Spectral transmission characteristics of intraocular lenses

Douglas Clarkson takes a look at how the increasing body of evidence for light toxicity effects on the retina have influenced the design of intraocular lenses

Intraocular lenses (IOLs) remain something of a relatively recent innovation in ophthalmology, with uptake of such lenses not really taking off until the mid-1970s with the introduction of cataract extraction techniques of phacoemulsification. It was around 1978 that the first reports were made by Mainster[1] linking intraocular lenses with photic retinopathy. This led to the introduction of IOLs with ultraviolet chromophores in the early 1980s. This was followed with the introduction of IOLs with a blue light absorption component in the 1990s when blue light became a suspected cause of retinal damage.

Photoprotection or photoreception

One of the key questions in selecting the transmission spectrum for IOLs is 'photoprotection or photoreception?' – as expertly described by Mainster.[2] The levels of protection of IOLs tend to be described as ultraviolet (200nm to 400nm), violet (400nm to 440nm) and blue blocking (440nm to 500nm). Initial considerations in the design of IOL transmission curves would appear to be dominated by the 'photoprotection' element – based on reduction of intensity of light levels on the retina in order to minimise potentially hazardous exposure. It is important, however, to identify the element of scotopic sensitivity which has an action spectrum which is more sensitive to shorter wavelengths as indicated in Figure 1 where the photopic peak is at 555nm and the scotopic peak is at 505nm. Thus an IOL which aggressively reduces the blue, violet and ultraviolet transmitted contributions is also likely to reduce the scotopic vision elements. The scotopic response of the eye is associated with the single photopigment rhodopsin.

It is now identified that the insertion of an IOL in the older patient may also provide an opportunity to improve their scotopic vision. The selection of an IOL which would further degrade scotopic vision is identified as a risk factor in modern living where, for example, components of night driving are mediated by scotopic vision. While identifying that consideration of scotopic vision is relevant in IOL characteristics, Werner[4] suggests that by reviewing the dynamic range of scotopic vision on a logarithmic scale, the role of the IOL is being overstated and that the actual effects are significantly less than stated by other observers such as Mainster and Sparrow.[5]

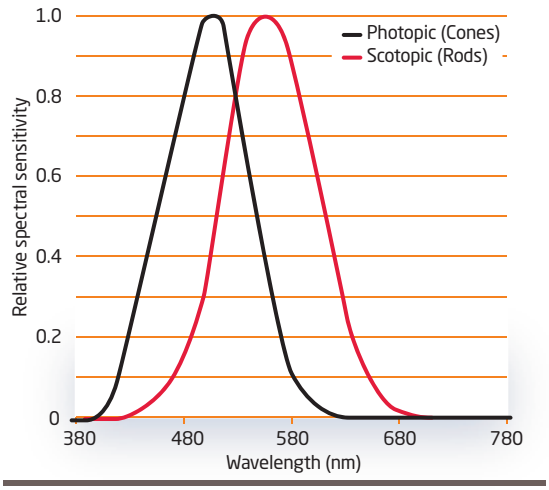

Figure 1 Photopic and scotopic response (Courtesy SPIE): after Schwiegerling[3]

Circadian rhythmicity

More recently, however, the relevance of circadian rhythmicity as modulated by melatonin produced through light exposure has been recognised by Skene[6] and where light within the wavelength range 420nm to 480nm – with peak at 460nm – appears to be primarily involved. In dark conditions the pineal gland secretes melatonin which reduces core body temperature. In the presence of bright light, melatonin levels are suppressed, core body temperature increases and alertness increases. The initial photosensitive component is modulated by the blue light sensitive photopigment melanopsin which is contained in photosensitive retinal ganglion cells. Numerous studies indicate that disorganisation of circadian rhythmicity may be associated in older adults with insomnia, depression and a wide range of ailments.[7,8,9] It is probably the case that circadian rhythmicity is not identified as a key parameter of the characteristics of an IOL lens – since the focus of the effect does not directly affect visual performance. Circadian rhythmicity, however, remains a relatively recent observation and has not significantly influenced IOL selection.

Photochromic IOLs

The dominant characteristic of mainstream IOL technology is that the spectral absorption of the lens material is designed to be invariant. Various researchers reference the potential advantage of the photochromic IOL where the transmission characteristics are modulated by the incident light level. Such a lens would typically have a constant UVR absorption component and with a violet and blue light absorption element which changed with the level of illumination. Such a lens would provide optimum scotopic response under conditions of low illumination but with transition to appropriate violet and blue light protection at conditions of higher illumination. The development of a UV-sensitive photochromic IOL by Meddenium of Irvine, California has been reported by Werner[10] – indicating validation of concept in an animal model.

Since May 2007 the Aurium photochromic IOL product developed by Meddenium has been available in Europe. The colour change to yellow takes about 10 seconds and it becomes colourless in about 30 seconds. The current Aurium product blocks about 50 per cent of both violet and blue light in the activated state.

Broadening the debate

The debate on the relative merits of the light-blocking characteristics of IOLs is ongoing where there appears to be an element of contradiction in epidemiological studies seeking to link light exposure and retinal damage. The Chesapeake Bay Waterman

Study reported by Taylor[11] identified that advanced age-related macular degeneration was more common in the group having increased exposure to blue light than the group exposed to increased levels of ultraviolet radiation. This is contrasted by the POLA study reported by Delcourt[12] where no link with blue light exposure was identified. In addition, work by Sparrow[13] has indicated there is biological evidence that blue light has a marked phototoxic effect on both the retina and for retinal pigment epithelium cells. Based on a more extensive set of studies, however, there is a general consensus, that, where appropriate, blue light exposure should be reduced. These concerns have recently been identified by Hawse[14] and where the precautionary principle is recommended to be actively extended to light exposure from a range of diagnostic equipment in ophthalmology – including slit lamps, direct and indirect ophthalmoscopes and operating microscopes. It can be surmised, however, that this is also an opportunity to develop 'smarter' devices which can estimate levels of exposure to patients and warn of risk of over-exposure.

The study by Hayashi[15] of 74 patients undergoing routine cataract surgery indicates that the use of yellow-tinted IOLs for removal of blue light did not significantly affect visual acuity and contrast visual acuity in photopic and higher luminance mesopic ranges. This result is taken as confirming the use of yellow tinted – blue absorbing – IOLs for routine implantation.

In analysis of retinal phototoxicity, there is identification of separate types – mediated by different receptors. The blue green or 'Noell-type' has an action spectrum similar to that of the aphakic scotopic sensitivity on account of the dominant response of rhodopsin which has an absorption peak around 500nm. The other component of retinal phototoxicity is referenced as the 'UV-blue', 'Ham-type' or 'blue light hazard' and is a more complex parameter than the 'blue-green' variant. The 'UV-blue' response closely matches the lipofuscin absoption curve though contributions are identified from cytochrome c and porphyrin. The 'UV-blue' response is also modified by the protective absorption of macular xanthopyll which extends from around 420nm to 520nm.

It can be identified, however, that there may be significant variations from person to person in their 'UV-blue' response functions due to variations in retinal pathology and distribution of protective agents such as macular xanthopyll. One area of work waiting to be undertaken is the estimation of the accumulated light exposure of the retina in wavelength bands based on patterns of solar exposure and transmission characteristics of structures in the eye. Within this model the change in optical transmission properties of the lens would play a key part in determining such lifetime retinal doses. Such a model would probably indicate that 50 per cent of lifetime dose at age 70 has been attained significantly earlier than age 35.

Measuring IOL spectral transmission values

Figure 2 indicates a specific system used to measure the spectral transmission properties of an IOL lens. The system in question is used in a range of applications in light and ultraviolet dosimetry within an acute hospital setting. In this example, measurements are made in air though measurements closest to conditions of IOL use should be made with the lens in a sample unit surrounded with

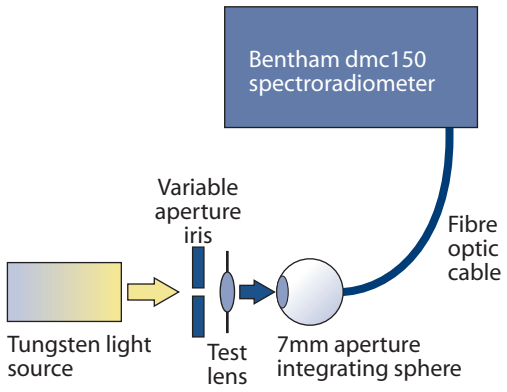

Figure 2 Detail of system to measure optical transmission of IOL (not to scale). The Bentham dmc150 spectroradiometer system detects the light transmitted to the 7mm aperture integrating sphere

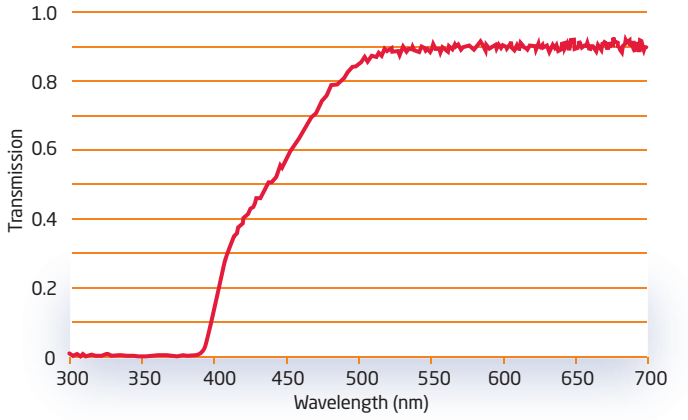

Figure 3 Typical transmission response of an Alcon yellow-tinted IOL as determined using the system outlined in Figure 2

saline. The tungsten light source in association with the high gain of the photomultiplier system in the Bentham dmc150 system allows a single lamp system to determine the transmission profile of the IOL from around 300nm. The Bentham dmc150 system is a double grating monochromator system where light is diffracted using a diffraction grating in one stage and the resultant diffracted light passed through another diffraction stage at which point it is detected by a highly sensitive photomultiplier. The double grating system is especially useful in detection of low levels of ultraviolet radiation on account of the very low level of 'stray light'. Typically, a spectral measurement between 250nm and 800nm will take around two minutes to complete. The transmission values are calculated as the ratio of detected transmission wavelength irradiance values to the equivalent 'clear path' irradiance values.

This method allows measurements to be made over a range of beam sizes for simulation of lens transmission properties as a function of pupil size. It is anticipated that light transmission will increase towards the periphery of the lens where it is thinner.

The transmission characteristics indicated in Figure 3 show non zero transmission of light from around 390nm.

Conclusion

Prior to the development of the photochromic IOL, the art of IOL selection was regarded as a balancing act between levels of blue light protection and possible reduction of scotopic vision. The recent awareness of factors relating to circadian rhythmicity does not appear to be a significant factor in IOL selection. With ophthalmology very much rooted in evidence-based medicine, it may take some time before results of clinical trials of photochromic IOLs significantly change prescribing patterns, though in the longer term it is anticipated that photochromic lenses will occupy a significant role in IOL prescribing. It should not, however, be imagined that the spectral profile of the IOL is the dominant factor that will lead to device selection. Aspects of stability of material, biocompatibility, ease of insertion, cost and size of insertion aperture will remain significant factors.

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