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A REVIEW OF THE EFFECTS OF ULTRAVIOLET LIGHT ON THE VISUAL SYSTEM

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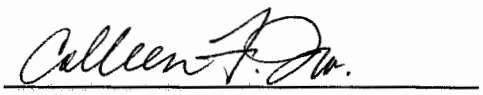

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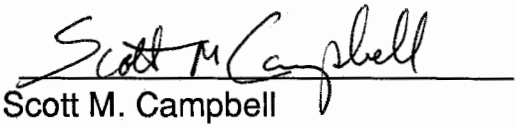

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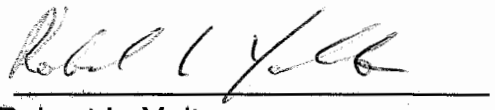

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ABSTRACT

An accumulation of epidemiologic and experimental studies support the notion that ultraviolet radiation may be hazardous to the human eye. This review will examine the role and effects of ultraviolet radiation on the visual system as well as present some prescribing considerations for the eye professional with regards to ultraviolet radiation.

INTRODUCTION

Over the last two decades a steadily increasing interest in the effects of ultraviolet radiation (UVR) has been voiced by the general public. Being a primary care health practitioner/eye professional neccessitates a sound understanding of therapeutic, occupational, genetic, demographic and legal considerations when offering advice or prescribing for ultraviolet (UV) protection. The consumer seems to be caught up in the media blitz promoting UV protection but very few are aware of why the protection is beneficial, presenting yet another avenue to build a practice through patient education.

Between the ages of 45 and 65, 75% of americans will suffer from lens clouding. Experts once thought that cataracts were unpreventable and unpredictable. But more than a dozen studies in the last decade have clearly linked the problem to UV radiation.[1,2,3,4] In fact, the relationship of UV radiation and cataracts has progressed to the point where it is likened to that of smoking and lung cancer. Recently Corning made a statement in their November 11, 1987 "Dispensing Info": "There is no conclusive scientific proof that either UVA or UVB has any effect on the cause of the growth of cataracts in humans." These statements are true when taken literally, (because it is impossible to experiment on humans), however UV has been shown to cause cataracts and retinal damage in mice. This statement is very similar to claims that the tobacco industry was making 10 years ago. At that time, there was no conclusive proof that cigarette smoking caused cancer; however, there was a large body of evidence that pointed in that direction (smoking caused cancer in mice). Smoking does not cause cancer in all smokers, therefore, the cancer is probably a multifactorial consequence.

On the other hand, psychologists are beginning to explore the beneficial effects of UV light on our emotional and mental status. The point at which UVR becomes detrimental is extremely difficult to determine and is dependent on several factors which include length of exposure, intensity of exposure, and the individuals' predisposing condition.

Definition and Sources of Ultraviolet Radiation

What is ultraviolet radiation? UVR is the section of the solar light spectrum between 200nm and 400nm (nanometers). The UV spectrum is subdivided into three categories: UVA, UVB, and UVC.

1) UVC is the lowest part of the spectrum between 200nm and 286nm and is filtered by the ozone layer in the earth's atmosphere, so presently has nc measurable effect. These wavelengths can be produced by welding arcs and germicidal lamps.[1]

2) UVB is the central part of the spectrum, from 286nm to 320nm. UVB is the solar energy which causes you skin to tan or burn.

3) UVA is from 320nm to 400nm and is the closest to the visual spectrum and foı many years was considered harmless; however, in recent years (as previously stated) much research has been done on UVA and its effect on the human eye. Many top researchers believe UVA and UVB have a damaging effect on the eye with chronic low-dose exposure[5].

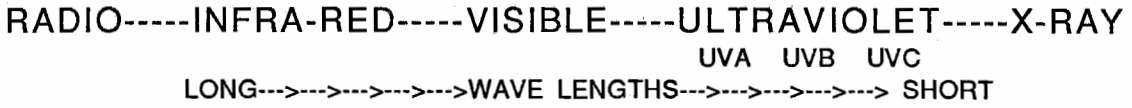

Figure 1. The electromagnetic spectrum

While the main source of ultraviolet radiation is the sun, especially for those living in the sun belt, it is not the only source of UV. There are many man-made sources of near UV (UVB and UVA) such as Xenon arc lamps, photo-flood lamps, and high intensity mercury lamps. Even common flourescent lamps such as daylight and cool white produce small amounts of UV radiation.

Role and Effects of Ultraviolet Radiation

Injury to ocular tissues occurs either by photochemical (ionizing radiation) or thermal (non-ionizing radiation) mechanisms. Photochemical mechanisms are associated with the ultraviolet radiation bands (UVC, UVB, UVA) and the short wavelength region of

the visible spectrum. With ionizing radiation, the energy of individual photons of electromagnetic energy is sufficient enough to convert individual molecules into free radicals which may severely damage biological structures.[1] Free radicals are unstable short-lived structures which are toxic to tissues.[6] Ocular insult due to photochemical mechanisms requires a repeated series of short rapid bursts or prolonged exposure (ten seconds to days). Thermal injury can be attributed to brief intense acute exposures (100 milliseconds to 10 seconds) and predominately occurs in the infrared bands (IRA, IRB, IRC). Non-ionizing radiation may adversely affect ocular structures by emitting heat. In reality, a transitional range (in the UVA band) exists where both photochemical and thermal effects occur.

Phototoxicity is dependent on the ability of specific ocular tissues to absorb specific wavelengths. Figure 2. illustrates the average absorption characteristics of the ocular media to the shorter wavelength UVR.

The near ultraviolet and lower wavelength visible radiation have been identified as the etiologic agent of numerous detrimental ocular conditions. These are discussed below.

CORNEAL AND CONJUNCTIVAL PHOTOTOXICITY

The most common effect of UVR on the cornea is acute epithelial damage associated with photokeratoconjunctivitis. This condition can be produced by welding systems or approximately one hour of skiing in bright sunlight ('welders flash' or 'snowblindness', respectively).[3] Photokeratoconjunctivitis may result from exposure to light between 180nm to 380nm. However, the effects of UVR become increasingly apparent at approximately 325nm.

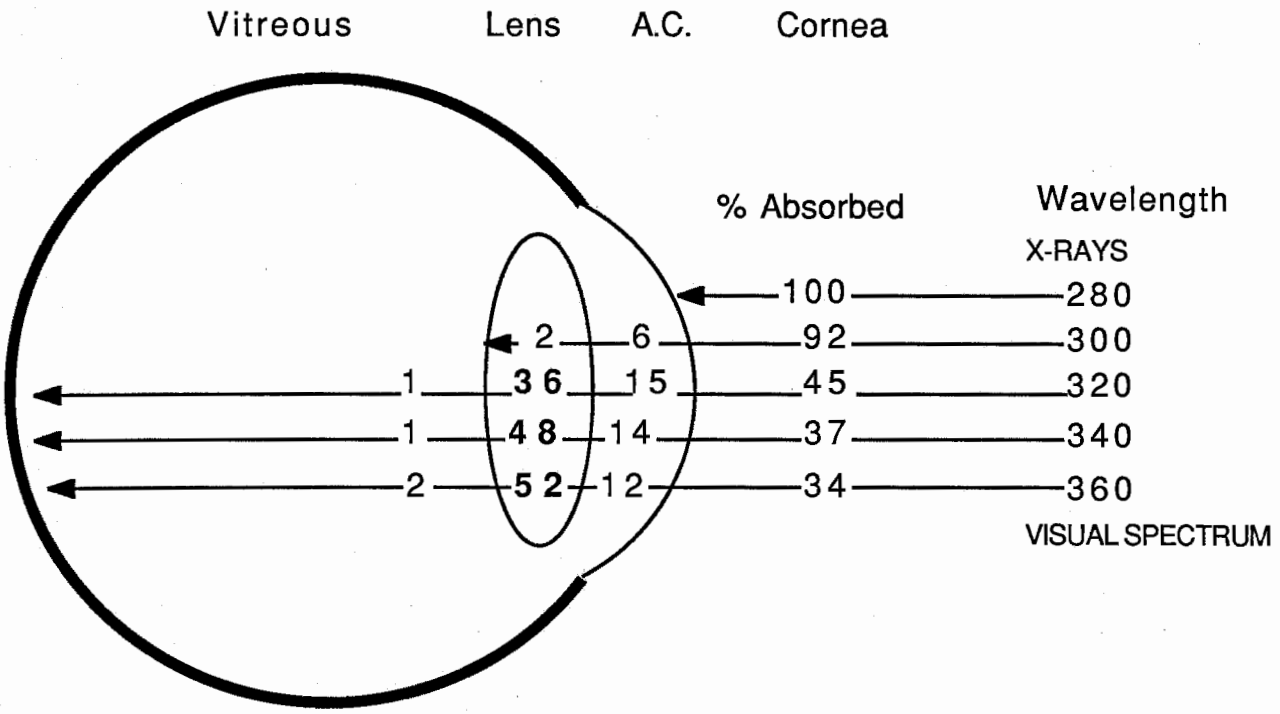

FIGURE 2. Absorption characteristics of ocular media to UVR

After a latency period of 6-12 hours, photokeratoconjunctivitis presents as erythema, lacrimation and blepharospasm, with moderate to severe photophobia.[1] In response to the UVR, the epithelial cells slough off and expose nerve endings which accounts for the painful symptoms encountered. The epithelial cells will be replaced and subsequently, almost all discomfort will disappear within 48 hours. Recently, stromal and permanent endothelium cell damage have also been demonstrated.[7] Ultraviolet energy levels consistent with sunbathing on the beach have also been associated with corneal polymegathism (eight days after exposure).[8]

In specific geographic areas, characterized by unshaded and highly reflective environments, an associated group of corneal degenerations have been identified. These degenerations present with a common histological appearance including nodular band keratopathies: Labrador keratopathy, Bietti's corneal degeneration, and droplet degeneration of the cornea. White or yellow-brown nodular opacities between the epithelium and Bowman's layer are distributed bilaterally and symetrically in the interpalpebral areas. Because the degenerations occur in a "band" across the cornea within the palpebral aperture, it is suggested that the condition may be caused by environmental exposure.[2]

The incidence of pinguecula is greater in regions of strong sunlight and among outdoor persons. Although no quantitative studies have been performed, the association between pinguecula and UVR is broadly accepted. The role of UVR in pterygium is not as well defined or accepted. Physical agents other than (or in addition to) UVR, such as wind, dust, and aridness seem to have a significant role in the development of pterygia.

The only ocular carcinoma directly associated with UVR is

epidermoid carcinoma of the bulbar conjunctiva. This cancer appears with greater frequency in the tropics and subtropics . Similar malignant tumors could be produced in experimental lab animals who were exposed to UVR. [9]

IRIS PHOTOTOXICITY

A recent study by Tucker, et al, has suggested that UVR may an important contributing factor in the pathogenesis of uveal malignant melanomas.[10] The majority of these tumors occur in the iris and especially in individuals with light irides. The protective function of melanin, which accounts for iris color, is to absorb UV and neutralize the free radicals which are formed by the radiation rupture of molecular bonds. Malignant melanomas may result due to lack of adequate amounts of melanin.[13]

LENS PHOTOTOXICITY

The human lens absorbs ultraviolet radiation between 305nm and 400nm, with a peak absorbance of 360nm. Therefore, both photochemical and thermal insult may occur to lens proteins, membranes and deoxyribonucleic acid (DNA) as a result of exposure to intense UVR. In vivo studies have demonstrated that UVR can induce experimental cataracts in mouse, rat, rabbit, and primates.[6] Several laboratories have demonstrated that anterior sub-capsular cataracts can be induced by intense exposure to UVR.[11] Epidemiologic studies by Zigman and co-workers[4], suggest a correlation between hours of solar exposure and cataractogenesis. They observed a remarkable increase in brunescent cataracts with decreasing latitude: 10% increase at 35 degrees north, 20% at 27

degrees north, and 50% at 15 degrees north. Upon absorption of UVR, the lens accumulates fluorescent chromophores (yellow pigments) primarily within the lens nucleus due to photochemical mechanisms. It is important to note that this discoloration does not necessarily constitute a cataract. Ironically, the yellowing of the crystalline lens is beneficial because it filters UV and short wavelength visible radiation and therefore may protect the retina from cumulative phototoxicity.

Despite the abundance of studies, authorities are hesitant to implicate the direct correlation of UVR in cataractogenesis. Difficulties in proof of causation include unmatched genetic variablility, dietary and water differences, relative health, and malnutrition.[2]

RETINAL PHOTOTOXICITY

The media of the human eye transmit to the retina wavelengths between approximately 400 and 1400nm. Only a small fraction of near UVR actually reaches the retinal tissues. According to Sliney[12], it is less than 0.1% in a normal phakic adult. Currently, ophthalmologists are implanting intraocular lenses with UVR protective materials to simulate the properties of the normal human crystalline lens. However, it is also important to prescribe sunglasses for aphakic and pseudophakic patients to protect the cornea during UVR exposure.

The shorter wavelength segment of the visible region (400 to 500nm) is significantly more hazardous to the retina than the longer wavelength portion (from 500 to 700nm).[13] Between 325 and 350nm, the retina is approximately six times more sensitive to damage than it is to short wavelength visible radiation of 441nm.[14]

Between 325 and 350nm, the perceived colors are green and blue, therefore, the phenomenon is termed the "blue-light hazard". Both photochemical and thermal mechanisms contribute to retinal damage, however, the former predominates under natural environmental conditions.

Solar Retinopathy

Permanent trauma to the retina has been observed after direct viewing of the sun and solar eclipses.[2] The 1% of incident energy in the 300 to 315nm spectral region that reaches the retina during childhood may be sufficient to cause foveomacular injury.

Age-related macular degeneration

Age-related macular degeneration (AMD) is characterized by a process of progressive deterioration which may ultimately result in cell death and loss of vision. Research has firmly established that the deterioration is most severe in the outer layers of the center of the retina.[13] The first sign of senescence is the appearance of residual bodies (lipofuscin) within the retinal pigment epithelium (RPE). Cellular impairment progresses and may produce a central scotoma, either directly from cell degeneration or indirectly from choriodal neovascular invasion of the extracellular deposits. A key factor in the etiology of age-related macular degeneration appears to be molecular damage corresponding to the location which is most exposed to radiant energy. In addition to UVR, other factors have been suggested to contribute to the etiology of AMD: age, age of onset of exposure, rate and spectral composition of exposure, outdoor activity patterns, race, family history of AMD, iris color, height, sex, nonspecific exposure to chemicals, hyperopia, systemic hypertension, cardiovascular disease, and cortical cataracts.[2,13] Currently, treatment involves optimizing the body's natural

defenses against photodynamic effects by dietary regulation, and, of course, protecting the retina from deleterious UVR by using the appropriate radiation filters.

Cystoid Macular Edema

Cystoid macular edema (CME) was seen as a complication of cataract surgery. However, studies with and without an ultraviolet filter over the operating microscope were inconclusive.[15] In a study by Fine[15], there was an increase in angiographic CME for eyes implanted with a clear intraocular lens (18.8%) as compared to those with a UVR filtering chemical in the intraocular lens (9.5%). Therefore, incorporating a UVR filtering chemical in the intraocular lens may be beneficial to possibly decrease the incidence of CME in pseudophakes.

PHOTOSENSITIZING DRUGS

A photosensitizing drug is a compound whose chemical structure endows it with the ability to absorb optical radiation (UV and visible) and undergo a primary photochemical reaction resulting in the generation of highly reactive and relatively long-lived intermediates (triplets, radicals, and ions) that can cause chemical modifications in other (nearby) molecules of the biologic system.[20] Patients who are prescribed photosensitizing drugs should also be prescribed UV protective eyewear to prevent ocular phototoxicity.

There are various categories of photosensitizing drugs:

1. Sulfonamides (Sulfanilamide, Sulfathiazole, Sulfamethazine) These are utilized in chemotherapy and produce phototoxic and photoallergic reactions.
2. Sulfonylureas (Carbutamide, Tolbutamide, Chloropropamide) These are hypoglycemic or anti-diabetic agents and cause phototoxic reactions.
3. Chlorothiazides (Benzothiadiazine, Quinethazone) These are diuretics and anti-hypertensives.
4. Phenothiazines (Choropromazine, Promethazine, Mepazine)

These are tranquilizers and anti-psychotic drugs. Chlorpromazine is reported to be cataractogenic.[20]

5. Antibiotics (Cholorotetracycline, Oxytetracycline, Doxycycline) These are used to protect against bacterial infections. They produce phototoxic reactions and cataracts.
6. Griseofulvin is an antifungal agent which can cause severe allergic reactions and also phototoxic reactions.
7. Naladixic acid is a gran negative specific bacterial drug which produces phototoxic reactions.
8. Furocumarins (Psoralen, Trimethylpsoralen, 8-Methoxypsoralen) These are used in many dermatology clinics to treat psoriasis and vitiligo. They may cause phototoxic reactions and cataracts.
9. Oral contraceptives (Estrogens and Progesterones) These may produce phototoxic reactions.
10. Chlordiazepoxide (Librium) is used as a tranquilizer and causes eczematous eruptions.
11. Cyclamates (Calcium cyclamate, Sodium cyclohexylsulfamate) These are artificial sweeteners and may produce phototoxic and photoallergic reactions.

SEASONAL AFFECTIVE DISORDER

It would seem that UVR is almost entirely detrimental to us. Actually, exposure to the natural sunshine in moderation positively influences our physical and mental health. Holick[16] has investigated the influence of UVR, acting through the skin, on production of Vitamin D and its affect on our immune systems. He suggests that the elderly should go outdoors for 10 or 15 minutes per day in the summertime, two or three days a week, to maintain adequate amounts of vitamin D. Lewy[17] has demonstrated that light affects the production of melatonin, a hormone associated with the human pineal gland, and that melatonin is related to certain mood disorders. Lewy has also associated natural light cycles with biological rhythms and sleep-wake cycles as well as possible annual rhythms. Seasonal affective disorder (SAD) is a syndrome with symptoms including fatigue, oversleeping, overeating, craving

for carbohydrates, sadness and depression. SAD has been recognized by psychiatrists as occurring mainly during the winter months when light intake is reduced. This syndrome is more commonly known as the "February blahs" or the "rainy day blues". Rosenthal and colleagues[16] found that the symptoms of SAD could be reversed by exposing patients to high levels of sun-simulating "natural wavelength" light.

Protection from Ultraviolet Radiation

Protection from the harmful ultraviolet rays can be accomplished either by natures own mechanisms or by ophthalmic ultraviolet radiation filters. Natural mechanisms include pupil response, lens pigmentation, and retinal and macular pigments. In bright light, the pupil automatically constricts to reduce the relative amount of all UVR entering the eye. As mentioned earlier, the lens accumulates yellow pigment and absorbs progressively more blue and ultraviolet light with age. There appears to be an inverse relationship between the degree of the lenticular opacity and the occurance of age-related macular degeneration.[13]

The RPE contains two substances which efficiently absorb photons: melanin and lipofuscin. Both substances absorb radiation from the infrared through the visible and far into the ultraviolet, with an increasing efficiency as photon energy increases. Melanin is known to protect against UVR damage, by confining any side-effects of radiation absorption within the boundaries of the melanosome.[18] Following absorption of near-UV photons by lipofuscin, radiation is re-emitted into the cytoplasm of the RPE cell with blue and yellow-orange wavelengths.[13] Therefore, side-effects from absorption by lipofuscin may be numerous and uncontrolled.

Nature has incorporated a carotenoid pigment (xanthophyll) within the foveas of primates to absorb shorter wavelengths and diminish photoexcited states of sensitizing pigments and oxygen (free radicals).[6] The macular pigment , lutein, serves a protective function of counteracting the "blue-light hazard" by absorbing the appropriate wavelengths of UVR and dissipating them harmlessly.[13]

Ophthalmic ultraviolet radiation filters include sunglasses, contact lenses, and intraocular lens implants. The ANSI Z80.3-1986 standard for sunglasses titled "Requirements For Non-prescription Sunglasses and Fashion Eyewear" is currently the most authoritative guide for the transmittance of UVR (and prescription lenses). The ANSI Z80.3-1986 standard contains three classifications of sunglasses based on their primary functions.

Table 1. ANSI Z80.3-1986 standards for sunglass transmittance

Category of Sunglasses	Light Transmission	UVA Transmission (315-380nm)	UVB Transmission (290-315nm)
Cosmetics	>40%	No > LT	No > 50% of LT with 30% max
General Purpose	8% - 40%	No > LT	No > 50% of LT with 5% max
Special Purpose	3% min	50% of LT max	1% max

LT= light transmittance

Most ophthalmic materials provide some protection from UVR.

Crown or white glass filters out 100% of UV wavelengths up to 300nm. Plastic CR-39 can block 100% up to 320 nm. Polycarbonate lenses block to approximately 380nm. Photochromic lenses block 100% up to 350nm in the lightened state. In the darkest state (at 77 degrees F, 2mm thick), photochromic lenses may block UVR to approximately 380nm. Polarized lensed reduce reflected glare off glass and water, but polarization itself has no effect of UVR.

Lenses may be cast with a UV absorber or dyed to absorb UV. The cast lens is a superior UV filter because the inhibitor is incorporated throughout the lens. UV dyed lenses may have reduced effectiveness because over time the dye will fade, rub off, or scratch. The advantage of the UV dyed lens is that it is less expensive and easier to produce. (The UV treatment must be applied before a fashion tint or a scratch-resistant coating.)

Bergmanson and colleagues[7] concluded that UV-filtering hydrogel contact lenses effectively absorbed hazardous UV radiation (and prevented photokeratitis) while the standard soft lens provided little protection. Five rabbits were fitted with UV-filtering lenses on one eye and a standard soft contact lens on the other eye. Both eyes were exposed to a UV source emitting a 5nm waveband centered at 300nm. The eyes that wore the UV-filtering lens maintained normal corneas. However, the eyes that wore the standard hydrogel lens showed pronounced epithelial, stromal and endothelial changes. They suggest that UV-filtering contact lenses be prescribed for people who experience exposures to sunlight and artificial sources such as sunlamps and tanning solarium sources that contain UVB radiation.

CONCLUSIONS

According to Doctor/Attorney John Classe', to date there has been no litigation over failure to prescribe UV protection because proof of negligence would require expert testimony that the plaintiff's injury was due to the UV radiation, and the expert would have to assert that, to a reasonable medical certainty, it was the UV radiation and no other cause that produced the injury. This would be most difficult to prove. However, the optometrist as a primary care practitioner should not disregard the prescription of UVR protecting eyewear. He must be able to identify those individuals who may be susceptible to ocular UVR damage and properly prescribe against UV light.

The following is a list of recommendations for individuals who require protection against UVR:

1. Aphakics and pseudophakics to prevent solar retinal damage
2. Cataract patients to reduce lenticular scatter
3. Patients with pinguecula, pterygia and macular degeneration
4. Persons who spend excessive hours in UV rich environments
   -vocations such as welding, and electronics
   -avocations such as snow skiing, sunbathing, and mountain climbing
5. Persons who live in high-altitude areas or near the equator
6. Persons who use sunlamps
7. Persons who take photosensitizing drugs

Thorough questioning of the patient's visual environment and ocular history is recommended because a properly worded question may indicate the need for a UV-absorbing lens that might otherwise be overlooked.

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