

Yellow Intraocular Lenses – To Block or Not to Block

Elfriede Wenzl,¹ Matthias G Wirtitsch^{1,2} and Navid Ardjomand¹

1. Department of Ophthalmology, Medical University Graz; 2. Department of Ophthalmology, Hietzing Hospital, Vienna

Abstract

Yellow filters for the eye have been of interest to ophthalmologists and optometrists for the last 30 years. Certain fish species can change the colour of the cornea in response to the level of illumination and regulate the amount of short-wavelength light reaching the retina. A positive influence of yellow eye filters on reduction of chromatic aberration has been found in a fish eye model. Blue-light-filter (yellow) intraocular lenses (IOLs) were introduced for cataract surgery almost 20 years ago. The main advantage of yellow IOLs is thought to be the reduction of chromatic aberration under photopic conditions and protection of the retina from phototoxic short-wavelength light, especially in eyes at risk of age-related macular degeneration (AMD). This article highlights the importance of yellow IOLs for cataract surgery in terms of quality of vision and AMD protection.

Keywords

Age-related macular degeneration (AMD), chromatic aberration, contrast sensitivity, intraocular lens, blue-light filter, yellow

Disclosure: The authors have no conflicts of interest to declare.

Received: 20 October 2009 **Accepted:** 18 November 2009 **DOI:** 10.17925/EOR.2009.03.02.77

Correspondence: Navid Ardjomand, Department of Ophthalmology, Medical University Graz, Auenbruggerplatz 4, A-8036 Graz, Austria.

E: navid.ardjomand@meduni-graz.at

The fact that short-wavelength blue light has a phototoxic effect on the retina was discovered in the late 1970s.¹⁻³ It is known that certain fish species change the colour of their corneas in response to the level of illumination and regulate the amount of short-wavelength light reaching the retina.⁴ It was further proposed that this phenomenon might also have a positive influence on visual quality by reducing longitudinal chromatic aberration.⁴⁻⁶ This led to the development of yellow-tinted intraocular lenses (IOLs) for cataract surgery in the early 1990s.⁷ These IOLs, first developed and produced by Hoya Healthcare Corporation, Japan, did not become popular until recent years, when Alcon in the US started a big marketing campaign to relaunch these IOLs worldwide.

There is no doubt about the importance of ultraviolet (UV) blockers in IOLs, but there is still a lot of discussion about the usefulness of filtering short-wavelength blue light with IOLs. People advocating these IOLs argue that they might protect the retina from phototoxic damage and increase visual quality by reducing chromatic aberration. Surgeons refusing to use the lens are worried about mesopic and scotopic contrast and colour sensitivity. This article highlights the pros and cons of blue-light-filter yellow IOLs.

Blue-light-filter Intraocular Lenses and Age-related Macular Degeneration

Cataracts and age-related macular degeneration (AMD) are the most common causes of visual loss after 60 years of age. AMD has a complicated pathogenesis involving a variety of hereditary and environmental factors. Lipofuscin in post-mitotic cells, such as the retinal pigment epithelium (RPE) cells, is considered to be a biomarker for cellular ageing. It represents incompletely degraded membrane

products and waste products that accumulate in the RPE cells with ageing and deteriorating cellular function.⁸ Lipofuscin contains different fluorophores, one of which – A2E – most probably originates from oxidative damage to the photoreceptor outer segments. These A2E-laden RPE cells are likely to mediate the formation of reactive oxygen species, which are speculated to be one of the causes of AMD, particularly in response to short-wavelength light.⁹⁻¹¹

Animal experiments have shown the induction of apoptotic cell death in photoreceptors and RPE cells after exposure to high-dose white light.¹² The short-wavelength visible blue light with its high-energy photons has the power to damage the cellular function of photoreceptors and RPE cells. It creates reactive oxygen species that damage the DNA and therefore result in apoptotic cell death. Blue light is 50–80 times more harmful than green light. However, red light is unable to induce retinal damage at a certain intensity.

The crystalline lens of the ageing human progressively increases absorption within the short-wavelength spectrum of visible light. During its life the lens becomes increasingly yellowish, acting as a natural protective filter against blue light. During cataract surgery the crystalline lens is removed and is replaced by an IOL, dramatically increasing the transmittance of radiation. This is despite the fact that the removal of the cataractous lens leaves the RPE at an age when its content of blue-sensitive A2E-laden cells is high and will continue to increase over a lifetime.¹³

In vitro and *in vivo* studies in animals showed a significantly higher RPE cell death when irradiating with short-wavelength visible light in

comparison with cells protected with blue-light filters. Pigmented rabbits were exposed to xenon light, with one eye of the animal protected by a yellow filter and the other eye by a UV filter. Electrophysical measurements showed significantly higher cell damage of the neuroretina and RPE functions in the eyes with the UV filter compared with the eyes with blue-light filters.¹⁴

Sparrow et al. compared the effect of blue light on human A2E-laden RPE cells protected by a yellow IOL compared with four other traditional IOLs without a yellow filter in a laboratory setting. The experiments demonstrated that visible blue, green and even white light may have detrimental effects on these cells when not protected by a yellow IOL. Death of the A2E-laden RPE cells could be reduced by 78–82% using a yellow IOL.¹³ A recent publication by Rezai and co-workers evaluated the effect of 10-day blue-light exposure on RPE cells protected by a yellow filter compared with a clear UV-filtering IOL. The results reveal that the RPE cells protected by the blue-light-filtering IOLs showed a statistically significantly lower rate of apoptosis.¹⁵

The Beaver Dam Eye Study shows that pseudophakic eyes have more than double the odds for AMD progression or developing late AMD than phakic eyes.¹⁶ The Blue Mountains Eye Study also showed an increase in late AMD in pseudophakic eyes compared with phakic ones.¹⁷ The pooled data of the Beaver Dam Eye Study and the Blue Mountain Eye Study reveal a considerably higher risk of developing late AMD in pseudophakic eyes compared with phakic eyes, with an odds ratio of 5.7.

Based on the results of the experimental and epidemiological studies mentioned above, it is not possible to draw conclusions on the effect of cataract surgery on the development of AMD. However, there is enough evidence from well-conducted observational studies to assume an association between cataract surgery and subsequent onset of late AMD. Additional clinical trials with well-defined length and sufficient statistical power as well as adequate control for confounding variables are therefore needed to prove this assumption.

UV light below 300nm is absorbed by the cornea, but UVA light (320–400nm) in turn is blocked by the crystalline lens. To reduce the phototoxic effect of UVA light on the retina, all commercially available IOLs have had integrated UV blockers since the 1980s. Blue-light-filtering IOLs were introduced in cataract surgery in the 1990s as there were data suggesting improvements in clarity of vision, contrast acuity and reaction time, as well as reduced glare. In addition to filtering UV light, they absorb a larger part of the high-energy visible blue light between approximately 380 and 500nm. In recent years, these IOLs have experienced a renaissance due to some evidence for visible blue light being a contributing factor to apoptosis of human RPE cells, and therefore blue-light-filtering IOLs may have a positive impact on AMD.¹⁸ Another study reported on an inhibitory effect of blue-light-filtering IOLs on vascular endothelial growth factor, which is one of the pro-angiogenic factors in the pathogenesis of exudative AMD.¹⁹ Nowadays, the age of patients undergoing cataract surgery is decreasing, which is inversely proportional to life expectancy and therefore elongates the period of pseudophakia. Furthermore, the acceptance of refractive lens exchange is growing. This implies a potential long-term effect or even a cumulative effect of short-wavelength visible light and its possible consequences.

Even so, there is no definite proof of the positive effect of filtering toxic short-wavelength light via yellow IOLs. However, there is some clinical and investigative evidence that such an IOL might be useful in reducing the risk of AMD in pseudophakic eyes.

Visual Performance with Blue-light-filter Intraocular Lenses Theoretical Background

The hypothesis that filtering blue light might increase visual performance was first suggested in the 1970s.⁶ Protagonists of these lenses argued that such an IOL would increase visual quality by reducing longitudinal chromatic aberration, which is three times higher with clear UV-blocking IOLs compared with the crystalline lens.²⁰ Opponents of blue-light-filter IOLs argue that these lenses might have a negative influence on the scotopic and mesopic contrast sensitivity due to the Purkinje shift, since blue light is much more important for scotopic than for photopic vision. The scotopic luminous efficiency peak, mainly contributed to by rods, is at 507nm, whereas photopic luminous efficiency peak is at 555nm, mainly contributed to by cones.²¹ Blocking blue light up to 500nm should theoretically result in a decrease in mesopic vision.

Hoya Healthcare Corporation introduced the first blue-light-filter IOL with yellow chromophores at the beginning of the 1990s²² to protect the retina and RPE from toxic blue light. Yellow lenses did not become popular until Alcon introduced a yellow IOL called Acrysof Natural after intense marketing of the lens in 2000. They called it 'natural' because it has a similar transmission spectrum to the crystalline lens of a 53-year-old person. Nowadays several companies offer blue-light-filter IOLs.²³ The expression 'blue-light-blocking IOLs' is now sometimes found in the literature. However, it must be stated that all of these IOLs are blue-light-filter IOLs with different transmittance capacities and are not absolute blue-blockers. Brockmann et al. have recently shown that commercially available blue-light-filter IOLs have a different transmission spectrum, especially the orange IOL,²³ and UV transmission spectrum depending on the IOL material used. There was a significant difference between hydrophilic and hydrophobic acrylic materials.²³ Mainster actually propagates implantation of orange IOLs to filter violet instead of blue light. This would protect the retina from the phototoxic short wavelengths between 400 and 440nm and transmit blue light of more than 440nm for better scotopic vision.^{21,24,25} However, the orange IOL has been shown to have a transmission spectrum of less than 60% at 500nm, whereas the yellow IOLs have a transmission spectrum of 80–90% at 500nm. The crystalline lens of a 53-year-old person shows a transmission spectrum of 70% at 500nm and so, in theory, scotopic vision should actually be better with yellow IOLs in pseudophakic patients than in the phakic eye of a 53-year-old patient.^{23,26}

Clinical Evidence

The first clinical study on yellow IOLs was published in 1996,²² but a high number of clinical studies have been published since on blue-light-filter IOLs with a special focus on the visual quality of the patients.

There is general agreement that yellow IOLs do not have any significant negative impact on visual acuity, photopic contrast performance and colour sensitivity.^{22,27–31} Some studies actually showed better contrast sensitivity with yellow rather than with clear IOLs,²² especially in patients with diabetes.³³

There are no studies showing a statistically significant influence of yellow IOLs on colour discrimination using the Farnsworth-Munsell D-15, Farnsworth Munsell 100-hue and Lanthony desaturated D-15 test. However, Mester et al. reported some colour disturbance in the early, but not in the late, clinical follow-up period.²⁹ Some patients do notice a difference if a yellow IOL is implanted in one eye and a clear IOL in the other,^{28,33} but the difference between the patient groups was not statistically significant. Kara-Junior et al. also studied the effect of yellow IOLs on blue–yellow perimetry and did not find any statistically significant difference in a study with intra-individual comparison. There is only one report of a patient's intolerance for mixed implantation of yellow and clear IOLs requiring an IOL exchange.^{34,35} A statistically significant difference in terms of colour discrimination has therefore not yet been shown in the literature; however, a mixed implantation in patients should be avoided, especially in patients with colour-sensitive professions, e.g. photographer, flower seller, painter, etc.

The literature is not conclusive in terms of mesopic and scotopic contrast sensitivity. However, clinical trials in general do not show any clinically significant difference in terms of mesopic contrast sensitivity between clear and yellow-tinted IOLs. Whereas few studies with intra- and inter-individual analysis showed a trend towards better mesopic contrast sensitivity with clear IOLs,^{28,29,36} other studies did not show any statistically significant difference at all,^{27,30} which is also the experience of the authors.²⁷ However, these studies are poorly comparable, since different tests were used to examine contrast sensitivity. Illumination was 85cd/m², 3cd/m² and <1cd/m² in most of the studies. A second problem in comparing the published studies lies in the IOL power implanted. Whereas Rodríguez-Galietero et al. included patients in the study only if they had an IOL power of +21.00 to +22.5D,^{30,32} other studies report on IOLs implanted between +10 and +30D.²⁹ However, the transmittance capacity of the IOLs also depends on the IOL power, and the published data are given for a +21D IOL.²³

To overcome the eventual mesopic and scotopic problem with yellow IOLs, Medennium Company in the US developed a phototropic IOL that is clear in the absence of UV radiation and turns yellow in the presence of UV light. This system should provide optimal protection from short-wavelength blue light during the day and turns clear at

night to transmit as much blue light as possible to the retina for optimal scotopic vision. However, a study with inter-individual comparison from the authors' group comparing patients with phototropic IOLs versus those with clear or yellow Hoya IOLs did not show any clinically or statistically significant difference between the patients in terms of best corrected spectacle visual acuity, photopic and mesopic contrast sensitivity or colour discrimination.³⁷

Conclusion

Published data on yellow-tinted IOLs do not provide any clear clinical evidence at the moment that implantation of these IOLs is superior to clear UV-blocking IOLs in reducing the incidence of AMD in pseudophakic patients, but this might be a potential advantage. Clinical data do not show any clear disadvantage on visual performance with these IOLs. Therefore, even though there are few studies showing some loss of contrast sensitivity under mesopic condition, it is questionable whether this is of clinical relevance. ■



Elfriede Wenzl is a Resident in the Department of Ophthalmology at Medical University Graz. Her research focus lies in the anterior segment of the eye, especially cataract and refractive surgery. She is a member of the Austrian and German Society of Ophthalmology and the European Society of Cataract and Refractive Surgery (ESCRS).



Matthias G Wirttsch is a Resident in the Department of Ophthalmology at Hietzing Hospital in Vienna. He is also conducting research in the Department of Ophthalmology at Medical University Graz, where his interests are focused on light filters in intraocular lenses and their influence on colour perception and contrast vision.



Navid Ardjomand is a Consultant Ophthalmic Surgeon at the University Hospital Graz and an Associate Professor of Ophthalmology at Medical University Graz. He is a member of several societies, including the European Society of Cataract and Refractive Surgery (ESCRS) and the Association for Research in Vision and Ophthalmology (ARVO).

- Ham WT, Jr., Mueller HA, Ruffolo JJ, Jr., et al., *Photochem Photobiol*, 1979;29:735–43.
- Ham WT, Jr., Mueller HA, Silney DH, *Nature*, 1976;260:153–55.
- Ham WT, Jr., Ruffolo JJ, Jr., Mueller HA, et al., *Invest Ophthalmol Vis Sci*, 1978;17:1029–35.
- Heinermann PH, *Exp Biol*, 1984;43:127–47.
- Sivak JG, Bobier WR, *Vision Res*, 1978;18:453–55.
- Sivak JG, Bobier WR, *Am J Optom Physiol Opt*, 1978;55:813–17.
- Nilsson SE, Textorius O, Andersson BE, et al., *Prog Clin Biol Res*, 1989;314:539–53.
- Schutt F, Bergmann M, Holz FG, et al., *Graefes Arch Clin Exp Ophthalmol*, 2002;240:983–8.
- Rozanowska M, Pawlak A, Rózanowski B, et al., *Invest Ophthalmol Vis Sci*, 2004;45:1052–60.
- Wang JJ, Klein R, Smith W, et al., *Ophthalmology*, 2003;110:1960–67.
- Cugati S, Mitchell P, Rochtchina E, et al., *Ophthalmology*, 2006;113:2020–25.
- Grimm C, Wenzel A, Williams T, et al., *Invest Ophthalmol Vis Sci*, 2001;42:497–505.
- Sparrow JR, Miller AS, Zhou J, *J Cataract Refract Surg*, 2004;30:873–8.
- Nilsson SE, Textorius O, Andersson BE, et al., *Lasers Light Ophthalmol*, 1990;3:1–10.
- Rezai KA, Gasyna E, Seagle BL, et al., *Graefes Arch Clin Exp Ophthalmol*, 2008;246:671–6.
- Klein R, Klein BE, Jensen SC, et al., *Arch Ophthalmol*, 1998;116:506–13.
- Mitchell P, Wang JJ, Foran S, et al., *Ophthalmology*, 2002;109:1092–7.
- Rezai KA, Gasyna E, Seagle BL, et al., *Graefes Arch Clin Exp Ophthalmol*, 2008;246:671–6.
- Yanagi Y, Inoue Y, Iriyama A, et al., *J Cataract Refract Surg*, 2006;32:1540–44.
- Siedlecki D, Ginis HS, *Optom Vis Sci*, 2007;84:984–9.
- Mainster MA, *Arch Ophthalmol*, 2005;123:550–55.
- Niwa K, Yoshino Y, Okuyama F, et al., *Ophthalmic Physiol Opt*, 1996;16:297–302.
- Brockmann C, Schulz M, Laube T, *J Cataract Refract Surg*, 2008;34:1161–6.
- Mainster MA, Sparrow JR, *Br J Ophthalmol*, 2003;87:1523–9.
- Mainster MA, *Br J Ophthalmol*, 2006;90:784–92.
- Boettner E, Wolter J, *Invest Ophthalmol*, 1962;1:776–83.
- Wohlfart C, Tschuschnig K, Fellner P, et al., *Klin Monatsbl Augenheilkd*, 2007;224:23–7.
- Wirttsch MG, Schmidinger G, Prskavec M, et al., *Ophthalmology*, 2009;116:39–45.
- Mester U, Holz F, Kohnen T, et al., *J Cataract Refract Surg*, 2008;34:608–15.
- Rodríguez-Galietero A, Montés-Micó R, Muñoz G, et al., *J Cataract Refract Surg*, 2005;31:1736–40.
- Schmidinger G, Menapace R, Pieh S, *J Cataract Refract Surg*, 2008;34:769–73.
- Rodríguez-Galietero A, Montés-Micó R, Muñoz G, et al., *J Cataract Refract Surg*, 2005;31:2088–92.
- Eberhard R, Roberti P, Prünke C, *Eur J Ophthalmol*, 2009;19:235–9.
- Olson MD, Miller KM, *Am J Ophthalmol*, 2006;141:957–8.
- Shah SA, Miller KM, *Am J Ophthalmol*, 2005;140:941–2.
- Pierre A, Wittich W, Faubert J, et al., *J Cataract Refract Surg*, 2007;33:1248–52.
- Wenzl E, Wohlfart C, Vidic B, et al., *Spektrum der Augenheilkunde*, 2009;23:17–20.