Stringham and Hammond[40] supplemented subjects for six months with 12 mg of L and Z. This intervention raised subjects' MP levels and improved their ability to see under conditions of disabling glare by 58 percent and significantly shortened their photostress recovery.

Effects on vision are not relegated to nutritional influences on the eye itself. The brain is responsible for processing the signals that are initiated by the retina. Hence, effects on the brain might also be expected to influence visual processing. This expectation is consistent with data showing that L and Z levels within the retina (a good proxy indicator for levels within the brain) are related to faster visual processing speeds[41,42] and even cognition.[43] These central effects might be even more pronounced when xanthophylls are combined with DHA.[44] These effects may also be important for neural development. Meta-analyses (e.g., SanGiovanni et al.[45]) of all available data suggest that sufficient long-chain polyunsaturated fatty acid intake is critical to early visual system development. Nutrients like L, Z and DHA might not only protect the visual system but also promote its optimal function and development.

Conclusion

Prior to the advent of effective antibiotics, infectious disease was the primary source of human morbidity and mortality. Infectious diseases are still quite common in areas where medical facilities are still quite limited. In developed countries, however, degenerative diseases such as acquired cancers, neurodegenerative disease and cardiovascular disease are more prevalent and are expected to increase in incidence across the world as the world's population ages. These diseases, such as AMD and ARC, develop slowly over many years of life and have a disproportionately large impact

upon the elderly. Because they develop slowly, however, lifestyle then becomes a much more serious contributor to their development. Optimal dietary behavior over the lifespan, for instance, is probably of primary importance. Indeed, poor diet is a factor linking most of the acquired diseases emphasized on the Priority Eye Disease list.
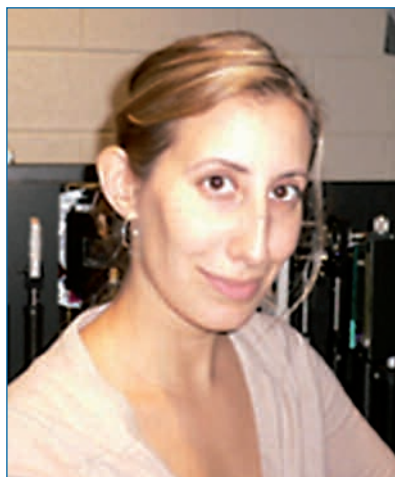

Lutein and zeaxanthin speed recovery after exposure to a blinding light source.

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