Original Article

Effect of the color of the intraocular lens on optical and visual quality

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Purpose: To analyze the optical quality of intraocular lenses (IOL) with an orange (PC440Y) and a yellow (SN60AT) filter, and correlate these results with the visual quality of patients with these implants. **Setting:** Fisabio Oftalmología Médica, Valencia, Spain. **Design:** Randomized prospective study. **Materials and Methods:** The IOL optical quality was determined using the modulation transfer function (MTF) and the spectral transmission. The visual quality of 87 eyes with cataract (51 with orange filter and 36 with yellow filter) was determined by best corrected visual acuity (BCVA) and contrast sensitivity function (CSF) under photopic and mesopic conditions. To analyze the results, we use a Student's *t*-test. **Results:** Orange lens filtered more of the blue spectrum (cut-off wavelength of 370 nm) than the yellow lens (390 nm). The MTF of the yellow lens was better than the orange lens (average modulation of 0.676 for natural and 0.672 for orange). The patients' BCVA was 0.02 + 0.10 logMAR for both lenses. The CSF obtained with the yellow lens was slightly better, although without statistically significant differences ($P > 0.05$). **Conclusions:** Both lenses are of good optical quality. The patients' visual quality was similar with both lenses, and optical quality was also similar. The color of the lens does not affect the visual quality of the patient.

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It is a well-known fact that crystalline lens properties change with age,[1,2] as do retinal sensitivity and retina properties in general.[3] One of the most striking transformation characteristics of the crystalline lens in a healthy subject is perhaps its change in shade of color. The human lens in healthy people is light brown in middle age.[2,4] Although not wholly demonstrated, it is believed that short wavelengths may contribute to retina damage in middle-aged to elderly patients due to the characteristics the retina acquires with age.[5]

Until a few years ago, this effect was not taken into account when choosing an intraocular lens (IOL) for a patient having cataract surgery. The patient had a totally transparent IOL implanted, with a filter for only ultraviolet wavelengths between 200 nm and 400 nm. This type of IOL endeavored to simulate the crystalline lens of a young patient, which was considered better than that of an older patient. Nevertheless, currently, in view of the above-mentioned evidence (although it has not been wholly demonstrated) IOL with various filters that endeavor to block the passage of blue light, simulating the crystalline lens of a middle-aged to elderly subject have been introduced on the market.

At present, there are several options of IOL with filters available. They all attempt to block the passage of blue light to the retina, establishing the cut-off at different wavelengths to provide good photoprotection. Thus, there are violet filter lenses that block the visible spectrum of the wavelengths from 400 nm to 440 nm, and blue filter lenses that block the spectrum between 440 nm and 500 nm.[6] The cut-off value considered the best for retinal photoprotection is established at around 445 nm.[7] But, in general, shortwave filter IOL have a very different spectral density from that of the natural lens, which usually makes filtering blue light exert a partial photoprotection of the retina. Furthermore, any spectral filter that reduces blue-green phototoxicity causes an equivalent percentage decrease in scotopic sensitivity.[6] Indeed, there are no IOL on the market that offer a good compensation between retinal protection and reduction in the blue light that reaches the ocular fundus (photoreception).[6,7]

Despite clinical evidence showing that a complete protection of the retina against light damage does not occur with this type of IOL, they are still used. This is because the inclusion of this filter in IOL implanted in patients does not seem to affect their everyday life.[8]

Clinical studies on IOL with filters of a yellowish shade show that, there are no significant differences in visual acuity and contrast sensitivity (CS) under different illumination conditions for patients with IOL with such filters and for patients without them.[9-18] Until date, most clinical studies performed on a change in chromatic vision with the insertion of a filter show small alterations in the area of the short wavelengths that the filter cuts off, but in no case do these changes appear to be significant when compared with a normal population group.[13,16-18]

Some IOL with different wavelength cut-off filters were designed, like the lenses with an orangey shade (Ophtec PC 440Y orange) and a yellowish shade (Alcon natural SN60AT), with a view to making IOL more similar to the physiological conditions of a normal lens.[2] There is a recent study that compare color differences and contrast sensitivity function (CSF) in photopic and mesopic illumination conditions

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between orange and yellow IOL, and it conclude that there are not significative differences in the results that they obtain with both lenses.[19]

Here we determine and compare the optical quality of both lenses, and we measure the modulation transfer function (MTF) and spectral transmission. We also analyze the influence of these factors on the visual quality of patients implanted with orange and natural yellow lenses in order to evaluate the possible advantages and disadvantages of these types of filters.

Materials and Methods

Optical properties

We evaluated spherical lenses. We do not use two aspherical lenses to avoid the way, in which each manufacturer compensates the asphericity of the eye, because this fact could influence on the results obtained.

The main difference between these lenses is that the natural SN60AT lens has an IMPRUV® filter, which gives it a yellow tint that filters the light spectrum up to approximately 400 nm, while the orange PC440Y lens filters up to 440 nm. We also determined its spectral transmission curves using a Perkin-Elmer Lambda 800 UV/VIS spectrometer, which provides a spectrum from 200 nm onward.

Similarly, and so any appreciable difference due to the optical quality of the lenses could be ruled out, the MTF of both lenses was determined. The Orientation and Processing of Airborne Laser Scanning data Vector System (Image Science Ltd) was used applying Fast Fourier Transform techniques.[20-22]

Clinical tests

The study adheres to the tenets of the Declaration of Helsinki for Research Involving Human Subjects and is approved by the Institutional Review Board.

The tests were performed monocularly. 87 eyes of 51 patients (mean age 72 + 6 years) were chosen for the study. The patients were suffering from cataracts, usually of a senile nature; they did not present retinopathies or any other ocular pathology or of any other type that could affect the results. The following subjects were excluded from the study:

- Patients who had anomalies or guttas in their endothelial count
- Patients undergoing ocular treatment of any nature for at least 1-month prior to the commencement of the study or who had been taking medication that could produce somnolence – antihistamines, etc.,– or with a history of drug addiction or alcoholism
- Patients who did not dilate properly with mydriatics or cycloplegics, as this would hinder surgery and moreover, it would prevent observing the peripheral effects that can easily occur in the IOL.

All the patients were examined two times. The first was before surgery, and 3 months later. The following tests were carried out at each appointment:

- Optical compensation to obtain best corrected visual quality (BCVA) with an Early Treatment Diabetic Retinopathy Study chart
- Corneal topography (with Pentacam). This was for assessing possible changes in the ocular morphology (especially corneal) after surgery that might give false results, attributing effects to the IOL that it could not produce
- Measurement of the CSF under mesopic (around 3 cd/m^2) and photopic (85 cd/m^2) illumination conditions with the CSV - 1000 test.

If at any time, an anomaly was detected in the tests that indicated that a patient might have been suffering from some type of pathology that would mask the results; the patient was excluded from the database of this study.

All the patients gave their signed, informed consent, and the ethics regulations were followed throughout the study.

Surgical technique

Both types of IOLs were implanted using peribulbar anesthesia for the technique to be applied. When natural SN60AT lenses were to be implanted, they were inserted through a corneal incision of approximately 2.75 mm; on the other hand, the incision was 3.00–3.20 mm, when the lens was an orange PC 440Y. The technique used in both cases was phaco-chop, with the Infinity System (Platform Alcon®, Inc. Fort Worth Texas, USA). Capsular bag implantation of the yellow filter lens was performed with the Monarch II injector (Alcon®, Inc. Fort Worth Texas, USA), while the orange lens was implanted with the Ophtec injector® (Groningen, Netherlands).

All the patients received postoperative antibiotic and topical corticoid treatment for 4 weeks at a dosage that was gradually decreased (tobramicine + dexamethasone) (Tobradex Ophthalmic Suspension, Alcon Cusí, Barcelona, Spain).

The natural IOL was implanted in 36 eyes, and the orange lens was implanted in the remaining 51.

Statistical analysis

For the purpose of comparison, the two eyes of the same patient were used as independent variables. We used the SPSS program version 22 (IBM, Chicago) with Student's *t*-test to check for statistically significant differences between points of the curve or between the same points of diverse curves. We used a paired comparison in samples of the same patient and lens and an unpaired comparison between results of both lenses. The null hypothesis is rejected if $P < 0.05$. These values are shown in all the figures.

Results

Fig. 1 shows the spectral transmission [Fig. 1a] and the MTFs (measured with pupil of 3 mm) [Fig. 1b] of both lenses. To simplify the comparison we used, in previous studies,[20] the average modulation (AM) value, which is the value of modulation averaged in the range of frequencies from 0 to 100; in this way each MTF is represented by only a numeric value (AM). These AM values are 0.674 for the natural lens and 0.672 for the orange lens. Although both parameters are similar, we can see some differences between these curves. While the MTF curve of the natural lens is slightly lower at low frequencies, at high frequencies the trend is reversed, because the MTF of the orange lens is worse than the natural lens.

Although the patients were selected at random, except for the criteria of age and gender, so that both groups would be similar, their CS under photopic and mesopic illumination conditions and BCVA were evaluated prior to surgery in order to confirm the uniformity of their vision. In addition, when the preoperative and postoperative topographical maps were analyzed, seemingly no severe induced corneal astigmatisms were observed 3 months after surgery, nor was any corneal damage, and nor drastic changes in the corneal morphology that could distort the results measured for each patient.

Best corrected visual quality prior surgery was 0.3 + 0.1 logMAR for natural lens and 0.3 + 0.2 log MAR for orange lens (P = 0.23), and 3 months after surgery was 0.02 + 0.10 logMAR for natural and orange lens (P = 0.84). We found statistical differences between BCVA obtained prior and after surgery for each lens (P < 0.000).

Fig. 2 shows the mean CSFs obtained with both lenses [natural: Fig. 2 top; orange: Fig. 2 bottom] under photopic and mesopic lighting conditions. In both figures, we show P value for each spatial frequency measured. For yellow filter, the change of illumination conditions was significant for all spatial frequencies, and for orange lens, it was significant except for low spatial frequency (3 cycles per degree [cpd]).

Table 1 shows the P value, when comparing both lenses at the same illumination conditions. We did not found significant differences between both lenses at any spatial frequency.

The different criteria each patient applied in their answers were observed, when the CS was being measured. So as to minimize dispersion of data, we now compare sensitivity functions to the photopic and mesopic contrast of the same patient; one assumes the same criteria would be used, when the CS was measured. These differences were then averaged out for all the patients. The result is given in Fig. 3. We observed that differences between illumination conditions were greater in the orange filter lens, although, as we could see in the figure, when we compared this illumination change between both lenses, the differences were not statistically significant.

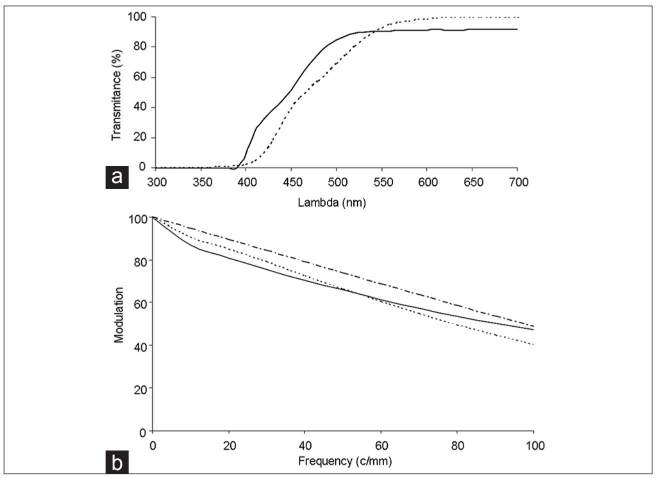

Figure 1: Spectral transmission orange and yellow filter lenses (a) and modulation transfer function (MTF) of both lenses (b) Solid line represents yellow filter lens and dotted line represents orange lens. In Figure 1b dashed-dotted line represents MTF of an ideal system without aberration effects and limited only by diffraction c/mm: Cicles/mm

Discussion

Orange lens filters more blue area compared to the yellow lens. In accordance with the studies that state that blue light affects the retina[3-5,23] this is an advantage, although it also means that it removes part of the visible light that reaches the retina, which is necessary for vision.[6] Nevertheless, if we take note of the height of the curves, when they reach their asymptotic value, we can see that the orange lens reaches 98% of transmission while the yellow lens only reaches 90%. However, this value is reached by the orange lens at 610 nm onward, that is, within the red area of the spectrum, while in the case of the yellow lens it is 550 nm onward, precisely at the maximum of the vision curve (V_{λ}), that is, where the visual system is most sensitive and most output is obtained from the light that reaches the retina. Regarding the cut-off point, the orange lens starts to transmit (1% approximately) from the wavelength at 370 nm, becoming appreciable (10%) at 420 nm and reaching 50% of transmission at 470 nm approximately. On the other hand, the yellow lens wholly filters all the wavelengths up to 390 nm, after which it starts to transmit, reaching 50% of transmission at 440 nm approximately.

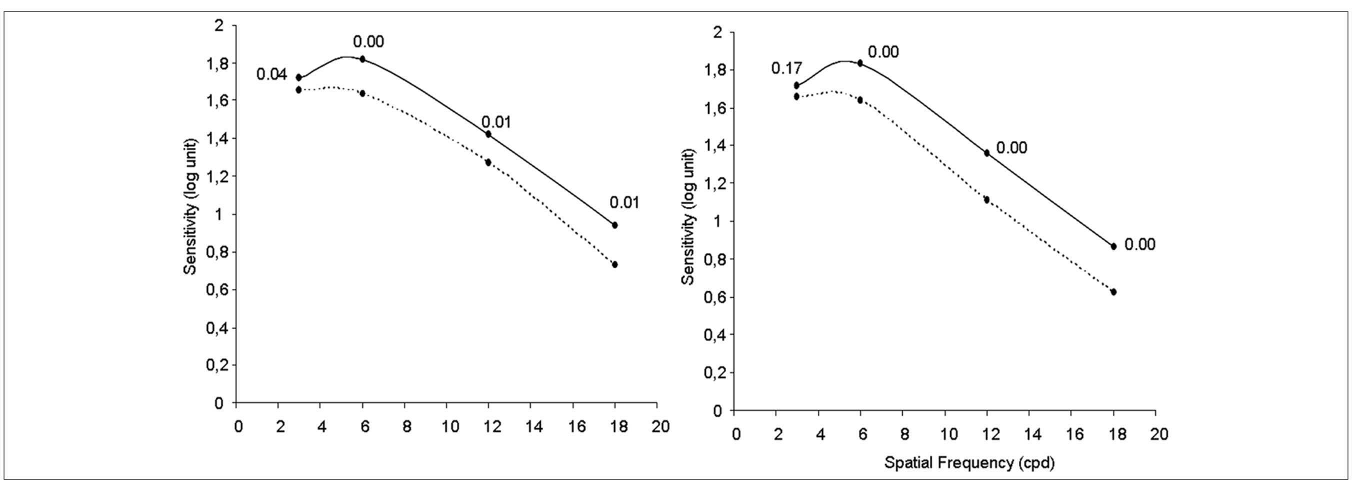

Figure 2: Photopic (continuous line) and mesopic (dashed line) contrast sensitivity function of patients with yellow lens (top) and orange lens (bottom). The values associated at each spatial frequency on the graph are the 'P' values, and show when the dots representing the same spatial frequency are statistically different (cycles per degree)

Table 1: *P* values between both lenses at the same illumination conditions

Spatial frequency (cpd)	Illumination conditions	
	Photopic level (>85 cd/m^2)	Mesopic level (3 cd/m^2)
3	0.74	0.68
6	0.93	0.92
12	0.40	0.08
18	0.22	0.35

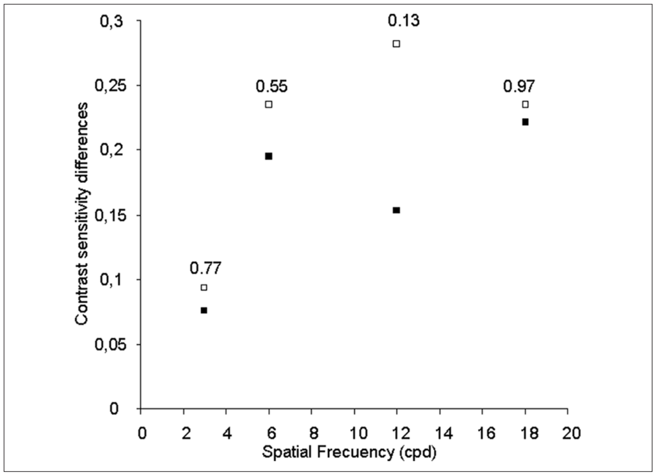

Figure 3: Mean of the contrast sensitivity differences between photopic and mesopic illumination conditions for each patient for both lenses (orange: empty squares; yellow: filled squares). The values associated at each spatial frequency on the graph are the '*P*' values, and show when the dots representing the same spatial frequency are statistically different (cycles per degree)

Therefore, it is clear from these data that each lens has its own advantages and disadvantages.

Regards to MTF curves, we observed that the optical quality is very good for both lenses, as it usually is for monofocal lenses.[20] If we analyze the AM of both lenses, as Felipe *et al*.[24] said in their article, only a difference of 25% in AM could provoke important differences in BCVA, so, in this case, the MTF of yellow IOL will not provoke better BCVA than orange IOL (there is only a difference of 0.59% between the two values), although we can observe that MTF at high frequencies in yellow filter is better than the orange filter. This effect is in concordance with BCVA obtained for both lenses.

With these results, in mesopic vision, we would expect obtain a visual quality better in yellow lens than in orange lens, due Purkinje effect by its high range of transmission and a slightly better modulation at high frequencies. Although the mesopic values of CSF for all frequencies in yellow lens are higher than in orange lens, these differences are not significatives and hence we can affirm that objective quality properties of these lenses does not affect subjective visual quality of the patients.

Contrast sensitivity under mesopic conditions is statistically lower than under photopic conditions for all the spatial frequencies studied, for the yellow lens and for medium-high frequencies (6, 12 and 18 cpd) for the orange lens. For the 3 cpd frequency, we did not expect to find significant changes on CS, when we changed lighting conditions because Weber's law[25] was played out, which highlights that for low spatial frequencies, illumination conditions hardly affect CS, but for yellow filter, we also found changes.

The differences between the two illumination conditions are not the same, depending on the spatial frequency measured, and they increase as it goes up, although not lineally. The greatest difference was observed for 12 cpd spatial frequency for orange filter, and the lowest for 3 cpd for both lenses, in concordance with Webber's law. Between both lenses, we observe the greatest changes in orange lens, because it removes more of the visible light that reaches the retina that is necessary for vision than yellow filter. When we compare both lenses, again these differences are not statistically significant. Hence, color lens differences do not provoke changes in CS, despite illumination conditions.

To complete the study, it will be interesting to compare our results with a IOL without color filter. Although we can find in the literature studies that affirm that there are no differences between lens with and without filter in BCVA and CS,[9,12,16] it will be interesting to check if differences between photopic and mesopic lightning conditions are similar or if these differences are greater in filter IOLs than in no filter IOLs, due to its transmission values.

Conclusion

Both lenses more or less imitate the spectral transmission conditions of a lens of the age range studied,[2] as we can see in the spectral transmission curves. Nonetheless, the orange lens filters more of the blue band than the yellow filter lens. However, the yellow filter lens reaches that asymptomatic value at 550 nm, practically at the maximum spectral sensitivity of the human visual system.

Nevertheless, this different filter does not involve a substantial difference between the visual results obtained with each lens. With regard to the CS, both lenses note the change of illumination conditions due its transmission. Finally, we can state that both lenses with their different filters provide a similar visual quality.

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