Ocular cells and light: harmony or conflict?

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Abstract

Vision is based on the sensitivity of the eye to visible rays of the solar spectrum, which allows the recording and transfer of visual information by photovoltaic reaction. Any electromagnetic radiation, if sufficiently intense, may cause damages in living tissues. In a changing environment, the aim of this paper is to point out the impact of light radiation on ocular cells, with its phototoxicity potential on eye tissues. In fact, faced with light and oxygen, the eye behaves like an ephemeral aggregate of unstable molecules, like a temporary crystallization threatened with entropia.

Keywords: ocular tissues, light, phototoxicity, electromagnetic radiations, ultraviolet radiation.

\section*{Introduction}

The mechanism of sight is because the eye tissues are sensitive to the visible rays of the solar spectrum, which extends from 380 to 700 nm and allows, by photovoltaic reaction, the recording and transfer of information conveyed by the spectrum [1]. The eye has several protective mechanisms against light damage, including miotic constriction of the pupils, light absorption by melanin in the retinal pigment epithelium (RPE), and macular antioxidants, such as lutein and zeaxanthin [2]. Lutein and zeaxanthin are members of the carotenoid family (like beta-carotene) and are the only two carotenoids in the macula [3]. Their concentration is higher in the macula than anywhere else in the body; the retinal tissue levels of these compounds depend on intake and are thus variable. They may protect against light damage because they are efficient absorbers of blue light [4–6].

All electromagnetic radiation is liable to damage the various structures of the eye if its intensity is strong enough [7–10]. However, it is mainly the visible spectrum, which is responsible for retinal injury [11, 12]. The most energetic form of radiation is ultraviolet radiation (UV).

Electromagnetic radiations can cause mechanical, thermal or chemical reactions in the ocular tissues, as results of the absorption of radiation of specific wavelength; photochemical damage is produced in the ocular tissues and is defined by an unstable absorbent molecule known as chromophore. Absorption of energy results in the creation of an unstable molecular state with the formation of free radicals [13, 14]. Accumulated energy is restored in various ways resulting in numerous modifications to tissues due to interaction with the surrounding molecules.

Ocular tissues defend themselves naturally using various mechanisms: filtration, molecular protection (using enzymes and anti-oxidant agents) or biological renewal (either partially or totally by means of reformation of the injured cell population).

When capacities for renewal weaken or become overwhelmed, photo-induced pathologies occur [15].

The article aims to point out the damaging potential on ocular tissues of ambiental UV radiation and visible light, in a changing environment.

\section*{Effects on the cornea}

The cornea plays an essential role in the transmission and filtration of electromagnetic radiation, which provides vision. Its transparency is necessary for the transfer of all physical frequency elements reflected by the object or the eye’s image and focused on the retina by the visible spectrum. The cornea acts as a filter, particularly for certain ultraviolet radiation, some A and B ultraviolet rays. Radiation has a traumatic effect on the cornea, producing painful, disabling keratitis, the most spectacular of which is snow blindness. In some regions, chronic cases of keratitis are observed, that may lead to blindness. Prolonged sun exposure causes changes to the posterior tissue of the cornea, liable to lead, in old age, to edema-type problems. Chronic solar toxicity, caused by prolonged exposure to ultraviolet radiation, may lead to pterygium, climatic droplet keratopathy, squamous metaplasia or squamous carcinoma [16].

We consider that, from all the eye structures, the most damaged one is the cornea. It acts as a protection screen for the deep structures of the ocular globe, especially for the crystalline and retina. Prolonged or repeated exposure to UV radiation determines important alterations in all the microscopic structures of the cornea.
The anterior epithelium may present lesions such as pseudo-keratinization up to complete necrosis and ulceration. The corneal stroma becomes the location of an inflammatory associated infiltrate edema, rich in lymphocytes and macrophages, and of a network of angiogenesis vessels [17, 18]. All these microscopic lymphocytes and macrophages, and of a network of an inflammatory associated infiltrate edema, rich in oxidative stress inside the tissues [19–21].

Epidermoid carcinoma of the bulbar conjunctiva is the only cancer associated with the ultraviolet radiation. Its frequency is increased in tropical and subtropical regions.

In mountain regions, exposure to radiation is about four times higher and affects the fragile or poorly protected cornea, causing a spectacular effect, which occurs after six to 24 hours latency. The cornea is scattered with small ulcers on its epithelium. This phenomenon is particularly painful and the condition can become chronic in patients without UV protection whom are exposed for a long period, generating glare [22].

Funnell et al. (2006) report a case of a patient who developed a corneal perforation secondary to UV radiation from a tanning lamp. The patient developed a full-thickness corneal perforation after 30 minutes of tanning lamp exposure without eye protection. The authors believe that this is the first case of corneal perforation caused by UV radiation [23].

Ultraviolet rays irritate the superficial corneal epithelium, leading to mitosis inhibition, production of nuclear fragmentation and loosening of the epithelial layer. Phototoxic effects occur at all levels of the cornea, including the stroma and endothelium.

At the cornea, the UV transmission decreases away from the center, fact explained by the scattering and the absorbance phenomena. The endothelial cells (cells which line the back of the cornea) are less numerous in the center of the cornea, therefore receive a higher dose of UV than those in the peripheral cornea. This is consistent with the observation that endothelial cells in the corneal periphery present less oxidative DNA damage than those in the central cornea [24].

Effects on the crystalline lens

Experimental research suggests that the lens is susceptible to UV radiation exposure. Epidemiologic evidence indicates that long-term exposure to sunlight is associated with increased risk of cortical cataract [25, 26]. Although sunlight exposure accounts for only about 10% of the total risk of cortical cataract in the general population, this risk is avoidable. Since exposure to UV radiation can produce other morbidity, avoiding excessive sunlight exposure should be encouraged. UV-absorbing corrective lenses and nonprescription sunglasses decrease UV transmission by more than 80%, and wearing a hat with a brim decreases ocular sun exposure by 30–50%.

UVA rays are absorbed entirely by the lens, as are the UVB rays that have been transmitted by the cornea, whereas visible rays pass through the lens to act on the retina. Short wavelengths in blue and near ultraviolet are the most dangerous for the crystalline lens. Cumulative chronic exposure to ultraviolet radiation causes an increase of chromophores in the crystalline, with coloring of the nucleus. At this stage, the crystalline completely absorbs short wavelengths, thus protecting the retina. However, continuous absorption of these shortwave lengths alters structural proteins of this body with a reduction in enzymatic activity. Radiant energy as external agent generates free radicals. These highly reactive free radicals can lead to the damage of lens fibers. Peroxidation of lens fiber plasma or lens fiber plasma membrane lipids has been suggested as a factor contributing to lens opacification. In the process of lipid peroxidation, the oxidizing agent removes a hydrogen atom from the polyunsaturated fatty acid, forming a fatty acid radical, which, in turn, attacks molecular oxygen, forming a lipid peroxy radical. This reaction may propagate the chain, leading to the formation of lipid peroxide (LOOH), which eventually can react further to yield malondialdehyde (MDA), a potent cross-linking agent. It has been hypothesized that MDA cross-reacts with membrane lipids and proteins, rendering them incapable of performing their normal functions.

Because oxygen tension in and around the lens is normally low, free radical reactions may not involve molecular oxygen; instead, the free radicals may react directly with molecules. DNA is easily damaged by free radicals. Some of the damage to the lens is reparable, but some may be permanent. Free radicals can also attack the proteins or membrane lipids in the cortex. No repair mechanisms are known to ameliorate such damage, which increases with time. In lens fibers, where the protein synthesis no longer takes place, free radical damage may lead to polymerization and cross-linking of lipids and proteins, resulting in an increase in the water-insoluble protein content [27].

The lens is equipped with several enzymes that protect against free radical or oxygen damage. These enzymes include glutathione peroxidase, catalase, and superoxide dismutase. Superoxide dismutase catalyzes the destruction of the superoxide anion, O2− and produces hydrogen peroxide (H2O2): 2O2− + 2H+ → H2O2 + O2. Catalase may break down the peroxide by the reaction: 2H2O2 → 2H2O + O2.

Glutathione peroxidase catalyzes the reaction of glutathione (GSH) and lipid peroxide (LOOH), resulting glutathione disulfide (GSSG) and lipid hydroxide (LOH): 2GSH + LOOH → GSSG + LOH + H2O.

The glutathione disulfide (GSSG) is then reconverted to glutathione (GSH) by glutathione reductase, using the pyridine nucleotide NADPH (nicotinamide adenine dinucleotide phosphate) provided by the acid form of monophosphate (HMP) shunt as the reducing agent: GSSG + NADPH + H+ → 2GSH + NADP+. Thus, glutathione acts indirectly as a major free radical scavenger in the lens. In addition, both vitamin E and ascorbic acid are present in the lens. Each of these substances can act as a free radical scavenger and thus protect against oxidative damage. The lens stores the cells
throughout its lifetime, so that this translates by gradual opacification. The result is that brown nuclear cataract forms [28].

Effects on the retina

This is the ocular tissue that is most exposed to the possibly damaging effects of luminous radiation. The luminous radiation that acts to form images is received and then transmitted to the retina, after the photons have crossed through all of the eye’s transparent media. The effects on the retina are photochemical in type and occur in the photoreceptors and the pigmented epithelium. Photochemical injury occurs due to biochemical reactions that cause retinal tissue destruction without elevation of temperature. Photochemical injury is the result of light energy being transferred to a molecule and this excess energy leads to reactions that produce tissue damage. For photochemical reactions to take place, the energy of the photon must exceed a certain threshold. Reactions that take place can include oxidation, photoisomerization, photochemical cleavage, and electrocyclic reactions [29–31]. Each of these may cause damage directly or indirectly through formation of reactive molecules such as lipofuscin, which are photoactive. Such changes are seen primarily at the level of the outer segments of the photoreceptors, which are more sensitive than the inner segments. Solar retinopathy is an example of photochemical injury. Solar retinopathy, also known as foveomacular retinitis, eclipse retinopathy or solar retinitis, is photochemical retinal injury caused by direct or indirect viewing of the sun; it usually occurs after viewing a solar eclipse or gazing directly at the sun. The damage is felt to be secondary to visible blue light and shorter wavelengths of UVA or near-UV radiation. Younger patients with clearer lenses and patients taking drugs that photosensitize the eye, including tetracycline and psoralens, are at a higher risk of solar retinopathy, compared to patients with high refractive errors and dark fundus pigmentation, whom are at a slightly lower risk. Patients complain of decreased vision, central scotomata, dyschromatopsia, metamorphopsia, micropsia, and frontal or temporal headache within hours of exposure. Visual acuity is typically reduced to 20/25–20/100, but may be worse depending on exposure. Most patients recover within 3–6 months, with vision returning to the level of 20/20–20/40, but residual metamorphopsia and para-central scotomata may remain.

The anterior structures of the eye (cornea, lens) absorb much of the UV radiation of the optical spectrum; despite this fact, the 315–400 nm UVA band penetrates into the retina. Natural sources (such as the sun) emit UV photons in long durations which do not result in energy confinement in the retina, and thus do not produce thermal or mechanical damage, but are capable of inducing photochemical damage. Some drugs, such as antibiotics, non-steroidal anti-inflammatory drugs or psychotherapeutic agents may act as photosensitizers that promote retinal UV damage, if they have sufficient retinal penetration [26].

The fundus findings are variable and usually bilateral. The characteristic finding in the first few days after exposure is a yellow-white spot in the fovea, which subsequently is replaced after several days by a reddish dot, often surrounded by a pigment halo. Mild cases, however, often have no fundus changes. After approximately two weeks, a small, reddish, well-circumscribed, 100–200 μm lamellar hole or depression may evolve. This lesion may lie at or adjacent to the fovea and is usually permanent. Fluorescein angiography reveals leakage in early stages and window defects in late stages.

It is theorized that solar retinopathy is caused by a photochemical injury, perhaps thermally enhanced. The extent of the damage depends on the duration of the exposure. Histopathological studies have shown RPE damage. No beneficial treatment exists, and prevention by education is critically important.

Due to light exposure and to abundant presence of oxygen (linked to particularly important blood flows in the choroid), the retina is particularly exposed to the release of “free radicals”. The latter are eliminated under normal circumstances but their accumulation may lead to toxic reactions [32]. The lipidic membranes of photoreceptor cells (cones and rods) are the main target of the newly created free radicals. However, numerous defense mechanisms exist normally in the retina. First, there is extremely rapid renewal of photoreceptive cells, particularly of their external segment and of the molecules of the discs of which they are comprised. Combined with this, is enzymatic restoration of the injured molecules. Finally, the retina has its own defense mechanisms, based on the presence of the melanin. Melanin is a photon trap, capable of eliminating free radicals. However, it is gradually reduced with age, by 50% between the ages of 24 and 72 years. The secretion of hypophyseal prolactin is liable to protect the pigmented layer to a certain extent. The cumulative effects of this radiation over a lifetime are an additional factor of aggravation. If the defense mechanisms against free radicals are diminished, as in albinism or in certain hereditary-degenerative disorders, such as retinitis pigmentosa, the effects of short wavelength radiation are a real threat. Weale put forward hypothesis that natural degeneration of the retina may be the consequence of an excess of UV light, accelerated perhaps by genetic factors [32]. Some retinal diseases are proof of light aggression. Such is the case with snow erythropsia (red vision) after extended exposure when objects appear to be red colored.

Although there is much speculation that ambient exposure to UV radiation or visible light is a potential cause of retinal toxicity or degeneration, further study and documentation are required.

Non-ionizing radiation generated by the sun is a major factor in our environment. The eye is a privileged receptor of light. This specific sensitivity explains the fragility of the ocular tissue with regard to the thermoluminescent that is responsible for the occurrence of various ophthalmological injuries, specifically chorioretinal injuries. The damaging effects to ocular structures are linked not only to the absorption capacity of the various wavelengths, but also to the energy threshold and the duration of the emission of the radiation. The cumulative pathogenic role of light in the appearance of certain cellular degeneration is suspected. The characteristics of transmission and absorption by the ocular tissue
will determine the scale of injuries related to light. The seriousness of the injuries depends on the regeneration capacities of the tissue. Cells in the upper layer of the cornea are rapidly renewed. The crystalline will retain traces of the photonic aggression, whereas in the retina, it is the central macular area, which is the most sensitive. The effects of sunlight are cumulative.

Prevention must involve first of all the identification of at-risk population, such as young children, those who have undergone cataract operations and people working in or exposed to the sun. We would add to this list patients subjected to a photosensitising treatment or those whose ocular membranes have been weakened by the pathology or natural phenomenon of degeneration.

The wearing of protective glasses is a simple, efficient way of protecting the eyes. However, the lenses must not only stop the visible rays that cause glare, but also ultraviolet rays. The lenses must be filtering, either tinted or not. The filter will absorb part of the ray’s energy to make it less intense.

The ultraviolet filtering power of a lens is not linked to its color, but to the material from which it is made. Thus, some prescription lenses may filter all ultraviolet rays, whereas a poor quality sun lens will offer only weak resistance to ultraviolet rays. There are three types of materials available: mineral, organic and polycarbonate, each one having filtering properties. Untreated mineral lenses allow between 80 and 90% of UV rays through. Organic lenses attenuate UV rays entirely below 350 nm and to a lesser degree those between 350 and 380 nm. Polycarbonate or high index organic lenses completely block UV rays below 380 nm. Any added color will reduce the intensity of the visible light.

Contact lenses with UV filter offer good protection, whatever the incidence of light, but may cause, due to lachrymal dryness, corneal disorders such as punctate keratitis. Because of their diameter, they only protect the cornea.

During recent years, international regulations were conceived, defining specifically the essential health and safety demands regarding sunglasses.

Conclusions

The tissues of the eye are specifically exposed to environmental sun radiation and this exposure is responsible for some cellular damages and degenerations at this level. Due to these circumstances, sun protection becomes undoubtedly necessary under the conditions of global warming with increased ultraviolet exposure and increased risk of sunlight ocular tissues damages.

Contribution Note

All the authors have equal contribution to the paper.

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