Moderate exposure to ultraviolet radiation (UVR) is necessary for human health, although excessive doses are associated with the development of a range of dermatological and ocular pathologies. Eye care practitioners have an important role to play in educating patients regarding the ocular risks of UVR and options for eye protection. This article will explore the ocular UV hazard and associated pathology, and discuss the use of contact lenses and sunglasses in reducing the risk posed by UVR.

Learning objectives
Understand the importance (and limitations) of UV-blocking contact lenses as an option for at-risk groups, such as outdoor workers. Be able to explain the differences between UV protection offered by contact lenses and sunglasses (Group 5.1.1)
Understand the role of ultraviolet radiation (UVR) in the development of acute and chronic common ocular conditions (Group 6.1.1)
Be able to identify anterior ocular pathology which may be related to UV exposure (for example UV keratocconjunctivitis, cortical cataract, pterygium) and be able to offer appropriate advice to patients with those ocular conditions not requiring referral (Group 6.1.4)

About the author
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Sunlight provides the principal source of UVR for most individuals, and during daylight hours, solar UVR is ubiquitous. UV wavelengths are shorter than those of visible light and range from 100 to 400 nm, with classification into three bands: UVA (generally defined as 400–315 nm); UVB (315–280 nm); and UVC (280–100 nm). UVC, representing the highest energy and most dangerous form of UVR, is completely blocked from reaching the earth's surface by the ozone layer such that it only occurs in artificial conditions such as arc welding and with use of UVC sterilising lamps. Longer UV wavelengths are less readily absorbed by the ozone layer; terrestrial UV comprises approximately 95% UVA and 5% UVB. Recent decades have seen a reduction in stratospheric ozone and while it is technically difficult to gauge the resulting changes in ground-level UVR, it has been estimated that by 2020, effective UVR levels in much of Europe will be 10% higher than in the 1980s.2

Exposure to UVA causes sun tanning, skin ageing and wrinkling, along with photosensitivity reactions.3 Although UBV cannot penetrate as deeply into the skin, it is more biologically active than UVA and is considered the principal harmful form of UVR.4 Excessive UVB exposure causes sunburn, blistering and is well-known to contribute to the development of skin cancers.5

UV hazard

Within-person and between-person doses of UVR vary significantly and are influenced by a number of important factors. Ambient UVB intensities are strongly dependent on solar angle. The higher the sun in the sky, the greater the UVR as perpendicularly-incident light projects to a smaller surface area than oblique light, concentrating the light energy. Travelling a reduced distance through the atmosphere results in less diffusion and attenuation of UV. Solar UVR levels, therefore, are generally greatest at low latitudes, during the summer months, and around noon daily.6 Thick cloud cover can absorb high levels of UV, reducing local levels, although clouds are complex and ever-changing. Light, broken clouds cause little attenuation of incoming UVR, and cumulus-type clouds have even been shown to have the potential to cause local increases in UVB as a result of scattering from their sides.7 Surface reflection, or albedo, will have an impact upon ambient UV levels with very reflective substances, most notably fresh snow, reflecting around 90% of incident UVA and UVB. The UV reflectances of dry sand and asphalt are approximately 15–18% and 4–9%, respectively.8 Higher altitudes are also associated with greater levels of UBV, with an increase of around 6% for every kilometre of elevation above sea level.9

Moderate UVR exposure to the skin is required to generate vitamin D, deficiency of which is known to cause rickets in children and osteoporosis and osteomalacia in adults.10 Only a relatively small proportion of vitamin D is derived from dietary intake. The majority is synthesised following UVB irradiation of steroid precursors in the skin.11 Excessive exposure to UVR, however, can lead to the development of various skin and ocular pathologies, termed the ‘dermatohelioses’ and ‘ophthalmohelioses,’ respectively (see Table 1).12

UVR-induced cellular damage may occur directly or indirectly. Cells are rich in UV-absorbing structures such as nucleic acids and proteins. Direct UV damage occurs when UVR absorption forms mutagenic photoproducts which interrupt DNA processing, leading to a number of potential biological effects such as apoptosis, carcinogenesis and immune suppression.13 Complex cellular repair pathways exist to overcome the threat to DNA, although these mechanisms can be disrupted by repeated low-level UV exposure or a single supra-threshold dose.14 UVA is not readily absorbed by DNA but may damage genetic material through indirect effects, where its absorption by cellular chromophores triggers the formation of reactive oxygen species which can transfer UVR energy to DNA through various intermediates.4 Given that UV damage can be cumulative, the risk posed by UVR is potentially greater now than in previous decades. The depletion

<table>
<thead>
<tr>
<th>Pathologies with strong epidemiological evidence of UVR-induced causality</th>
<th>Pathologies in which UVR is implicated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocular</td>
<td></td>
</tr>
<tr>
<td><strong>ACUTE</strong></td>
<td></td>
</tr>
<tr>
<td>• Acute UV keratitis and conjunctivitis</td>
<td>• Pinguecula</td>
</tr>
<tr>
<td>• Acute solar retinopathy</td>
<td>• Climatic droplet keratopathy</td>
</tr>
<tr>
<td><strong>CHRONIC</strong></td>
<td>• Early presbyopia</td>
</tr>
<tr>
<td>• Pterygium</td>
<td>• Ocular melanoma</td>
</tr>
<tr>
<td>• Conjunctival or corneal squamous cell carcinoma (ocular surface squamous neoplasia)</td>
<td>• Age-related macular degeneration</td>
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<tr>
<td>• Cortical cataract</td>
<td></td>
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<tr>
<td>Cutaneous</td>
<td></td>
</tr>
<tr>
<td><strong>ACUTE</strong></td>
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</tr>
<tr>
<td>• Sunburn</td>
<td>• Photodermatoses</td>
</tr>
<tr>
<td><strong>CHRONIC</strong></td>
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<td>• Malignant melanoma</td>
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<td>• Basal cell carcinoma</td>
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<td>• Squamous cell carcinoma</td>
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<td>• Solar keratosis (or actinic keratosis)</td>
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Table 1 Ocular and cutaneous diseases where sufficient epidemiological evidence of a causal association with UVR exists, or in which UVR is implicated, but insufficient evidence of a causal effect exists.10,12
Ocular UV exposure

The Global Solar UV Index (UVI) developed by the World Health Organization, in conjunction with a number of other international bodies, provides an approximation of UVR levels at the earth’s surface. The key purpose of the index is to alert people to the need to take appropriate protective measures against the harmful effects of UVR. Local UVIs are reported along with the weather forecast in many countries during the summer months, with the values ranging from 0 (no protection required) to 11+ (maximum protection required). The UVI scale relates to skin erythema (redness) dose, rather than the ocular risk associated with UV and measurements are based on UV levels on an unobstructed horizontal plane, unlike the location of the eyes. The unique anatomy of the eye and orbital region and some natural protective mechanisms mean that the ocular UV hazard is markedly different to that of the skin.

The natural aversion response, coupled with squinting, limits exposure to potentially hazardous bright light sources and reduces the risk of acute effects. Shielding of the eyes from UV is also provided by the eyelids, brows, cheeks and nose. The recent research work of Sasaki and colleagues, based in Japan, has demonstrated that the UVI does not adequately represent the need for ocular UV protection. Using dummy heads fitted with multiple UVB sensors and positioned outside during daylight hours, the team discovered that the peak times for ocular UV exposure for most of the year were between 8am and 10am, and 2pm to 4pm – not 10am until 2pm as is generally recognised for the skin. The results demonstrate that when the sun is highest in the sky, around noon, the
younger children. For UV wavelengths between 300-325nm for the spectral transmittance of the human crystalline lens during the first two decades of life; of note is the window of transmittance of the crystalline lens is most transparent, a far higher proportion of UV is transmitted through the lens to the retina. Ocular protection from UVR is therefore especially important for children. Figure 2 illustrates the spectral transmittance of the human crystalline lens during the first two decades of life; of note is the window of transmittance for UV wavelengths between 300-325nm for younger children.

**Peripheral light focusing**

Humans benefit from a large temporal field of vision due to the anatomy of the eye and face. However, UVR incident from the temporal side represents a particular hazard to the eye due to peripheral light focusing (PLF), or Coroneo Effect.17 As illustrated in Figure 1, light (including UVR) is refracted by the temporal peripheral cornea, traverses the anterior chamber and is focused at the nasal limbus, at an intensity approximately 20 times greater than that of incident light.14 Corneal stem cells located at the nasal limbus are protected from directly incident UVR by overlying superficial limbal cells, but can be struck by the beam of light originating from the temporal side of the eye. PLF is responsible for the typically nasal location of pterygia, and as the crystalline lens and eyelid margin are also affected, is implicated in the development of early cortical cataract and eyelid skin malignancies on the nasal side.

**Ophthalmohelioses**

In adults, the cornea and crystalline lens effectively filter the vast majority of UV, such that only approximately 1% (or less) of incident UVR reaches the retina.19 While the UV absorption properties of the cornea remain stable over time, those of the lens change significantly with age; yellowing of the crystalline lens results in greater absorption of UV. In childhood, when the crystalline lens is most transparent, a far higher proportion of UV is transmitted through the lens to the retina. Ocular protection from UVR is therefore especially important for children. Figure 2 illustrates the spectral transmittance of the human crystalline lens during the first two decades of life; of note is the window of transmittance for UV wavelengths between 300-325nm for younger children.

![Figure 3](image3.png) Conjunctival injection associated with UV keratoconjunctivitis. Injection may spare the superior and inferior conjunctiva, due to lid protection from UV.23

**Anterior segment**

The ophthalmohelioses predominantly affect the anterior segment, where the absorption of most UVR takes place. Acute overexposure to UVR can result in UV keratitis and conjunctivitis (Figure 3). Painful superficial punctate keratopathy occurs six to 12 hours after the suprathereshold dose, which may occur in natural conditions where the UV albedo is high (for example skiing or desert environments) or during arc welding, or sunbed use with inadequate cosmesis is unacceptable. Ophthalmological management may involve topical steroids to reduce acute inflammation and surgical excision, although recurrence frequently occurs.25 Also affecting the anterior segment, ocular surface squamous neoplasia (OSSN) occurs most frequently in elderly Caucasian men who have lived in areas exposed to high levels of UVB (typically near the equator).27 OSSN may involve the cornea and the conjunctiva, and commonly arises near the limbus (Figure 4, page 58). Patients may present with a foreign body sensation and/ or redness. Vision reduction is uncommon as a presenting feature. The lesions are slightly elevated and associated with feeding blood vessels. OSSN develops slowly and typically does not metastasise. Treatment consists of surgical incision and cryotherapy, although enucleation may be required in very advanced cases.28

Several epidemiological studies have identified UV exposure as an important risk factor in the development of cortical cataract.29, 30 The aetiology of cataract is multifactorial, although it has been estimated that 6-38% of cortical cataract occurs due to sunlight exposure.31 Early cortical opacities typically develop in...
the infero-nasal region of the lens, as a consequence of PLF. Although cataract surgery with intraocular lens implantation is a routine surgical procedure in industrialised nations, with an estimated 300,000 NHS surgeries per year, the treatment of cortical cataract due to excessive UV exposure is an important consideration in healthcare budgets.

**Posterior segment**
Acute solar retinopathy (also termed eclipse retinopathy or solar retinitis) may occur after direct, or indirect, viewing of the sun. The principal mechanism of damage is believed to be retinal irradiance from high energy short wavelength visible blue light and lower levels of UVA. Children may be more at risk of the condition due to their clearer crystalline lenses. Following the 1999 solar eclipse, UK hospital eye departments experienced a significant increase in patients presenting with symptoms of the condition. Visual acuity ranges from near-normal to approximately 6/60 and patients may be aware of a central scotoma. Retinal changes vary widely and include parafoveal hypopigmentation, macular oedema and a foveomacular yellow spot. The condition typically improves over the course of several weeks or months, although a reduction in visual acuity and scotoma may be permanent.

UV exposure has also been implicated in the development of age-related macular degeneration (AMD), although a causal connection has not been established. Even the trace levels of UVR which is transmitted to the retina in the adult eye may represent a significant hazard due to the high energy of UV photons and the sensitivity of the retina to photochemical reactions. Results from studies investigating a link between sunlight and AMD have been mixed, and it seems likely that visible blue light (400-500nm) plays a more significant role than UVR in the development and progression of AMD. The Beaver Dam Eye Study, based in Wisconsin, provided epidemiologic evidence of a significant relationship between extended exposure to the sun and the incidence of early age-related maculopathy (ARM), while a study of watermen in Chesapeake Bay found an increased incidence of severe AMD among those exposed to higher levels of blue and visible light over the previous 20 years.

**Ocular UV protection**
Given the range of ophthalmohelioses which can occur as a result of excessive UV exposure, and the year-round ocular hazard posed by UVR, ocular protection from UV is an important topic for consideration by eye care practitioners and discussion with patients. The two main forms of ocular UV protection are sunglasses and UV-blocking contact lenses.

**Sunglasses**
Sunglasses are commonly recommended as an effective method of protecting the eyes from the harmful effects of UVR. Lenses incorporating a UV block will prevent the transmission of UVR directly incident on the front of the lens. However, depending on the style and fit of the sunglasses, significant levels of UVR may still reach the eyes from around the edges of the lenses. Previous research has demonstrated that for sunglasses to provide effective ocular protection from UVR, they should be close-fitting and wraparound in style. Using a mannequin head incorporating UV sensors, Kwok and colleagues determined that standard, non-wraparound sunglasses provided no protection from the hazard of PLF in sunlight, while Rosenthal et al. observed that, when a variety of sunglasses were displaced just 6mm from the forehead, around 20% of incident UVR was able to reach the eyes. Other potential disadvantages of sunglasses include the reduction in glare from bright, visible light sources, such that the increased level of comfort means wearers inadvertently increase their exposure to UV, and tinted lenses may induce undesirable pupil dilation proportional to the depth of tint.

**UV-blocking contact lenses**
UV-blocking soft contact lenses can provide...
effective ocular UV protection for patients requiring refractive correction.20,38 Unlike sunglasses, which would typically be worn only on a part-time basis during bright conditions, contact lenses are frequently worn full-time, and can protect from UV during all outdoor activities. As soft contact lenses cover the limbal area, they can limit the PLF hazard and provide protection from all angles of incidence. The PLF is substantially reduced with UV-blocking contact lenses, whereas clear (non UV-blocking) soft contact lenses offer negligible protection from this hazard.34 In vivo and in vitro laboratory studies have demonstrated the efficacy of UV-blocking contact lenses, compared to no lens and minimal UV-blocking contact lens conditions, in preventing UV-induced damage to corneal and lenticular tissues.41,42

UV-blocking capacity in contact lenses can be achieved through the incorporation of a UV-absorbing monomer with the lens matrix during manufacture.43 Contact lenses offering protection from UVR are categorised as either Class I or Class II, as defined by the American National Standards Institute Z80.2 (2010) and the International Organization for Standardization 18369-2 (2006) criteria. Class I UV blocking lenses, offering the highest level of protection, block ≥90% of UVA and ≥99% of UVB radiation at their minimum thickness (usually taken as -3.00DS) as UV-blocking capability is a function of lens thickness where the UV-blocking monomer is co-polymerised with the lens material.43 Class II protection is defined as blocking ≥50% of UVA and ≥95% of UVB radiation. UV-blocking contact lenses have been available for well over a decade, although relatively few designs are available offering Class I protection. The Acuvue family of contact lenses (Johnson & Johnson) includes several silicone hydrogels which provide Class I protection: Acuvue Oasys; Acuvue Advance; Acuvue Oasys for Astigmatism; Acuvue Advance for Astigmatism and 1day Acuvue TruEye. Class II UV protection is available from 1day Acuvue Moist; 1day Acuvue Moist for Astigmatism; Acuvue2; Acuvue Bifocal; Biomedics 55 Evolution and Biomedics Toric; Avaira and Avaira Toric (CooperVision); FreshLook (Alcon) and Biotrue Oneday (Bausch & Lomb).

The key advantages of UV-blocking contact lenses are protection from PLF, shielding of limbal stem cells from UVR and typical morning through to night-time wearing patterns. Importantly, however, such contact lenses do not cover the entire conjunctiva, or protect the eyelids. UV-blocking contact lenses are recommended by both manufacturers and researchers as an additional form of ocular UV protection, rather than a substitute for measures such as sunglasses and hats.35,44,45

The role of eye care practitioners
Given the year-round risk to the eyes posed by UVR, and the potential for peak ocular levels to occur at different times to the skin, (meaning the hazard may be underestimated) UV-blocking contact lenses would be an appropriate form of refractive correction for people spending much of their time outdoors for example outdoors workers. Children are particularly susceptible to the ocular UV hazard, typically spending more time outdoors than adults, and their clearer crystalline lenses transmit a higher proportion of harmful UVR to the retina. As the harmful effects of UVR are cumulative, ocular protection from UVR should ideally be commenced at a young age to reduce lifetime exposure, using well-fitting sunglasses along with brimmed hats. UV-blocking contact lenses are an option for those requiring refractive correction.

Aphakic patients lack the benefit of UV absorption by the crystalline lens, meaning that the retina is at a greatly elevated risk from UVR. Furthermore, those with thinner corneas, for example after refractive surgery, or with corneal ectasias, are at higher risk as the corneal stroma usually absorbs high levels of UVR. UV eye protection is particularly important for these groups.

While the general public is broadly aware of the need to protect skin from the harmful effects of UV, recent data from the American Optical Association’s Eye-Q survey suggests that patients are poorly informed regarding the importance of UV eye protection – 35% were unaware of the eye health risks posed by UVR, while less than one-third (29%) of parents ensure their children wear sunglasses when outdoors.46 A further survey revealed that protection from UVR was not an important factor for the majority of patients opting to wear sunglasses.47 It is clear that much work needs to be done in informing the public of the ocular UV hazard.

Conclusion
Exposure to excessive levels of UVR can result in a range of acute and chronic ocular pathologies. The ocular risk posed by UVR is poorly understood by the public, although the hazard may be increasing with longer life expectancies and depletion of the ozone layer. Effective ocular protection from UVR can be achieved using hats, well-fitting sunglasses and UV-blocking contact lenses. Eye care practitioners are well placed to provide advice on ocular UV protection, especially to those at particular risk from the UV hazard.

MORE INFORMATION

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