Ultraviolet Radiation as a Risk Factor for Cataract and Macular Degeneration

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Abstract: The human eye is constantly exposed to sunlight and artificial lighting. Light transmission through the eye is fundamental to its unique biological functions of directing vision and circadian rhythm, and therefore, light absorbed by the eye must be benign. However, exposure to the intense ambient radiation can pose a hazard particularly if the recipient is over 40 years of age. This radiation exposure can lead to impaired vision and transient or permanent blindness.

Both ultraviolet-A (UV-A) and UV-B induce cataract formation and are not necessary for sight. Ultraviolet radiation is also a risk factor for damage to the retinas of children. The removal of these wavelengths from ocular exposure will greatly reduce the risk of early cataract and retinal damage. One way this may be easily done is by wearing sunglasses that block wavelengths below 400 nm (marked 400 on the glasses). However, because of the geometry of the eye, these glasses must be wraparound sunglasses to prevent reflective UV radiation from reaching the eye. Additional protection may be offered by contact lenses that absorb significant amounts of UV radiation.

In addition to UV radiation, short blue visible light (400–440 nm) is a risk factor for the adult human retina. This wavelength of light is not essential for sight and not necessary for a circadian rhythm response. For those over 50 years old, it would be of value to remove these wavelengths of light with specially designed sunglasses or contact lenses to reduce the risk of age-related macular degeneration.

Key Words: Ultraviolet radiation—Cataract—Blue light hazard—Macular degeneration—Singlet oxygen—Superoxide—Xantherenic acid—Lipofuscin—A2E—Contact lens.

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INTRODUCTION

Aside from the skin, the eye is the organ most susceptible to sunlight and artificial lighting–induced damage. Solar radiation exposes the eye to ultraviolet-B (UV-B; 280–315 nm), UV-A (315–400 nm), and visible light (400–700 nm).[1] Light is transmitted through the eye and then signals the brain directing both sight and circadian rhythm. Therefore, light absorbed by the eye must be benign.

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However, under certain circumstances, the eye may be damaged by solar and artificial radiation.

FACTORS THAT DETERMINE LIGHT DAMAGE TO THE EYE

The primary factors that determine whether ambient radiation will injure the human eye are the intensity of the light, the wavelength emitted and received by ocular tissues, and the age of the recipient.[2]

Intensity

The greater the intensity of light, the more likely it is to damage the eye. Light that may not ordinarily be harmful can cause acute damage if it is sufficiently intense. For example, it is well known that the eye can be damaged (temporarily or permanently) by exposure to sunlight reflected from snow (snow blindness) or by staring at the sun during an eclipse.[3,4] There is an increase in UV radiation with a thinning of the protective ozone layer.[5] Similarly, the eye can sustain damage from artificial light sources that emit UV-A or UV-B.[6] Cumulative light damage results from less intense exposure over a longer period of time and is often a result of an underlying age-related loss of protection.[7,8]

Wavelength

Ambient radiation, from the sun or from artificial light sources, contains varying amounts of UV-C (100–280 nm), UV-B (280–315 nm), UV-A (315–400 nm), and visible (400–700 nm) light.[1] The shorter the wavelength, the greater the energy and therefore the greater the potential for the radiation to do biological damage. However, although the longer wavelengths are less energetic, they more deeply penetrate ocular tissues.[9]

For a photochemical reaction to occur, the light source must be absorbed in a particular ocular tissue. The human eye and most primates have unique filtering characteristics that determine in which area of the eye each wavelength of light will be absorbed. All radiation below 295 nm is filtered by the human cornea (all UV-C and some UV-B) before they reach the human lens.[10] The transmission characteristics of the human lens change with age. In adults, the lens absorbs UV-B above 295 nm and all of UV-A (295–400 nm). However, the young human lens transmits a small window of UV-B light (320 nm) to the retina, whereas the elderly lens filters out much of the short blue visible light (400–500 nm).[11] Transmission characteristics through ocular tissues also differ with species; the lenses of mammals other than primates transmit UV light longer than 295 nm to the retina.[12]

Age

Most damage by ambient light to the young and adult eye is avoided because the eye is protected by an efficient antioxidant system. In addition, there are protective pigments located in the young and adult retina and adult lens, which absorb ambient radiation and dissipate its energy without causing damage.[13,14] After middle age (40 years), there is a decrease in the production of ocular antioxidants and antioxidant enzymes. At the same time, the protective pigments are chemically modified, and now, these ocular pigments damage the lens and retina on exposure to ambient radiation.[15,16]

MECHANISM OF LIGHT DAMAGE TO THE EYE

There are two major mechanisms for light damage to the eye: an inflammatory response and phototoxidation.

Inflammatory Response

Acute exposure to intense radiation, for example, exposure to sunlight reflected from snow (snow blindness), or from staring at the sun during an eclipse,[3] or directly staring at an artificial light source that emits UV-A or UV-B[6,17] causes a burn in the eye similar to a sunburn. This results in an inflammatory response in the eye that can damage the cornea, lens, and retina.

The eye is immune privileged, which means that under ordinary stress its immune response is suppressed.[18] However, in the presence of very intense UV and visible light (for instance, emitted from lasers),[6,17] this suppression is overwhelmed. There is a release of interleukin-1, a T-cell and macrophage invasion at the site of irritation and a subsequent release of superoxide and peroxides and other reactive oxygen species, which eventually damage the ocular tissues.

Photooxidation

Chronic exposure to less intense radiation damages the eye through a phototoxidation reaction. In photooxidation reactions, a pigment in the eye absorbs light, produces reactive oxygen species such as singlet oxygen and superoxide, and these damage ocular tissues. The pigment may be endogenous (natural) or exogenous (drug, herbal medication, or nanoparticle that has accumulated in the eye).[19]

Absorption of light excites the pigment to an excited singlet state, which then undergoes intersystem crossing and reaches the triplet state. In its triplet state, the pigment then proceeds either by a type 1 (free radical) or type 2 (singlet oxygen) mechanism to cause the eventual damage. Photooxidation can occur in the eye by a type 1 mechanism, a type 2 mechanism, or by both concurrently.[20] If the pigment is excited by ambient radiation to the excited state (singlet) but very quickly (nanoseconds) goes back to the ground state, it will safely dissipate the energy received.[13]

HUMAN LENS

The lens is a transparent organ[21] located behind the cornea and the iris. The outer edge of the eye consists of a single layer of epithelial cells and a membrane that covers the entire organ.[22] Lens epithelial cells do not divide except when undergoing repair. Some epithelial cells lose their nuclei, and other organelles and become lens fiber cells.[23] These lens fiber cells are filled with a 30% solution of protein, known as cytosol (soluble) lens protein. Because there is little protein turnover in the lens fiber cells, damage to lens protein accumulates throughout life.[24]

CATARACTS

The primary function of the human lens is to focus light undistorted onto the retina. Although the transmission properties of most of the components of the eye are stable, the transmission properties of the lens change throughout life. The lens is clear for the first 3 years of life and then gradually develops yellow pigments (3-hydroxy kynurenine and its glucoside). This is a protective pigment, which absorbs UV radiation and safely dissipates its energy.[13]

As long as that pigment is present, no UV-A or UV-B radiation reaches the retina, and in this way, the adult human retina is protected against normal levels of UV radiation.[25] However, children are at particular risk for UV damage to the retina because UV is directly transmitted to their retinas.[11]

Intense acute UV radiation or chronic UV exposure, particularly in the presence of a photosensitizing dye or drug, will lead the formation of a cataract (a clouding of the lens). Any modification in the clarity of the lens impairs vision and has a dramatic effect on retinal function.[2,19]

The most common type of cataract is age related. More than 50% of those over 65 years of age suffer from cataracts, and this increases to 75% by the age of 75.[2] Cataracts induced by phototoxic dyes and drugs may occur as early as 40 years of age or sooner.[19]

The reason why there is an almost universal cataract formation among the elderly is that after middle age the protective pigment 3-hydroxy kynurenine is enzymatically converted into the phototoxic chromophore xanthurenic acid. Xanthurenic acid in the lens absorbs UV radiation, forms a triplet, and produces singlet oxygen and superoxide.[15,26–29] At the same time, there is a decrease in the production of antioxidants and antioxidant enzymes, which would normally quench these reactive oxygen species.[2] As a result, both the lens epithelial cells and lens proteins are injured, which results in the eventual clouding of the lens.

HUMAN RETINA

The retina is composed of the photoreceptor cells (rods and cones) that receive light and the neural portion (ganglion, amacrine, horizontal, and bipolar cells) that transduces light signals through the retina to the optic nerve. Behind the photoreceptor cells are the retinal pigment epithelial cells (RPEs), Bruchs membrane, and the posterior choroid. The function of the RPEs is to provide nutrient support (ions, fluid, and metabolites) and remove light-damaged debris from the rods and cones.[30]

MACULAR AND RETINAL DEGENERATION

The young retina is at particular risk for damage from UV exposure because the young lens has not as yet synthesized the yellow pigment that prevents UV transmission to the retina.[13,25] The UV damage to the eye is cumulative and may increase the possibility of developing eye disorders (ocular melanoma and macular degeneration) later in life.

If the UV radiation is of a sufficient intensity, the adult retina may be damaged through an inflammatory response. Staring at the

eclipse of the sun or a UV-emitting lamp, reflective UV from snow, sand, or water all enhance the intensity of UV radiation to the point where it may overwhelm even the filtering characteristics of the adult human lens.[3,6] The RPEs and choroid contain melanin, which absorbs UV and protects the retina against UV-induced damage. However, with age, ocular melanin is photobleached, and this decreases its protective effectiveness against UV damage.[14] Other chromophores may offer some protection to the retina against transretinal UV damage.[31,32]

In addition to UV damage to the adult retina, short blue visible light (430 nm) damages the retina in those over 50 years of age through a photooxidation reaction.[2,33–35] There is a phototoxic pigment, lipofuscin, which accumulates with age.[36,37] In response to short blue visible light (430 nm), lipofuscin produces singlet oxygen, superoxide, and free radicals.[38,39] These reactive oxygen species damage the RPEs. Because a primary function of the RPEs is to nourish the rods and cones, they eventually die resulting in a loss of (central) vision (macular degeneration).

Ordinarily lutein and zeaxanthan in the macular (center) of the retina[40] and glutathione[41] throughout the eye protects the retina against both inflammatory and photooxidative damage. Unfortunately, with age, these protective agents become depleted, and the retina loses its protection against singlet oxygen and free radicals.[41–43] Macular degeneration is the leading cause of irreversible blindness in the elderly.[44,45]

PROTECTION OF THE EYE

Antioxidants

Because age decreases the normal production of antioxidants in the eye, increasing the intake of fruits and vegetables has been suggested to replace the missing protection[46,47] and have been found to retard age-related cataracts and macular degeneration. In addition, supplementation with vitamins and antioxidants, including Vitamin E and lutein, quenches photooxidative damage,[48–50] whereas *N*-acetyl cysteine has been shown to be particularly effective in quenching UV phototoxic damage and inflammation.[51,52]

Other natural products such as green tea, which contains polyphenols (epigallocatechin gallate)[53] and Ashwagandha (root of Withania somnifera) used in traditional Ayurvedic medicine has also been shown to retard light-induced damage to the lens.[54]

Supplements should be balanced because damaging oxidation reactions can occur if only one antioxidant is taken.[55,56] In the The Age-Related Eye Disease Study sponsored by the National Eye Institute http://www.nei.nih.gov/amd/, it was found that excessive β-carotene was linked with increased risk for lung cancer for smokers, whereas excessive Zn was linked with an increased risk of developing prostate cancer. Because lutein, not β-carotene, is the carotenoid found in the lens and retina,[40] supplementation with β-carotene is not only unnecessary but is also hazardous.

Sunglasses and Contact Lenses

Both UV-A and UV-B induce cataract formation and are not necessary for sight. Ultraviolet radiation is also a risk factor for damage to the retinas of children. The removal of these wavelengths from ocular exposure will greatly reduce the risk of early cataract and retinal damage. One way this may be easily achieved is by wearing sunglasses that block wavelengths below 400 nm (marked 400 on the glasses). However, because of the geometry of the eye, these glasses must be wraparound sunglasses to prevent reflective UV radiation from reaching the eye[3,4,57]. Additional protection may be offered by contact lenses that absorb significant amounts of UV radiation.

In addition to UV radiation, short blue visible light (400–440 nm) is a risk factor for age related damage to the human retina. This wavelength of light is not essential for sight and not necessary for a circadian rhythm response. For those over 50 years old, it would be of value to remove these wavelengths of light with specially designed sunglasses or contact lenses to reduce the risk of macular degeneration.

CONCLUSIONS

Macular degeneration and cataract formation are age-related diseases. There are sufficient scientific data to prove that both UV-A and UV-B are very important risk factors for the development of these age-related diseases. Avoidance of UV light by using appropriate sunglasses and type 1 UV protective contact lenses may dramatically decrease the risk of developing these blinding diseases. Exposure to short blue visible light (430 nm) increases the risk of macular degeneration. Appropriate combination of oxidizing and reducing antioxidants (lutein, zeaxanthin, vitamin E, C, Zn, and Cu) supplementation and short blue filtering contact lenses may help retard or eliminate this blinding disorder in the elderly.

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