UV radiation and the Eye

Karen Walsh

Karen Walsh reviews UV induced ocular pathology, the challenges of providing adequate protection and the role of UV-blocking soft contact lenses.

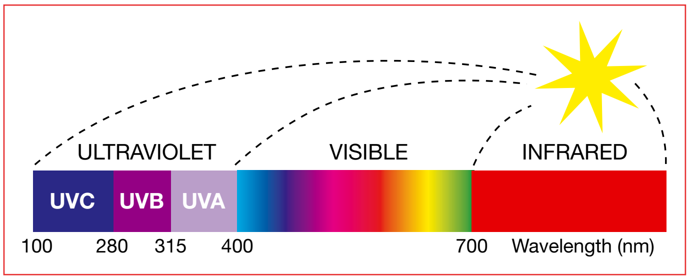
The consequences of exposing the skin to ultraviolet (UV) radiation are well understood in the general population with 95% of people associating UV with skin problems and 85% knowing about the risk of skin melanoma.[1] This level of understanding is substantially different when it comes to the eye however, with only 7% of people associating UV with eye problems.[1]

It has been said that aside from skin, the organ most susceptible to sunlight-induced damage is the eye.[2] In view of this, it can be argued that the optical industry and the eye care professional have an obligation, or at least, an opportunity, to educate the public more widely on the dangers of ocular exposure to UV and how best to achieve protection. This article summarises our understanding of the interaction of UV with ocular tissues, discusses the challenges of achieving adequate protection and finally reviews the role of UV-blocking soft contact lenses in ocular protection.

What is UV radiation?

It is important to begin with a clear understanding of what UV radiation is. This may be more clearly pictured by defining what it is not: UV is not light; it does not form part of the visible light spectrum. It sits adjacent to the blue end of the visible portion of the electromagnetic spectrum. Wavelengths from 400-100nm sit within the UV spectrum *(Figure 1)* which is further categorised as: UVA 400-315nm, UVB 315-280nm, UVC 280-200nm and UVvacuum 200-100nm.[3] The sun is a natural source of ultraviolet energy. The shorter and arguably more toxic wavelengths of UVC and UV-vacuum are blocked from reaching the earth by ozone in the stratosphere.[3] It is therefore more relevant to concentrate on the action of UVA and UVB in this article.

Figure 1: The Light Spectrum



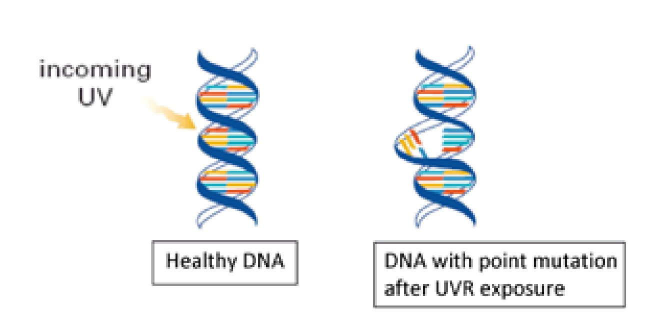
Mode of action

When a photon of solar radiant energy, such as UV, is absorbed, its energy is transferred to the molecule that absorbed it.[4] The mode of action of UV depends on its wavelength. Energy is inversely proportional to wavelength, therefore as wavelength decreases, the energy increases. The result being that short wavelength UV radiation has the highest potential for damage to organisms. This is illustrated by the fact that UVB at 300nm is roughly 600 times more biologically effective at damaging ocular tissue than UVA at 325nm.[5] Conversely, the longer the wavelength, the deeper into living tissue the radiation can penetrate. The extent of damage from UV radiation is determined by the wavelength, duration, intensity and size of exposure.

Some effects of UV are helpful, such as its role in the formation of Vitamin D by the skin. However the same wavelengths of UVA also cause sunburn on human skin.[6] UVA and UVB can both damage collagen fibres and thereby accelerate skin aging. UVA does not damage DNA directly like UVB, but can generate highly reactive chemical intermediates, such as

hydroxyl and oxygen radicals, which in turn can damage DNA. Because UVA does not cause reddening of the skin (erythema), it cannot be measured in sunlight protection factor (SPF) testing for sunscreens. With regard to skin protection, there is no good clinical measurement for blocking UVA radiation, but it is important that sunscreens block both UVA and UVB.
UV radiation at shorter wavelengths, designated as UVB, causes damage at the molecular level to the fundamental building block of life: deoxyribonucleic acid (DNA).[6] DNA readily absorbs UVB radiation. This commonly changes the shape of the molecule via disruption to hydrogen bonds, formation of protein-DNA aggregates and strand breaks *(Figure 2)*. Changes in the DNA molecule often mean that protein-building enzymes cannot "read" the DNA code at that point on the molecule. As a result, distorted proteins can be made, or cells can die.

Figure 2: UV radiation can disrupt chemical bonding with DNA, resulting in absent or misplaced nucleotide UVRtransmissibility of SiH materials



Consequences of exposure to the skin

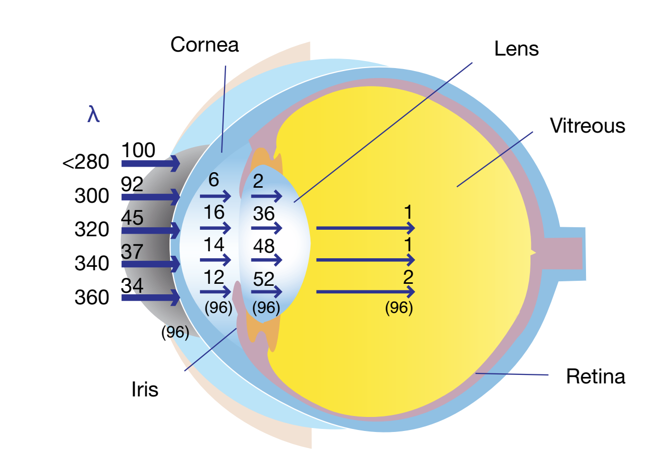
UV radiation is a major causative factor in the development of skin cancer.[7] It is well known that an increased incidence of malignant skin melanomas has been attributed to severe sunburn and/or exposure to excessive sunlight at an early age.[8] Chronic UV exposure has also been shown to be the leading predisposing factor to the development of squamous cell carcinoma of the lid.[9] Also, the incidence of basal cell carcinoma is significantly higher on the side of the nose than other parts of the face exposed to direct sun, with the curved shape of the eye creating a focusing effect and producing UV hot spots on the side of the nose.[10]

What can UV radiation do to ocular tissues?

Absorption characteristics of ocular tissue

It has already been illustrated that UVA and UVB exert different effects on biological tissue, determined by their respective wavelengths. Equally, there are also differences in the absorption characteristics of ocular tissue to UV radiation. The cornea and the intraocular lens are the most important tissues in the eye for absorbing UV radiation. Below 300nm (UV-B), it is the cornea that absorbs most radiation; the lens primarily absorbs UVA of less than 370nm *(Figure 3)*.[11] UV exposure has been implicated as a risk factor or cause in the pathogenesis of a large number of ocular conditions.[12,13]

Figure 3: Intraocular filtering of UV radiation by ocular tissues



Conjunctiva

The conjunctiva is easily damaged by UV, which activates a complex series of oxidative reactions and distinct pathways of cell death.[14] Squamous cell carcinomas of the conjunctiva are possible and frequently begin at the limbus.[9] A study showed ocular melanomas, such as choroidal melanoma, to be eight to 10 times more common in caucasians than blacks.[15] UV radiation is thought to be a risk factor in both of the above findings.

There is strong epidemiological evidence to support an association between chronic UV exposure and the formation of a pterygium.[16,17] This wing-shaped thickening of the conjunctiva and cornea is particularly seen in people who live in sunny climates and those who work outdoors *(Figure 4)*.[12,18,19] The prevalence of pterygia occurring on the nasal conjunctiva has been explained by peripheral light focussing onto the medial anterior chamber beneath the limbal corneal stem cells. Actively dividing stem cells are likely to have a lower damage threshold than non-mitotic corneal epithelial cells.[20]

Figure 4: Pterygium (With permission of Rachael Peterson, University of Waterloo, Canada)

A weaker link has been found between UV radiation and the formation of pingueculae[12,21] with a high prevalence found in populations that live in both sunny and snow covered environments.[22,23]

Cornea

Both the corneal epithelium and endothelium (which cannot regenerate) are vulnerable to UV radiation. Increased UVB exposure causes damage to the antioxidant protective mechanism, resulting in injury to the cornea and other parts of the eye.[24] A significant amount of UVB is absorbed by corneal stroma, so thinning with keratoconus or refractive surgery allows more UVB to reach the lens. It is not yet known whether surgical stromal thinning increases the risk of cataract.[25]

Whilst many of the pathologies associated with UV exposure are chronic, taking years to develop, photokeratitis is an obvious example of an acute response to UV radiation. Also known as snow-blindness, this reversible condition is characterised by severe pain, lacrimation, blepharospasm and photophobia.[26] The corneal epithelium and Bowman's layer absorbs about twice as much UV-B radiation than the posterior layers of the cornea.[27] It is the superficial epithelium that becomes irritated in photokeratitis. A one hour exposure to UV reflected off snow or a six to eight hour exposure reflected off light sand around midday is enough to cause a threshold photokeratitis.[23] At levels below this there may still be mild symptoms of ocular discomfort.

Climactic droplet keratopathy, or spheroidal degeneration, is a permanent pathological change characterised by an acculmulation of droplet-shaped lesions in the superficial corneal stroma.[11] Chronic exposure to environmental UV radiation has been suggested as a significant factor in its development.[16]

Anterior Chamber

The antioxidant ascorbic acid (vitamin C) is present in high concentration in the aqueous humour. It is able to scavenge free radicals in the aqueous and protect against UV-induced DNA damage of the lens.[28] Its presence acts as a filter for both UV-A and UV-B radiation, and it has been suggested that it has a protective role in the pathogenesis of cataract.[29] Patients with cataract have decreased levels of ascorbic acid in the anterior chamber[30] and a significant decrease in ascorbic acid has been observed in the aqueous humour following UV exposure.[31]

Crystalline Lens

Over time, the lens yellows and loses its transparency, primarily due to irreversible lens protein changes caused by aging, heredity and UV exposure.[32] Exposure to UV radiation has been shown to lead to the development of cataract in animal models33 and the link between UV and cataract formation in humans is well established.[34,35,36] Indeed the World Health Organisation estimates that of the 12 to 15 million people who become blind from cataracts annually, up to 20% may be caused or enhanced by sun exposure.[37]

The lens absorbs both UVA and UVB. It is exposed to three times more UVA, but both types of radiation are known to damage the lens via different mechanisms.[38] A significant positive correlation has been reported between UVB and cortical cataract; there is also a possible association with posterior sub-capsular cataract.[39,40]

Protein bound yellow chromophores are present in the ageing eye; they act as filters absorbing UV radiation. When exposed to UV-A the chromophores generate reactive oxygen species (ROS).[41] It is thought increased levels of ROS in the lens can lead to damage of DNA and cross-linking of proteins. Daily exposure to UV and subsequent induction of ROS results in cataract formation.[42,43]

Retina

Although the amount of UV radiation reaching the retina in the adult eye is very low, with protection by the filtering power of the crystalline lens (1% UV below 340nm and 2% between 340-360nm[44]), studies have linked the early development of age-related macula degeneration with greater time spent outdoors,[12,45,46,47] while some studies have found no association.[48] More recently a significant link between the 10-year incidence of early age-related macula degeneration and extended exposure to summer sun was reported.[49]

Risk of exposure

Ozone depletion

Atmospheric ozone provides a crucial protective barrier from shorter wavelength radiation. Not only does it filter out the harmful UV-C and UV-vacuum portions of the UV spectrum; it also attenuates the proportion of UV-B reaching the earth. The amount of ozone present in the upper atmosphere, which varies by location, time of year and time of day, determines the amount of UV-B and lower end UV-A, up to 330nm, that we are exposed to at the earth's surface.[50] The thinning of the ozone layer is particularly relevant when discussing UV exposure and will result in an increase of UVB reaching the earth. Following the ban on the widespread use of chlorofluorocarbons (CFCs), it has been estimated that ozone levels may not significantly recover until 2050.[51] It has been said that for those of us in practice, "UV protection must be regarded as an essential part of our critical mission".[52]

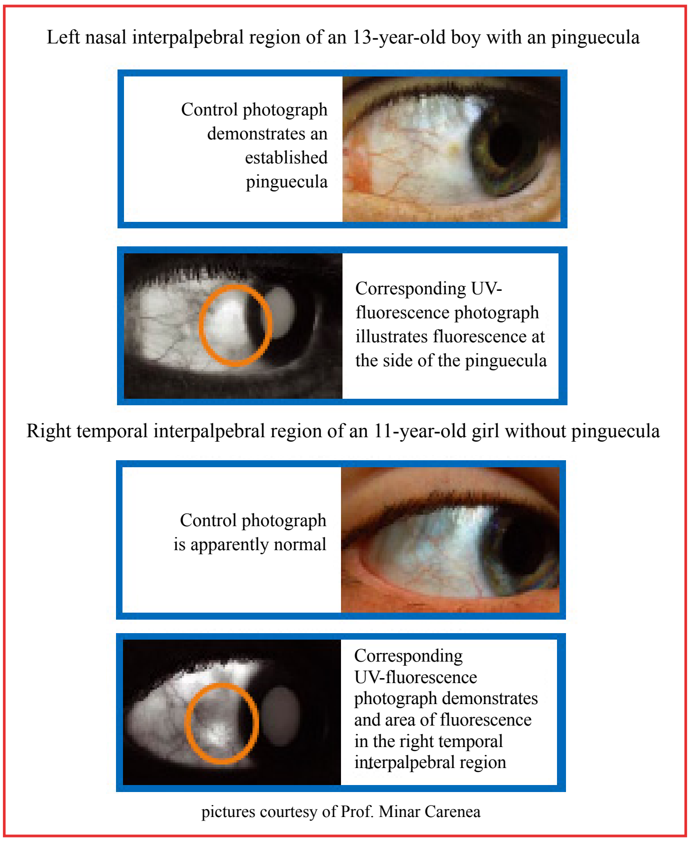
Altitude and latitude

UV radiation levels are affected by altitude; as the atmosphere is thinner at higher elevations, it absorbs less UV radiation, increasing exposure. UV doses increase with decreasing latitude; equatorial regions receive highest UV radiation levels.[53]

Cumulative effect

It is helpful to understand just when we are most exposed to UV radiation. To do so it is important to recognise several key points. Firstly, the effect of UV is cumulative over our lifetime. Also, many people have more leisure time and choose to spend it outdoors. This, coupled with the fact that life expectancy is rising, increases the opportunity for exposure and gives time for the induced tissue changes to develop.[3,54] The larger pupils and clearer ocular media of children make them especially vulnerable to UV; the World Health Organisation states that "up to 80% of a person's lifetime exposure to UV radiation is reached before age 18". Fluorescence photography makes it possible to view examples of early sun damage to young eyes that are not visible under normal white light viewing *(Figure 5)*.[55] It is clear from this evidence that provision of UV protection from a young age, sustained throughout life it extremely important.

Figure 5: UV Fluorescence photography reveals early sun damage not seen in standard photography (with permission of Coroneo)



Sources of exposure

Some ten years ago, Voke drew attention to the common belief that the primary risk of UV radiation is from direct sunlight.[44] Exposure from both scattered sources as UV passes through the atmosphere, and reflected sources such as snow, buildings and water are arguably more important. The amount of scattered or reflected UV radiation is dependant on the surface type; for example, snow reflects 80 to 94% of UVB rays compared to water reflecting 5 to 8%. Not only is this type of indirect exposure is responsible for 50% of the UV radiation we receive,[56] but it also represents a form of exposure that may not be obvious to the general public. Similarly, most clouds do not protect from UV; making overcast days, where people may not take steps to protect themselves, particularly dangerous.[44] Research has shown that even on overcast days with high cloud, the UV index is only attenuated slightly to 0.9 rather than the full 1.0 when no or minimal cloud is present. Only rain, fog and low clouds significantly reduce exposure to UV radiation.[57]

Exposure at unlikely time

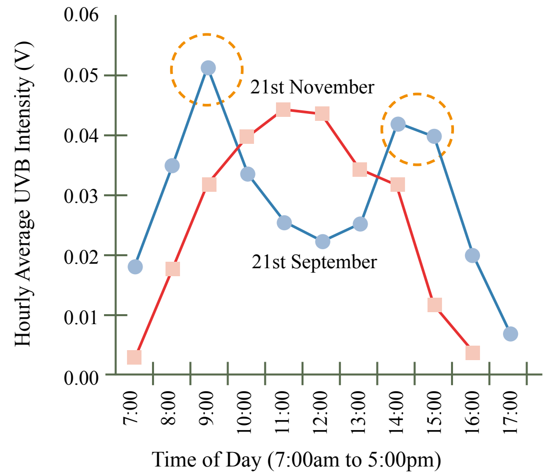
It has previously been quoted that around 80% of UV radiation reaches the surface of the earth between the hours of 10am and 2pm, with levels being particularly high in the summer months.[56] More recent research measured the ocular exposure to UV-B throughout the day and at different times in the year.[58] This Japanese study found that ocular UV exposure is greatest during early morning and late afternoon for all seasons except winter. During spring, summer and autumn, the exposure in these peak periods of early morning and late afternoon was nearly double that seen in the middle of the day *(Figure 6)*. The conclusion that can be drawn from this is to acknowledge the difficulty the general public have in knowing when they are most exposed to ocular UV radiation. There exists an opportunity to educate them on the need for constant UV protection when outdoors, both throughout the day and during all months of the year.

Challenges of protection

The shape of the orbit and eyebrow provide some anatomical protection from direct UV radiation, and in bright light the exposure is further reduced by squinting. It has been demonstrated however, that reflected light can still strike the orbits,[59] and the anatomy of the ocular adnexa is such that it makes it particularly vulnerable to scattered or reflected sources of UV, for example, reflected by the tear film interface.[56] It has been shown experimentally that the use of a brimmed hat can reduce UV exposure to the eyes by up to a factor of four.[60] The frequent use of sunglasses has been associated with a 40% decrease in the risk of posterior sub-capsular cataract.[39]

Advising on the use of hats and sunglasses is clearly important, but there are two further facts that must be considered. Firstly, the use of sunglasses varies in the population. A survey

Figure 6: Average UV-B Intensity from sunrise to sunset (after Sasaki)



suggests the majority of people do not wear protection for more than 30% of their time outdoors; moreover, almost a quarter never wear sunglasses.[61] Secondly, the majority of sunglasses do not prevent peripheral rays from reaching the eye.[62]

Children are also particularly vulnerable to UV radiation damage, since they have larger pupils,[63] clearer lenses[64,65] and spend more time outdoors, although only 3% regularly wear sunglasses.[66]

Peripheral light focussing effect

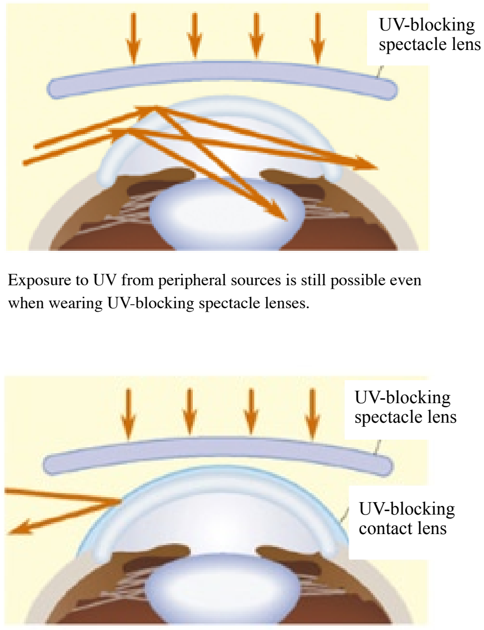
It is argued that peripheral UV rays are in fact the most dangerous.[62] Coroneo presented a hypothesis in the early 1990s as to why pterygia are more common on the nasal side of the conjunctiva.[67,68,69] Initial studies showed the cornea acts as a side on lens, focussing light incident on the temporal cornea onto the opposite side of the eye. The anatomy of the nose prevents this effect from occurring in the opposite direction, that is, light incident at the nasal limbus is not of such a peripheral angle as to allow a focussing effect onto the temporal limbus. The amount of limbal focussing is determined in part by the corneal shape and anterior chamber depth, perhaps explaining why certain individuals in particular environments are affected.[70]

It has been calculated that, via the peripheral light focussing (PLF) effect, the peak light intensity at the nasal limbus is approximately 20 times higher than the intensity of incident light.[69] Furthermore, light is also concentrated by the same mechanism on the nasal crystalline lens, with a peak intensity of between 3.7 and 4.8 times greater than normal incident light.[71] It is thought that PLF is a factor in the development of cortical cataracts, and this is supported by the fact that they most commonly occur in the inferior nasal quadrant.[45]

Protecting eyes from the PLF effect

The PLF has been shown to occur over a range of incidence angles, including very oblique trajectories that originate from behind the eye's frontal plane.[72] While well-made sunglasses block nearly all UV radiation that enters through the lens,[62] most designs provide inadequate side protection.[73] In fact it has been shown that non wrap-around sunglasses provide little or no protection from peripherally focussed UV radiation *(Figure 7)*.[74]

Figure 7: Peripheral light focussing effect



Exposure to UV from peripheral sources is still possible even when wearing UV-blocking spectacle lenses.

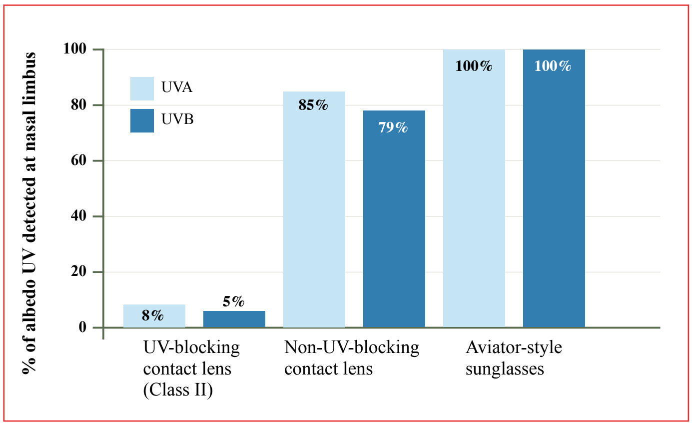
The use of a UV-blocking contact lens provides additional protection.

UV-blocking contact lenses

Well fitting soft contact lenses cover the entire cornea and limbus. Adding a UV-blocker into a soft lens provides protection to both this area and the interior of the eye from direct and reflected UV rays. Unlike some sunglasses, they are also effective at protecting from the PLF effect. This has been demonstrated experimentally where the presence of a UV-blocking contact lens, etafilcon A, was found to significantly reduce the intensity of UV peripheral light focussing at the nasal limbus *(Figure 8)*.[74] Protection was provided at all angles of incidence, and the authors raised the possibility that the risk of eye diseases such as pterygium and early cortical cataract may be reduced by wearing UV-blocking contact lenses.

Research into the protective effects of UV-blocking contact lenses is currently ongoing. The impact of UV-absorbing silicone hydrogel contact lenses on the prevention of UV-induced pathological changes in the cornea, aqueous humour and crystalline lens is

Figure 8: Peripheral light focussing effect – UV detection at the nasal limbus (after Kwok et al)

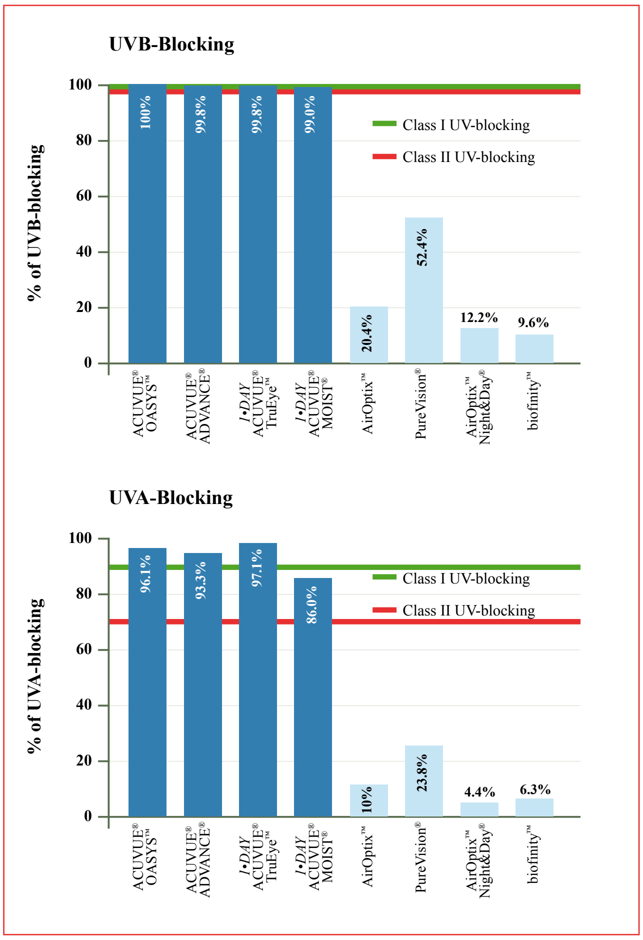


being measured by a team at Ohio State University. Matrix-metalloproteinases (MMPs) can be induced within the cornea by UV exposure and are associated with many pathologic inflammatory cascades. Levels of MMPs and anterior chamber ascorbic acid following exposure to UV were measured with and without the presence of a UV-blocking contact lens. The authors concluded that this is one of the first studies to show that UV-blocking lenses are capable of protecting the cornea, aqueous humour and crystalline lens from UV-induced pathological processes.[75]

Some soft contact lenses provide UV protection, with the amount of UV absorbed and transmitted by a lens depends on the material and design. UV-blocking contact lenses need to meet certain standards specified by the Food and Drug Administration (FDA), along with the International Standards organisation (ISO), based on their absorptive capacity at minimum thickness (often taken to be –3.00D);[76] for example, Class I must block at least 90% of UVA and at least 99% UVB and Class II must block at least 70% UVA and at least 95% UVB.

ACUVUE® brand contact lenses (Johnson & Johnson Vision Care) are unique in that all lenses available contain UV-blocking agents meeting either Class I or Class II standards *(Figure 9)*. The UV-blocking capabilities of ACUVUE® contact lenses are achieved by co-polymerising a benzotriazole UV-absorbing monomer with the lens monomer, for example etafilcon A, during manufacture. Benzatriazole absorbs UV-A and UV-B radiation and is known to be particularly stable once polymerised.[56] It has been shown that the addition of a UV-blocker to ACUVUE® contact lenses has not affected their clinical performance in daily wear.[77] Galyfilcon A and senofilcon A lenses, both with Class I UV-blocking, were the first to receive the World Council of Optometry's global seal of acceptance for their UV protection.

Figure 9: UV-blocking for a range of contact lenses



A study that examined the UV attenuating properties of various lenses[78] showed that senofilcon A had the lowest UV transmittance of all the lenses tested (8.36%), meeting the ANSI standard for UV blocking.[79] There was a statistically significant difference in the UV transmittance of senofilcon A and galyfilcon A compared with the other SiHs tested without UV-blockers. The authors also calculated a protection factor for each of the test lenses which is designed to quantify the UV protection of a CL in a similar manner to the protection factor with sunscreen. Senofilcon A was found to have a superior UV protection factor to the other silicone hydrogels tested.

UV-blocking, to Class II standard, can also be found in some other hydrogel and silicone hydrogel contact lenses (such as Precision UV from CIBA Vision and Avaira, Biomedics 55 Evolution and Biomedics 1-Day from Coopervision).

Education in practice

Once the benefits of UV protection have been explained to the patient, the interest in UV-blocking contact lenses is high. Three-quarters of contact lens wearers would be prepared to pay more for a contact lens that has UV protection.[80] Moreover, 85% of parents of teens and pre-teens involved in a recent study felt UV protection was either important or very important when deciding which contact lenses their children should wear.[81] Patient literature can be used in the reception area about ocular protection from UV radiation. During history and symptoms, include questions on lifestyle and medications to identify high-risk patients.

When discussing actions following the examination, include ways in which the patient can minimise their UV exposure, such as use of wrap-around sunglasses whenever outdoors and the benefits of UV-blocking contact lenses.

More information on UV radiation, the potential ocular damage and ways to educate patients is available at www.jnjvisioncare.com/acuvue-uv-initiative.htm

Conclusion

While the current level of knowledge is high in relation to the effects of UV radiation on skin, there exists a huge opportunity to educate the 93% of patients that do not associate UV with eye problems. The eye is exposed to both UVA and UVB; the latter, although present in smaller quantities, is arguably more dangerous due to its higher energy and ability to affect DNA directly.

Epidemiological and experimental evidence exists for the role of UV radiation in a number of ocular pathologies such as pterygia, photokeratitis and cataract.

The effects of UV radiation are cumulative over our lifetime, and young eyes are particularly vulnerable. Importance should be placed on starting ocular UV protection from a young age. Maximum exposure to ocular UV occurs at unlikely times and is relatively unaffected by cloud, making protection important year round. The peripheral light focussing (PLF) effect is implicated in the formation of nasal pterygia and cortical cataract.

Sunglasses without adequate side protection do not prevent the PFL effect. Use of Class I or II UV-blocking soft contact lenses significantly reduce exposure of the nasal limbus to peripheral light. UV-blocking lenses provide protection to the cornea, limbus and internal structures of the eye in situations where sunglasses are not appropriate. Perhaps the most comprehensive message to patients should be to advise them on the use of combined protection: a wide brimmed hat; good quality wrap-around well fitting sunglasses and, for those who require vision correction, UV-blocking contact lenses.

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