Ultraviolet radiation at Mediterranean latitudes and protection efficacy of intraocular lenses

Radiations ultraviolettes au niveau du bassin méditerranéen et efficacité de protection des lentilles intraoculaires

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Summary

Purpose. — After determining the mean intensity of ultraviolet radiation to which the human eye is exposed at Mediterranean latitudes, this data is used to evaluate the efficacy of the ultraviolet filters incorporated into various intraocular lenses.

Methods. — Ultraviolet radiation measured at Mediterranean latitudes was used as a reference for the theoretical calculation of the amount of radiation to which the human eye is exposed. The spectral transmission curve from 290 to 380 nm was measured for 10 IOLs using a UV/VIS Perkins-Elmer Lambda 800 spectrometer.

Results. — At Mediterranean latitudes, at sea level, with a mean annual solar irradiation of 50 J/cm\(^2\), the human eye receives a quantity of UVA and UVB that is lower than the threshold toxic dose for the rabbit crystalline lens (93 J/cm\(^2\) for UVA and 6.45 J/cm\(^2\) for UVB). However, at higher altitudes and with albedo approaching 0.9 (fresh snow), the amount of radiation increases, with duration of exposure potentially playing a significant role. The UV filters incorporated into the IOLs studied are, in general, protective against such levels of radiation.

Conclusion. — At Mediterranean latitudes, at sea level, the amount of UV radiation to which our eyes are exposed is insufficient to damage the crystalline lens; however, at higher altitudes, the risk of such damage exists. UV filters incorporated into intraocular lenses are generally effective, since they filter all radiation with wavelengths under 380 nm.

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Introduction

Intraocular lenses (IOLs) have filters that can block ultraviolet (UV) radiation and, in some cases, blue light [1–6]; these filters do not affect the image quality of these lenses [7–10]. The most energetic and potentially harmful solar radiation that reaches the Earth’s surface is UVA (315–380 nm) and UVB (290–315 nm). Its effect on living beings does not only depend on its spectral composition, but also on its intensity and exposure time, consequently it is very difficult to determine experimentally what radiation dose starts to be harmful to the eye. Moreover, one must not only consider the optical and radiometric parameters, but also the geometrical exposure factors [11].

It can be deduced from different epidemiological studies [11–14] that there is only limited evidence that exposure to solar UVB causes cortical and subcapsular cataracts in humans. Whatever the case, UV radiation is the most energetic in the solar spectrum that reaches the Earth’s surface as its wavelength is shorter, and it has been proved that it affects living beings [15] in different aspects. In view of this, a joint recommendation by the World Health Organization (WHO), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [16] defines the Global Solar UV Index as follows: “The Global Solar UV Index (UVI) describes the level of solar UV radiation at the Earth’s surface. The values of the index range from zero upward—the higher the index value, the greater the potential damage to the skin and eye, and the less time it takes for harm to occur’’. This warning by the WHO indicates concern about the effects UV radiation can have on eyes, as is clearly stated in their definition (Appendix 1).

Solar radiation, apart from visible radiation (400–700 nm), includes UV and infrared (IR) and covers a wide spectrum. As mentioned above, the radiation that produces the most harmful effects on living beings is UV (100–380 nm), which can be subdivided into three areas, depending on the biological effects it produces: UVA (315–380 nm), UVB (290–315 nm), and UVC (100–290 nm). UVC is totally absorbed by the atmosphere, therefore this study will not take it into consideration. As a result, the biological effects of solar radiation have only been associated with UVB and UVA.

At the top of the atmosphere, UVB irradiance amounts to 1.3% of the solar constant, but when it reaches the ground it is highly reduced, mainly due to the stratospheric ozone, amounting to less than 10% of total UV irradiance [17]. Nevertheless, the formation of holes in the ozone layer considerably increases the quantity of UVB that reaches the Earth’s surface. Ultraviolet A radiation at the top of the atmosphere represents 5.9% of solar radiation and it accounts for the majority of the radiation that reaches the Earth’s surface, its intensity varying throughout the day and the year [17–19].

The cornea absorbs the majority of UVB but damage occurs in the corneal epithelial surface and stromal cells and the exposure of the crystalline lens to an intense UVA and UVB radiation is associated, as previously stated, with cortical cataract formation [12,20].

For all these reasons, different types of filters with different characteristics have been included in IOLs [4–6]. These filters attempt to absorb UV radiation to a greater or lesser degree. However, in some cases they may let some UV radiation through and when this occurs, the intensity of the source of radiation, as well as the exposure duration, should be taken into account in order to analyze the harmful effect.
of the irradiation. The mean luminance in bright sunlight in Mediterranean latitudes can easily reach 10,000 cd/m² and an ordinary luminance would be around 5,000 cd/m². Furthermore, diffuse radiation is another aspect to be taken into account. Solar radiation is dimmed by absorption and by scattering through the atmosphere. Scattered or diffuse radiation is an important part of the total since as much as 50% of the UVB irradiance reaching the Earth’s surface comes from the scattering of solar radiation by air molecules and other particles in suspension in the atmosphere [21,22].

We know that an important role of the crystalline lens is to protect the retina of the UV radiation. But these protections produce harm in the lens. The goal of the present study is to analyze this harm. We know that a normal crystalline lens yellows with age, and it is important to establish what the maximum dose of radiation it can receive before irreversible harm to the crystalline lens occurs. This is very difficult to determine [23,24], as obviously no one can be subjected to an experiment of this type. Nonetheless, if we extrapolate the data Pitts et al. [25] obtained when they irradiated rabbits’ eyes with UVA and UVB radiation (between 295 and 365 nm) we can get an idea of this limit.

In a previous paper [26], we determine the spectral transmittance of intraocular lenses under natural and artificial illumination. This means that we know if the IOLs analyzed filters the UV radiation like a natural lens. In this study, we report data on the intensity of UV radiation that can reach our eyes. For this, we calculated the dose of UVA and UVB radiation the eye receives at different times of the year at a Mediterranean latitude and at sea level, and we compared it with the doses of UVA and UVB that cause reversible and permanent damage to the rabbit eye. We verified whether different IOLs with UV filters protect the retina, like a natural lens, effectively on the basis of these data.

**Methods**

In this study, we used the data on overall solar radiation, as well as UVA and UVB radiation, registered throughout the year in the Mediterranean locality of Valencia (Spain) [17–19], situated almost exactly at latitude 40° N and at sea level. Let us consider ± 5° around this latitude, which encompasses not only the Mediterranean but also almost the whole of China, Japan, the majority of the USA: in other words, it is a highly populated band and consequently representative.

The spectral transmission curve of 10 IOLs was measured, mainly focusing on the UVA and UVB interval (290–380 nm): Physiol Hydroli 60 C 18.5D (Physiol, Liege, Belgium), IOLTECH E4 T 20.5D (Carl Zeiss Meditec, Germany), PMMA MZ60BD 21.5D (Alcon, Fort Worth, Texas, USA), Physiol Slim Flex 21D (Physiol, Liege, Belgium), Acrysof IQ SN60WF 20.5D (Alcon, Fort Worth, Texas, USA), Acrysof MN60AC 22.5D (Alcon, Fort Worth, Texas, USA), Acrysof MA60BM 22.5D (Alcon, Fort Worth, Texas, USA), Acrysof SA60AT 20.5D (Alcon, Fort Worth, Texas, USA), Opthec PC 440 Orange Series 21D (OPTHEC BV, Groningen, The Netherlands) and OCULAID PC 510Y 21.5D (OPTHEC BV, Groningen, The Netherlands).

The transmission curves of the IOLs were obtained by using a Perkin-Elmer Lambda 800 UV/VIS spectrometer. This apparatus can measure the spectrum from 200 nm onwards, which means that spectral transmissions in UVA, UVB and part of UVC are accurately determined (precision is up to 1 nm). The air was taken as a reference to measure transmission.

For the solar light spectrum, we used the relative spectral power distribution curve of daylight (NASA standard data of spectral irradiance (W·m⁻²·μm⁻¹) for the solar disk at the Earth’s surface at air mass 2) which is the D65 of the CIE (The International Commission on Illumination, usually abbreviated to CIE (Commission Internationale de l’Eclairage) because of its French name).

**Results**

Fig. 1 shows the relative power distribution curve of sunlight (D65 illuminant). Fig. 2A shows the amount of solar energy that reaches the ground level at a latitude of approximately 40° N (a Mediterranean latitude) in one year [17,18]. Fig. 2B shows the amount of UVA and UVB energy that reaches the Earth’s surface in one year at this latitude [17,18], and Fig. 2C shows the proportion, with regard to overall radiation, of UVA and UVB radiation that reaches the ground level at these Mediterranean latitudes.

Figs. 3 and 4 show how four different IOLs filter the UVA and UVB interval of the solar radiation spectrum: OCULAID PC 510Y (OPTHEC) and Alcon MZ60 (Fig. 3), Physiol Hydroli 60 C and Alcon IQ MN60 (yellow) (Fig. 4). As previously stated, the spectral transmission of 10 IOLs was measured, however in the A and B ultraviolet interval (290–380 nm) seven of them (Alcon MZ, Alcon MA and SA, Alcon SN and MN, Opthec PC 440 Orange Series, and IOLTECH E4 T) filtered it completely, so we only show the curve of the Alcon MZ60 in Fig. 3. In addition, we provide the curve of the OCULAID PC 510Y (OPTHEC), which presents a different curve.

**Discussion**

The data used in this discussion section were determined at a Mediterranean latitude, at sea level, situated at around 40° N. Overall and UVA and UVB radiation vary greatly in intensity throughout the year, the intensity in summer
months being around threefold that of winter months. However, the emission of UVA and UVB radiation relative to overall radiation remains more or less constant throughout the year at around 3.3% (Fig. 2C), reaching a maximum of 4.1% in August. In a study performed in New Zealand (latitude 40°S, the antipodes of Spain) on exposure to solar UV radiation by outdoor workers (26) concludes that all the workers recorded mean daily UV radiation exposure in excess of the current recommended occupational exposure limits.

Nonetheless, not all the radiation that arrives at the Earth’s surface reaches our eyes, so calculating the proportion of indirect light that reaches the eye is usually difficult [27]. Rosenthal et al. [28], when studying the ocular dose of ultraviolet radiation to outdoor workers, positioned different sensors on a mannequin’s head to determine the amount of radiation that reached different areas of the head. If we take the sensor positioned at the top of the head as registering direct radiation, and the one positioned at the bottom of the eye as registering the radiation that reaches the eye, and the mannequin is exposed outdoors to an unobstructed sky, 10 to 20% of ambient UV radiation on a horizontal surface reached the eyes. These measurements were determined with an albedo of 0.37, which is the Earth’s mean albedo (Albedo: the ratio of the intensity of light reflected or diffused from an object or surface, that of the light it receives from the sun). In the extreme case of fresh snow the albedo is about 0.9.
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Fig. 2B shows that on average we receive an intensity of some 50 j/cm² (500 Kj/m²) of UVA and UVB radiation throughout the year. If we assume that a mean of 15% [27] of direct radiation reaches our eyes, this indicates that around 7.5 j/cm² of UVA and UVB radiation (290–380 nm) reaches our eyes. If we consider the month of August, when UVA and UVB radiation reaches 750 Kj/m² (Fig. 2B), and if we apply the reasoning described above, 11.25 j/cm² could reach the eye.

Fig. 1 suggests that the UVA and UVB radiation the sun emits is to be found in the 300 to 380 nm interval and approximately 95% of that radiation is UVA while only 5% is UVB. Therefore, of the 7.5 j/cm² of mean solar radiation that reaches the eye, only 0.4 j/cm² is UVB. If we now consider the results of the experiments by Pitts et al. [25] (Table 1) performed on rabbit corneas and lenses, the threshold radiant of UVB exposure of reversible damage to the crystalline lens, with the corresponding interval added to 295 to 315 nm, is 6.45 j/cm², with exposure durations varying between eleven minutes and two hours. If we now address the case of permanent damage (Table 1), we can see that the total UVB radiation to cause permanent damage to the rabbit crystalline lens is 9.5 j/cm² (adding for all the wavelengths) with exposure durations that range from two minutes to two and a half hours. Thus we can see, that the 0.4 j/cm² of our example is a long way from the 9.5 j/cm² that causes irreversible damage to the rabbit crystalline lens. Although in this case, apart from the logical reservations when comparing a rabbit crystalline lens with that of a human’s, we must also bear in mind the possible difference there may be between a continual and indirect exposure to UV radiation for years (the case of the human eye) and the short, intense, direct exposure applied in the experiment by Pitts et al. [25] to the rabbit eye.

With regard to UVA, Pitts et al. [25] only present partial data on reversible damage to rabbit crystalline lens. Particularly they indicate that the threshold of radiant exposure for reversible damage is greater than 8.00 j/cm² for 320 nm; greater than 15.00 j/cm² for 335 nm, and greater than 70.00 j/cm² for 365 nm, without specifying the exposure duration. As the sun’s spectrum (Fig. 1) increases for those three wavelengths, more or less, at that same proportion (8:15:70), we can add them up and say that for intensities of UVA radiation greater than 93 j/cm² reversible damage to the rabbit crystalline lens can be caused. This UVA intensity is considerably higher than the intensity that generally reaches our eyes, which is around 7.1 j/cm² (95% of the UVA and UVB that reaches our eyes), but which are still comparable quantities.

In the extreme case of being in a setting of clear skies and fresh snow, the albedo can register a value of 0.9 and therefore 70% of the direct radiation could easily reach our eyes. Moreover, altitude bears a considerable influence on the intensity of radiation [29] as in the UVB band the altitude effect ranged from 6–8% km⁻¹ at noon, while for the UVB band it reached 7–11% km⁻¹. In this case, the intensity that would reach our eyes, taking the albedo of the fresh snow and the altitude (p.e. 2000 m) into account, would be around 38 j/cm² in UVA and around 2.1 j/cm² in UVB; such quantities approach the dose of 93 j/cm² for UVA and 9.5 j/cm² for UVB for reversible damage to the rabbit crystalline lens.

The easiest and most effective solution for phakic eyes is using sunglasses with a cut-off filter at 400 nm. However, implanted IOls in pseudophakic eyes should have a UV filter that provides adequate protection. Figs. 3 and 4 show how four different IOls filter UVA and UVB. It can be seen that the Physiol Hydriol 60 C, and the Alcon MZ60 and IQ (yellow), as well as all the IOls measured that show the same curve at that interval, wholly filter UVA and UVB radiation, so they provide perfect retina protection. However, the OCULARID PC 510Y IOL let approximately 52% of UVA and 2.6% of UVB through. This means that of the 7.1 j/cm² of UVA radiation that on average reaches our eyes, this IOL lets 3.7 j/cm² through; this value, though low, starts to become significant as the natural crystalline filters all this radiation. With regard to UVB radiation, the quantity this IOL lets through is, on average, 0.01 j/cm², which is very low, but as this radiation is highly damaging it would be better if it was wholly filtered. Moreover, these amounts increase on altitude reaching 20 j/cm² of UVA (maximum dose > 93 j/cm²) and 0.05 j/cm² of UVB (maximum dose 6.45 j/cm²).

According to these data, we can assess the effectiveness of the UV filters incorporated to the all IOls analyzed in this study. Nine of the 10 IOls analyzed filters practically the whole amount of UVA and UVB reaching the human eye; that is, they do not transmitted any wavelength under 380 nm, thus protecting the retina against this radiation. The remaining IOl incorporates a filter allowing pass some amount of UV radiation, nevertheless which does not reach the levels of risk.

Table 1 Reversible and permanent damage caused by UVB to the rabbit crystalline depending on the intensity of the radiation and the exposure duration.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Radiant exposure (J/cm²)</th>
<th>Exposure duration (sec)</th>
<th>Radiant exposure (J/cm²)</th>
<th>Exposure duration (sec)</th>
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<td>1.0</td>
<td>8064</td>
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<td>6374</td>
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<td>8721</td>
</tr>
</tbody>
</table>

Adapted from Pitts et al. [25].
Disclosure of interest

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Appendix 1. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jfo.2012.03.018.

References