Blue-light filtering intraocular lens in patients with diabetes: Contrast sensitivity and chromatic discrimination

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PURPOSE: To evaluate potential changes in contrast sensitivity and color discrimination in diabetic patients who had cataract surgery and implantation of the blue-light filtering AcrySof Natural (SN60AT) intraocular lens (IOL) compared with an ultraviolet-only filtering (AcrySof SA60AT) IOL.

SETTING: Refractive Surgery Unit, Hospital NISA Valencia al Mar, Valencia, Spain.

METHODS: Forty-four eyes of 22 diabetic patients were enrolled in a blue-light filtering fellow-eye control study. Patients received yellow-tinted IOLs (AcrySof Natural) in 1 eye and non–yellow-tinted IOLs (AcrySof SA60AT) in the fellow eye. Three months after surgery, monocular contrast sensitivity function was measured with the CSV 1000-E contrast sensitivity chart at distance and color discrimination was tested with the Farnsworth-Munsell 100-hue test.

RESULTS: Eyes implanted with the blue-light filtering IOLs showed better contrast sensitivity values than fellow eyes implanted with non–yellow-tinted IOLs ($P<.05$). The blue-light filtering IOL did not modify chromatic discrimination compared with the non–yellow-tinted IOL ($P = .62$). In the blue–yellow axis discrimination study, the eyes implanted with the AcrySof Natural IOL had statistically significant better color vision ($P = .008$).

CONCLUSIONS: In diabetic patients, the AcrySof Natural IOL provides better contrast sensitivity than the AcrySof SA60AT. The blue-light filter of the AcrySof Natural IOL did not cause chromatic discrimination defects based on total error scores and improved color vision in the blue–yellow chromatic axis in diabetic patients.

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It has been reported that diabetic patients develop color vision alterations,[1–11] particularly in the blue–yellow axis.[3–7] Blue–yellow discrimination loss was present at varying percentages in several studies: 26.0%,[7] 66.5%,[5] and 70.0%.[6] Previous studies suggest that the blue–yellow axis (the short-wavelength-sensitive cone system, or S-cones) is more vulnerable to diabetes that the green axis (medium-wavelength-sensitive cone system, or M-cones) and the red axis (long-wavelength-sensitive cone system, or L-cones).[12,13]

It has been postulated that diabetic patients have S-cone dysfunction,[11,12] and thus, theoretically, the use of yellow filters may increase visual performance in these patients, improving the function of the blue-yellow chromatic axis. The new AcrySof Natural intraocular lens (IOL) (Alcon) has a blue-light absorbing chromophore designed to approximate more closely the light-transmittance characteristics of the natural crystalline lens at wavelengths below 500 nm. The internal structure of this IOL has 2 filters: One is similar to other IOLs, with protection from wavelengths less than 400 nm; the other filter reduces the transmission of wavelengths between 400 and 500 nm. (See Ernest[14] for a full description of the light-transmission spectrum.)

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Despite the theoretic benefits of ultraviolet-light filtering, a yellow-tinted IOL may modify visual performance. Research has suggested that yellow filters could improve contrast sensitivity at medium spatial frequencies, reduce the reaction time in response to stimuli, and increase the apparent brightness in daylight conditions.[15–17] However, studies of the effect of yellow-tinted lenses on color vision in healthy subjects concluded that this IOL may cause changes in color perception.[18,19]

The Farnsworth-Munsell 100-hue test is the most specific test for assessing color vision abnormalities. Studies using this test in diabetic patients have shown increased error scores compared with normal subjects.[5,20] Furthermore, diabetic patients show spatial resolution defects that may be assessed by means of the contrast sensitivity function (CSF).[1,8,12,21,22]

The purpose of this study was to determine the visual performance achieved in diabetic patients with the AcrySof Natural IOL and compare it with that with a non–yellow-tinted IOL (AcrySof SA60AT).

PATIENTS AND METHODS

The study included 44 eyes of 22 consecutive diabetic patients (insulin-dependent diabetes mellitus of more than 20 years duration) who had implantation of the AcrySof Natural IOL in 1 eye and the AcrySof SA60AT IOL in the fellow eye (age 68.2 $\pm$ 2.1 years, range 67 to 71 years). Exclusion criteria included ocular disease other than cataract and history of prior ocular surgery or inflammation. Fundoscopy was performed in all patients and showed incipient degrees of diabetic retinopathy without severe macular alteration. Patients with mild, moderate, or severe macular alteration were excluded from the study. All cataracts in this study (grade 2 on a scale of 1 to 4) were extracted by 1 surgeon (A.R.G.) through a clear corneal 2.75 mm temporal incision under topical anesthesia. Phacoemulsification was followed by irrigation and aspiration of the cortex and IOL implantation in the capsular bag. All patients were satisfied with the surgical outcomes; the best spectacle-corrected visual acuity (BSCVA) was $\geq$20/25 3 months postsurgery.

The AcrySof Natural IOL is optical and structurally identical to the AcrySof SA60AT except for the blue-light filtering material. The overall diameter of the IOLs in this study was 13.0 mm, and the optical diameter was 6.0 mm; IOL power varied from +21.00 diopters (D) to +22.50 D.

To evaluate visual performance in the study participants, the CSV 1000-E contrast sensitivity (CS) test and the Farnsworth-Munsell 100-hue test were performed.

Contrast Sensitivity Function

The performance index that most usefully documents human spatial vision is the CSF.[23–26] The CSF was measured monocularly with CSV 1000-E contrast test (Vector Vision). The nonviewing eye was occluded for each measurement, and best spectacle refractive correction, if necessary, was initially used with the viewing eye in accordance with the normal practice of the patient. This CSF test allows presentation of sine-wave grading of different spatial frequencies (3, 6, 12, and 18 cycles per degree [cpd]) with changing contrast. The manufacturer's recommended testing procedures were followed with a testing distance of 3 m and room illumination at 85 cd/m^2. Absolute values of logCSF were obtained for each combination of eye, and spatial frequency, and means and standard deviations were calculated.

Farnsworth-Munsell 100-Hue Test

The Farnsworth-Munsell 100-hue test is a widely used tool to detect chromatic discrimination abnormalities and provide a noninvasive method to assess macular area damage.[27] Once the CSF was obtained, patients rested for 15 minutes before doing the Farnsworth-Munsell test.[28] The test was performed monocularly with best spectacle correction in all patients. Colored caps belonging to the first box were removed and placed on a black table. Patients were then asked to place them in the box in the correct order. The same was done with the other 3 boxes. When the 4 boxes were completed, the examiner recorded the results without disclosing them to the patients. Following the test instructions, the error score for each cap was calculated by adding the difference between the cap's number and the number of the caps the subject placed on both sides of it. Using this method, the score for a correctly placed cap is 2, and thus an error score for a particular cap was less than 2. Following previous studies, color vision examination was performed under photopic conditions (85 cd/m^2).[29] Blue–yellow dischromatopsy is indicated by scores in the ranges of 46 to 52 and 4 to 84 on the Farnsworth-Munsell test.[29] All examinations were performed by the same ophthalmic technician who was masked to the IOL status of each eye. The tenets of the Declaration of Helsinki were followed in this research,[30] and informed consent was obtained from all patients after the nature and possible consequences of the study had been explained.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows version 12.0. Normality was checked with the Shapiro-Wilk test, and *t* tests were performed to compare eyes. Differences were considered to be statistically significant at $P<.05$.

RESULTS

Patient demographics are shown in Table 1. There were no statistically significant differences between groups in corneal astigmatism, BSCVA, and spherical equivalent before or after cataract surgery.

Logarithmic contrast sensitivity values were used for statistical analysis, and normalized values were used for graphic representation. Figure 1 shows the mean normalized monocular best corrected logCS as a function of the IOL at the 4 spatial frequencies indicated. To evaluate the significance of the differences between the contrast sensitivity values of the IOLs, a *t* test was performed at each spatial frequency.

Once the total error scores in all patients were obtained for each eye, a *t* test was performed to look for differences between the scores obtained with the AcrySof Natural IOL and the AcrySof SA60AT IOL. No statistically significant

Table 1. Demographic characteristics of participants.

Parameter		AcrySof Natural IOL	AcrySof SA60AT IOL	*P* Value
N	—	22	22	—
Mean age (years) ± SD	68.2 ± 2.1	—	—	—
Sex (M/F)	10/12	—	—	—
Interval (months)*	3	—	—	—
Mean astigmatism (D)† ± SD	—	0.83 ± 0.31	0.94 ± 0.32	.2412
BSCVA	—	0.94 ± 0.10	0.93 ± 0.12	.5021
Mean postoperative spherical equivalent (D) ± SD	—	0.55 ± 1.09	0.64 ± 1.08	.3562

*Elapsed time between surgery and examination
†Postoperative corneal astigmatism

differences were found between IOLs ($P = .62$). Figure 2, *A*, shows the average total error scores, means, and standard deviations for both IOLs. Because the blue–yellow axis of the diabetic patients could be affected by the pathology, a specified analysis over this axis was performed (Figure 2, *B*). A *t* test to assess the difference in total error scores in this axis was performed showing statistically significant differences between eyes implanted with the Natural IOL and those implanted with the non–yellow-filter IOL ($P = .008$).

DISCUSSION

The ability to discriminate color is a function of the fovea. Three cone types,[31] defining 3 photopigments, are known. The S-cones are more sensitive to blue pigment, the M-cones to green pigment, and the L-cones to red pigment. No S-cones are presented in the innermost circle of the fovea (only M- and L-cones), creating foveal tritanopia.[32] The relatively lower number of S-cones is responsible for reduced visual acuity and contrast sensitivity in blue light.[33]

Color vision defects acquired in retinal disorders result in a tritan-like defect, with blue–yellow axis abnormalities.[13] Several mechanisms have been proposed to explain this circumstance: (1) optical media short-wavelength filtering (dark cataracts, blood vitreous, old vitreous)[34];

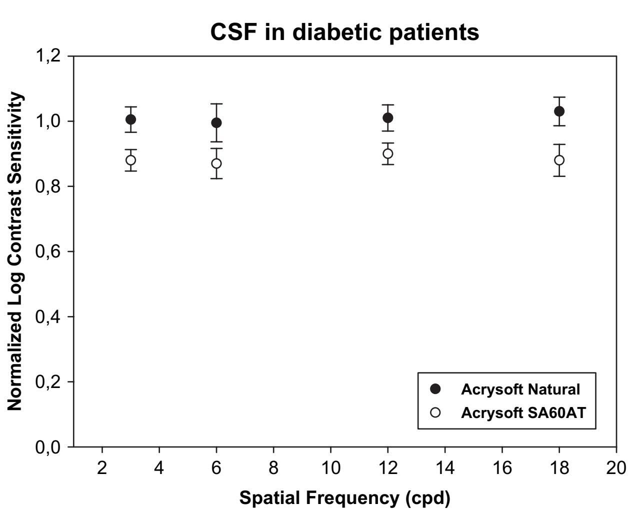

Figure 1. Normalized monocular best corrected logCS at the 4 spatial frequencies indicated. Filled data points refer to the AcrySof Natural and open data points to the AcrySof SA60AT IOL. Vertical bars represent ±1 SD. The *P* values were 0.02, 0.04, 0.03, and 0.01 at 3, 6, 12, and 18 cpd frequencies, respectively.

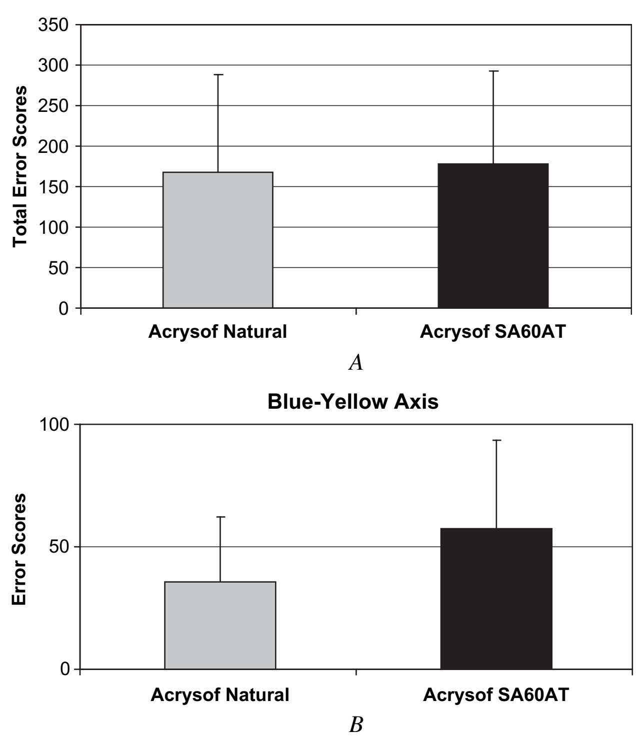

Figure 2. Average scores (mean and SD) of the Farnsworth-Munsell 100-hue test for both IOLs in the study. The AcrySof total error scores (*A*) and blue–yellow axis (*B*).

(2) S-cone paucity (In humans, only 9% of cones are blue sensitive.[35] The loss of a small percentage of S-cones can cause considerable alteration, which could be more important than the loss of an equal percentage of L- or M-cones.[36,37]); (3) the limited response range of the S-cones (which is narrower than that of the L- and M-cones[35,38,39]); and (4) selective cone fragility (blue-sensitive S-cones might be more susceptible to retinal stress than L- and M-cones[13,40]).

In diabetes, color vision defects often precede the onset of retinopathy.[41] Studies with the Farnsworth-Munsell 100-hue test in diabetic patients have demonstrated an increase in error scores compared with normal subjects.[5,20] A large proportion of patients with diabetic retinopathy have impaired color vision. Diabetes has been associated with a specific type of color defect involving the blue–yellow system, with between 66.5% and 70% of discrimination loss among various studies being in this system.[5,6] Several reports suggest that the blue–yellow axis is more vulnerable to diabetes than the red–green axis[8]; defects of the blue–yellow axis are also present in diabetic patients with little or no retinopathy.[1,7,42,43]

Spatial resolution in diabetic patients has been assessed by means of the CSF.[1,8,44,45] However, some discrepancy must exist to correlate the contrast sensitivity changes with the presence or severity of the retinopathy.[21,22,46] Trick et al.[7] found that contrast sensitivity deficits were detected more frequently in diabetes, occurring in 24.3% of diabetic patients without retinopathy and 45% of diabetic patients who had background retinopathy. Della Sala et al.[21] found contrast sensitivity reductions in 41% of diabetic patients without retinopathy. Sokol et al.[22] observed a similar proportion of contrast sensitivity alterations in diabetic patients with no retinopathy (28%) but a higher rate of contrast sensitivity abnormalities (59%).

Previous works suggest that yellow filters can improve several visual conditions such as visual clarity, glare, and contrast sensitivity medium spatial frequencies under photopic and mesopic conditions.[15,17] Diabetic patients who show a reduction in contrast sensitivity could benefit from implantation of a yellow IOL.

This study shows that distance contrast sensitivity for both IOLs achieved normal values (near to 1.0 normalized logCS at all spatial frequencies, Figure 1). When inter-IOL differences were evaluated for best corrected distance contrast sensitivity, the *t* test revealed statistically significant differences between the AcrySof Natural IOL and the AcrySof SA60AT IOL at all spatial frequencies ($P<.05$). The AcrySof Natural IOL showed better contrast sensitivity (about 10% of increment) than the AcrySof SA60AT IOL. Previous studies reported that the use of yellow filters in healthy patients improves image contrast, and consequently CSF.[15,19] Our results reveal an improvement in CSF at all spatial frequencies in eyes implanted with the yellow-filter IOL. Lower values were found in eyes implanted with the non–yellow-filter IOL. This type of IOL thus benefits contrast sensitivity in diabetic patients.

In relation to color vision evaluation, we found no statistically significant differences between IOLs considering total error scores (Figure 2, *A*, $P = .62$). However, blue–yellow axis error scores revealed a statistically significant difference between groups ($P = .008$, Figure 2, *B*). This could be related with the fact that only 9% of cones are blue sensitive.[13] Considering these results, a reduction in S-cone function may affect the chromatic perception in the blue–yellow axis. The use of yellow-filter IOLs improves this blue–yellow chromatic alteration.

We have shown that patients with diabetic retinopathy show S-cone function alteration that may be improved using yellow-filter IOLs. If this alteration is functional and nonpermanent, this filter could simulate the neural function of the S-cones, improving contrast sensitivity and color vision in the blue–yellow axis. Previous results[11] agree with this hypothesis, showing an increased foveal tritanopic zone in some patients with diabetes and indicating severe local S-cone pathway dysfunction in the fovea sufficient to reduce color vision to a dichromatic state; in the majority of patients tested, however, the foveal tritanopic zone was normal in size.

In conclusion, the AcrySof Natural IOL provided better contrast sensitivity than the AcrySof SA60AT 3 months following IOL implantation. The blue-light filter of the AcrySof Natural IOL did not cause chromatic discrimination defect and improved color vision in the blue–yellow chromatic axis.

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