Color perception and contrast sensitivity of either UV-light filtering or blue-light filtering intraocular lenses

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PURPOSE: To evaluate contrast sensitivity and color perception after implantation of either UV-light filtering or blue-light filtering with a yellow chromophore intraocular lenses (IOL).

SETTING: Laserlens. Ophthalmology Institute. Ioannina-Greece.

METHODS: A prospective, longitudinal, comparative and interventional study including 200 eyes of 100 patients undergoing phacoemulsification. The first group included 150 eyes from 75 patients implanted with blue-light filtering with yellow chromophore IOLs, while the second group included 50 eyes from 25 patients implanted with UV-light filtering IOLs. All patients underwent a complete ophthalmological examination and complementary studies of contrast sensitivity and chromatic perception.

RESULTS: The desaturated Farnsworth-Munsell D-15 test (FM-15) showed higher mean accuracy in the postoperative period (ANOVA $p = 0.028$). The confusion index, determined by the degree of color loss, demonstrated a significant difference with implantation of IOLs (SN6AD1 and SN60WF), in both saturated (ANOVA $p = 0.017$) and desaturated colors (ANOVA $p = 0.009$). The strong polar orientation of the dyschromatopsia was evaluated with the selectivity index (S-index), noting that the desaturated colors showed a significant variation in both groups (ANOVA $p = 0.048$), unlike the saturated colors (ANOVA $p = 0.098$). The IOL did not determine a statistically significant change (S-index) in either saturated (ANOVA $p = 0.266$) or desaturated colors (ANOVA $p = 0.156$). Contrast sensitivity was higher in patients treated with blue-light filtering and yellow chromophore (SN60WF, SN60AT and SN6AD1).

CONCLUSION: Blue-light filtering with 0.04% yellow chromophore IOLs improves contrast sensitivity in both photopic and mesopic conditions, and also improves the quality of color perception.

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Cataract surgery is the most frequently performed surgical procedure worldwide, with good clinical outcomes. Both surgical technique and technology have been refined, as have the equipment and instruments. Today, intraocular lenses (IOL) are better designed, with higher quality and biocompatibility and a wider range of refractive indices; moreover, the new thickness and aspheric surfaces reduce the spherical aberration of the cornea, and there is a greater variety of multifocal and toric lenses available, which also provide retinal protection from ultraviolet light and visible light wavelengths[1].

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Mainster[2] noted that, with aging, chromatic (color) perception changes, either by the decreasing number of photoreceptors in the eye, or as a result of sclerosis in the crystalline lens, resulting in attenuation of light perception in the range between blue and violet radiation (330 to 400 nm). Thus, a pseudophakic patient with an IOL with no filter to absorb these wavelengths may suffer retinal phototoxicity[2].

According to the von Helmohltz trichromatic theory, there are 3 different cone populations, each with specific sensitivity and different wavelengths[3].

Sunlight comprises the set of electromagnetic radiation; the radiant spectrum (ultraviolet radiation [UV]) is between 100 and 390 nm. There are three types of UV radiation: UVA, UVB and UVC. The cornea has the ability to filter out UVA radiation (low energy) and the crystalline lens UVB radiation (medium energy), so a filter that absorbs this type B radiation has been added to IOLs since their introduction on the market.

The cornea is an ellipsoid, whose prolate curvature (Q-0.26 = 25 μm) in the third decade of life is neutralized by the negative spherical aberration of the crystalline

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lens (25 μm). During the sixth decade, the crystalline lens generates a positive spherical aberration (+25 μm), resulting in a +50 μm spherical aberration, which causes the marginal rays to focus in front of the paraxial rays, reduces the contrast sensitivity and consequently, could cause a deterioration in visual quality[4].

There have been recent changes in the IOL design to obtain an aspherical lens, which can reduce or even offset the positive spherical aberration of the cornea, with improvement in visual quality and greater contrast sensitivity[5,6,7]. However, changes in coma and in the aberration induced by the corneal incision need further examination[7].

The aim of this study was therefore to determine whether patients undergoing phacoemulsification and IOL implantation with UV-light filtering or blue-light filtering between 440 and 400 nm present significant changes in contrast sensitivity and color perception.

SUBJECTS, MATERIAL AND METHODS

This cohort, prospective, longitudinal, comparative and interventional study was designed to assess changes in color perception and contrast sensitivity. It was performed at the anterior segment department of the ophthalmology Institute "Laserlens" (Ioannina, Greece), and adhered to the tenets of the Declaration of Helsinki. The protocol was presented to the research ethics committee at Laserlens Institute, and each patient signed a consent form.

The study included 200 eyes from 100 patients of both sexes aged ≥40 years old diagnosed with cataract (classified as LOCS III: NO2 to NO5, P2 to P5). Patients underwent phacoemulsification and IOL implantation with UV-light filtering IOL or with blue-light filtering and 0.04% yellow chromophore.

Patients with a history of eye injury, tear film abnormalities or eye diseases such as uveitis, glaucoma, corneal and retinal disease, as well as those patients on treatment with medications that can cause some impaired color perception, were excluded.

Patients were randomized to 2 groups: the first group included 150 eyes from 75 patients, implanted with blue-light filtering with 0.04% yellow chromophore IOLs, (SN60WF, SN60AT, SN6AD1 Alcon®), while the second group included 50 eyes from 25 patients who were implanted with UV-light filtering IOLs without chromophore and one-piece platform (SA60AT Alcon®).

Preoperative evaluation

All patients underwent a complete ophthalmology examination and complementary studies that included contrast sensitivity (CSV-1000E test cycles/degree) and a color vision test with the Farnsworth-Munsell D-15 test (FM-15) 15 days before phacoemulsification and IOL implantation.

Postoperative evaluation

Postoperative evaluations were performed 2, 7 and 30 days after surgery; contrast sensitivity tests (CSV-1000E cycles/degree) and the FM-15 color perception test were performed at the last visit. Data was captured in a spreadsheet in Microsoft Excel version 2003 and analyzed using SPSS 11.0 (Chicago, INN). Numerical variables were summarized as mean and standard deviation. Visual acuity was a simple correlation between the different factors to determine possible associations. For statistical analysis of contrast sensitivity in each age group, data from the CSV-1000E graphics cycles/degree were used and analyzed in logarithmic units for each spatial frequency (3, 6, 12 and 18 cycles/degree).

Statistical analysis

Statistical analysis could not be applied to the color vision due to the sample being nominal and not numerical in nature. Therefore, this test did not provide statistical values of central tendency and dispersion. Correlation was explored between changes on the axis, selectivity index (S-index) and confusion index (C-index), in order to calculate the mean and be able to verify the correlation of each group before and after the surgery. Non-parametric tests were performed (Levene's variance and ANOVA) and a significance level of $p \leq 0.05$ was established.

RESULTS

We evaluated 200 eyes from 100 different patients with mean age of 64 years. Patients were predominantly female (70%). There was a statistically significant difference in preoperative and postoperative visual acuity tested in LogMAR units (0.21 ± 0.15), with a marked improvement postoperatively.

Patients (LOCS III) were divided into 2 groups (40-50 years and 50-70 years) and then further subdivided into 4 subgroups postoperatively (SN60WF, SN60AT, SA60AT and SN6AD1). In the preoperative subgroup, the scale of contrast sensitivity (CSV-1000E), analyzed in cycles per degree (cpd), showed a statistically significant difference, with increased contrast sensitivity in the 40-50 year age group (Tables 1 and 2).

Similarly, in the postoperative period, a statistically significant difference was found in each of the subgroups, noting increased contrast sensitivity in patients with IOL treated with blue-light filtering and 0.04% yellow chromophore (SN60WF, SN60AT, SN6AD1), compared with UV-light filtering IOL without chromophore and one-piece platform (SA60AT). Contrast sensitivity in the postoperative group showed a significant increase in all spatial frequency rows (cpd): A ($p = 0.003$), B ($p = 0.001$) C ($p = 0.002$) and D ($p = 0.000$) (ANOVA).

This increment was statistically significant for all types of IOL implanted, and was also higher in those IOL treated with 0.04% yellow chromophore, especially in the spatial frequency 3 cycles/degree and 6 cycles/degree (Tables 3 and 4; Figure 1).

The saturated and unsaturated color vision test (FM-15) seeks to assess the degree of accuracy, the patient's hits divided by the total number of attempts multiplied by 100. Saturated tests showed higher preoperative variance; however, the mean was similar

Table 1. Preoperative contrast sensitivity. Cataract. Age 40 to 50 years old.

ROW (cpd)	Subgroup 1 mean ± SD	Subgroup 2 mean ± SD	Subgroup 3 mean ± SD	Subgroup 4 mean ± SD
A (3.0)	1.28 ± 0.15	1.13 ± 0.30	1.23 ± 0.09	1.25 ± 0.22
B (6.0)	1.35 ± 0.30	1.31 ± 0.29	1.27 ± 0.13	1.5 ± 0.25
C (12.0)	0.90 ± 0.17	0.96 ± 0.25	0.91 ± 0.00	1.09 ± 0.24
D (18.0)	0.41 ± 0.18	0.44 ± 0.19	0.47 ± 0.00	0.66 ± 0.24

cpd, cycles per degree; SD, standard deviation.

Table 2. Preoperative contrast sensitivity. Cataract. Age 50 to 70 years old.

ROW (cpd)	Subgroup 1 mean ± SD	Subgroup 2 mean ± SD	Subgroup 3 mean ± SD	Subgroup 4 mean ± SD
A (3.0)	1.37 ± 0.13	1.41 ± 0.14	1.26 ± 0.12	1.17 ± 0.24
B (6.0)	1.38 ± 0.17	1.55 ± 0.11	1.30 ± 0.12	1.30 ± 0.12
C (12.0)	0.94 ± 0.08	1.11 ± 0.21	0.91 ± 0.00	0.91 ± 0.00
D (18.0)	0.50 ± 0.08	0.57 ± 0.15	0.47 ± 0.00	0.47 ± 0.00

cpd, cycles per degree; SD, standard deviation.

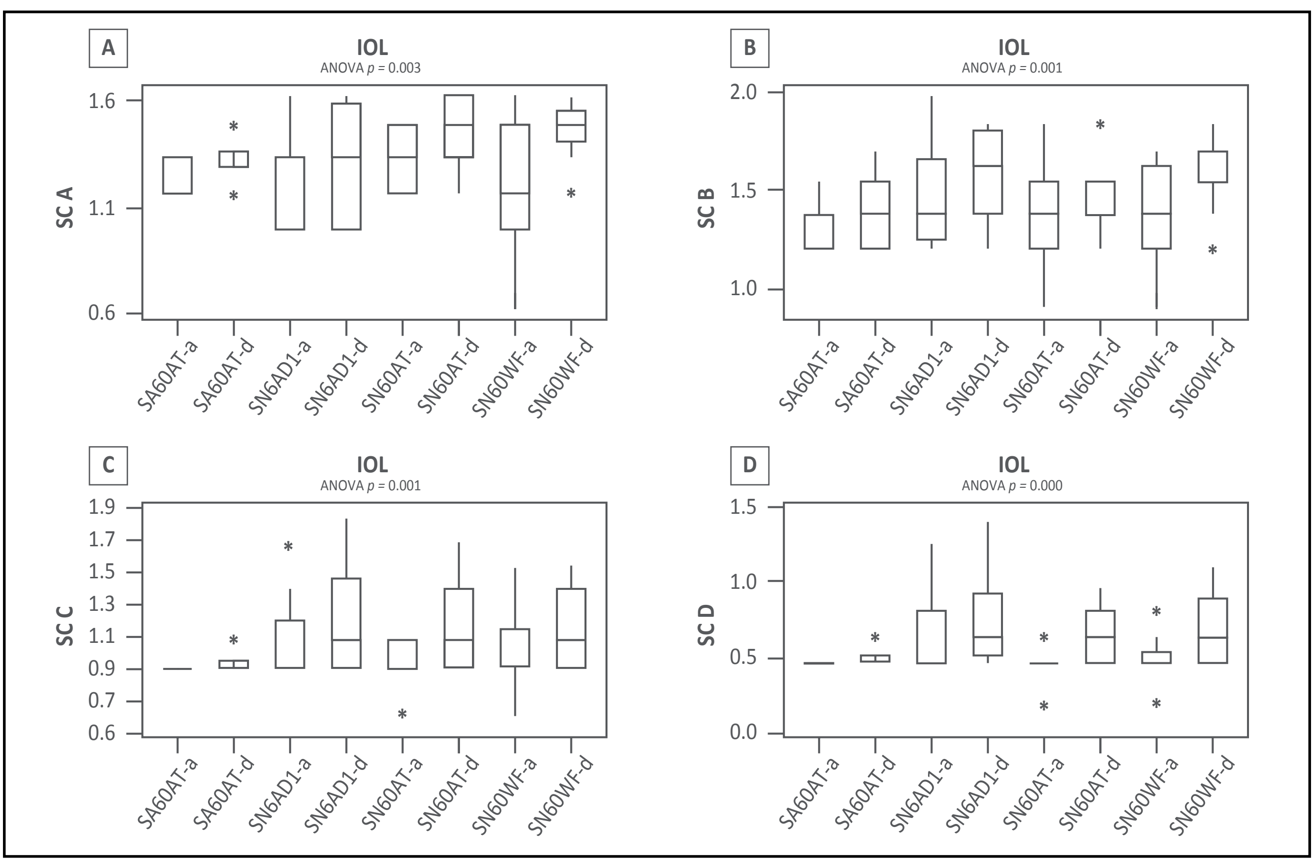

Figure 1. Contrast sensitivity: 1A: Row A, 1B: Row B, 1C: Row C, 1D: Row D.

Table 3. Postoperative contrast sensitivity. Intraocular lens. Age 40 to 50 years old.

ROW (cpd)	Subgroup 1 SN60AT mean ± SD	Subgroup 2 SN60WF mean ± SD	Subgroup 3 SA60AT mean ± SD	Subgroup 4 SN6AD1 mean ± SD
A (3.0)	1.41 ± 0.16	1.42 ± 0.17	1.34 ± 0.09	1.29 ± 0.27
B (6.0)	1.43 ± 0.20	1.60 ± 0.23	1.40 ± 0.21	1.58 ± 0.23
C (12.0)	1.13 ± 0.20	1.07 ± 0.24	0.95 ± 0.08	1.18 ± 0.31
D (18.0)	0.66 ± 0.16	0.63 ± 0.20	0.51 ± 0.08	0.77 ± 0.26

cpd, cycles per degree; SD, standard deviation.

Table 4. Postoperative contrast sensitivity. Intraocular lens. Age 50 to 70 years old.

ROW (cpd)	Subgroup 1 SN60AT mean ± SD	Subgroup 2 SN60WF mean ± SD	Subgroup 3 SA60AT mean ± SD	Subgroup 4 SN6AD1 mean ± SD
A (3.0)	1.52 ± 0.12	1.55 ± 0.08	1.26 ± 0.12	1.49 ± 0.21
B (6.0)	1.52 ± 0.08	1.64 ± 0.08	1.38 ± 0.00	1.54 ± 0.23
C (12.0)	1.26 ± 0.34	1.31 ± 0.14	0.91 ± 0.00	1.00 ± 0.12
D (18.0)	0.67 ± 0.21	0.77 ± 0.21	0.47 ± 0.00	0.47 ± 0.00

cpd, cycles per degree; SD, standard deviation.

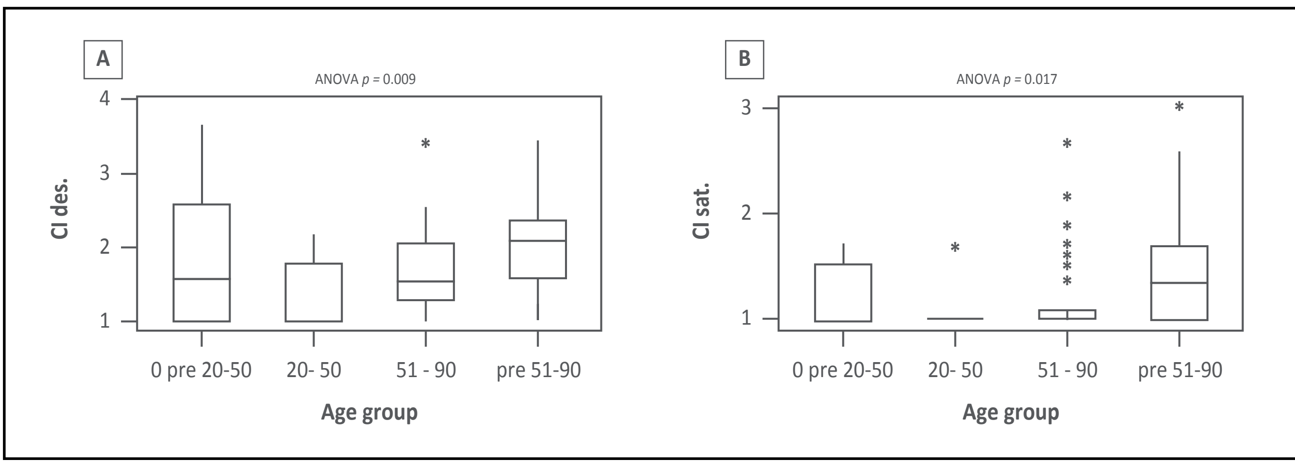

Figure 2. Confusion index in (A) *desaturated* color perception and (B) *saturated* color perception according to age group and preoperative (pre) and postoperative measurement.

(Levene's test, $p = 0.048$) and the mean accuracy was not statistically significant (ANOVA, $p = 0.13$). In contrast, the desaturated color vision test had a higher mean accuracy in the postoperative period (ANOVA, $p = 0.028$). Accordingly, we applied the Vingry and King-Smith method, which allowed us to measure the expectations of impaired color vision test (FM-15). The C-index is determined by the degree of color loss, and a value above 1.77 might suggest disruption of both saturated (ANOVA; $p = 0.017$) and desaturated colors (ANOVA; $p = 0.009$). In this way, we noticed that patients with cataract (desaturated color perception) had protanomaly, especially those aged over 50 years (2.03 ± 0.66), which improved significantly after surgery in both groups (Figure 2).

The C-index varied significantly with the use of hydrophobic acrylic lens with blue-light filtering and 0.04% yellow chromophore (SN60WF, 1.43 ± 0.45 and SN6AD1, 1.47 ± 0.46), which improved desaturated color vision. However, IOLs without a yellow filter (SA60AT) presented a scarcely noticeable improvement in desaturated color perception (2.31 ± 0.86) (ANOVA; $p = 0.000$). We did not find similar results in saturated color vision when the C-index was applied, due to cataract progression with a non-specific alteration in color perception (protanomaly).

There was an improvement with the use of IOLs, especially with hydrophobic acrylic lens with blue-light filtering and 0.04% yellow chromophore (SN60WF, 1.12 ± 0.38 and SN6AD1, 1.16 ± 0.45), although this

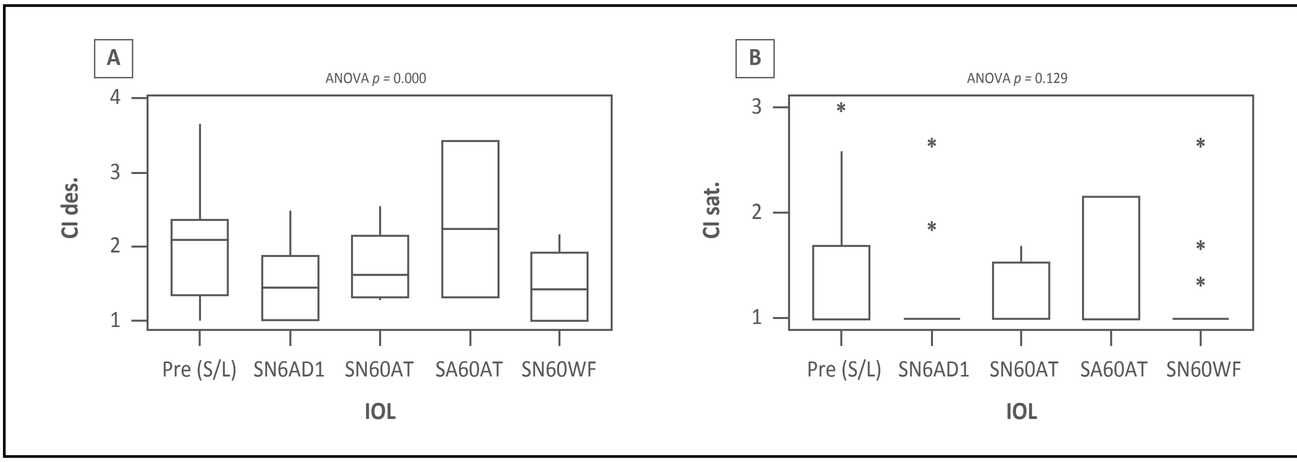

Figure 3. Confusion index in (A) the *desaturated* color perception and (B) in the *saturated* color perception according to IOLs.

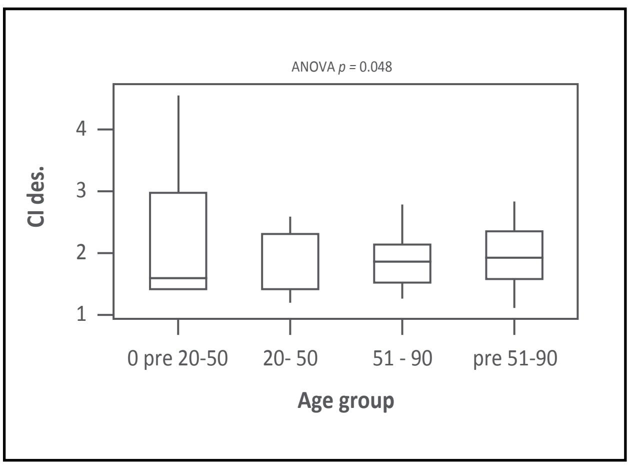

Figure 4. Selective index in the saturated color perception according to age group and preoperative (pre) and postoperative measurement.

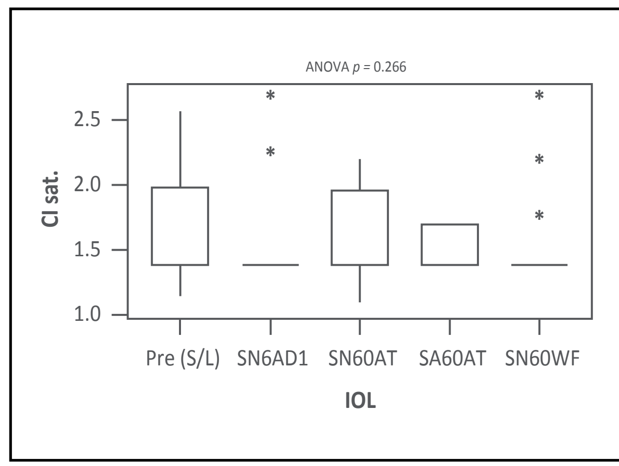

Figure 5. Selective index in the saturated color perception according to IOLs.

was not statistically significant (ANOVA; p = 0.129) (Figure 3).

Patients with crystalline lens opacity showed nonspecific dyschromatopsia (protanomaly), which is blindness between the blue and violet range. Accordingly, we applied the selectivity index (S-index 09.01 –1.38), which evaluates the strong polar orientation of patients by dyschromatopsia, and noticed that the desaturated color vision in patients with cataract showed protanomaly in both age groups: patients aged 20-50 years (2.33 ± 1.20) and patients aged 50-70 years (2.00 ± 0.42). The change was statistically significant (ANOVA; p = 0.048) in the latter age group, and although the same improvement was observed in the 20-50 years age group (1.70 ± 0.54), it was not statistically significant (ANOVA; p = 0.098) (Figure 4).

This was not the case with the saturated color perception; although the IOL showed a slight improvement in color perception, this was not statistically significant for either saturated (ANOVA; p = 0.266) or desaturated colors (ANOVA; p = 0.156) (Figure 5).

DISCUSSION

Adding a yellow chromophore filter to the IOL can block purple and blue light, and partially block green light, as the crystalline lens of any 50-year-old adult would do. This filtering capability avoids overexposure of the retina to light, especially to blue light. As we observed in our study, the addition of blue-light filtering and 0.04% yellow chromophore filters to the IOL (Alcon® SN60WF, SN60AT, SN6AD1) provides the patient with higher contrast sensitivity, determined by the specific test for different frequencies under mesopic conditions.

However, the patients did not experience any changing color perception compared to those patients who were implanted with a hydrophobic acrylic lens without the chromophore (SA60AT). This justifies the inclusion of filters that can limit the passage of UV light, as well as prevent the passage of radiation between 440 and 400 nm. However, some authors suggest that such filtering could also have negative effects in certain clinical situations, such as decreasing the mesopic sensitivity[8].

IOLs do not yet have the same optical characteristics as the normal crystalline lens, which by definition would not have interfered to obtain adequate chromatic perception[6].

In our study, patients with crystalline lens opacity showed protanomaly — blindness between the blue and violet range — so we evaluated the strong polar orientation of patients with dyschromatopsia, noting that the desaturated color vision presented a significant variation in different groups, which was not the case for saturated color perception. The C-index varied significantly with the use of hydrophobic acrylic lens with 0.04% yellow chromophore, and showed an improvement in color perception. Other studies have agreed that when using filters, a wide wavelength improves color perception in people with dyschromatopsia disorders[9].

IOLs with blue-light filtering and 0.04% yellow chromophore have shown that they do not impair the patient's vision, and even improve contrast sensitivity.

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