ARTICLE

Luminance contrast with clear and yellow-tinted intraocular lenses

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PURPOSE: To determine whether yellow-tinted intraocular lenses (IOLs) negatively affect luminance contrast in postoperative cataract patients.

SETTING: Department of Ophthalmology, Sir Mortimer B. Davis Jewish General Hospital, McGill University, Montreal, Quebec, Canada.

METHODS: Luminance contrast was measured using the minimum-motion technique. The stimulus consisted of blue and red sinusoidal gratings differing in luminance. Patients had implantation of a clear or yellow-tinted IOL and were tested monocularly 2 to 9 weeks after cataract surgery. No patient had concomitant ocular diseases or congenital color defects, assessed by their ophthalmologist, or flicker-sensitive epilepsy. All patients had a visual acuity of 20/40 or better a mean of 4 weeks $\pm$ 2 (SD) postoperatively.

RESULTS: Patients ranged in age from 55 to 89 years. An independent-samples Student *t* test showed that patients with a yellow-tinted IOL had significantly lower luminance contrast values than patients with a clear IOL ($P<.05$).

CONCLUSIONS: The results suggest that yellow-tinted IOLs affect the perception of luminance under photopic conditions. More blue light was required to make luminance judgments with a yellow-tinted IOL than with a clear IOL. Further study of the functional impact of luminance reduction by yellow-tinted IOLs is warranted.

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Cataract is the most common age-related lenticular pathology.[1] The only treatment is surgery, which consists of replacing the cloudy natural lens with an artificial intraocular lens (IOL).[2] The importance of having an IOL that closely mimics the protection afforded by the natural lens led to the development of various types of IOLs.[3] For example, in the 1980s, a UV-blocking chromophore to filter wavelengths between 320 nm and 400 nm was added to the original clear IOL to mimic the protection provided by the natural lens against ultraviolet (UV) light.[4,5] A decade later, although epidemiological studies showed inconclusive results on a correlation between exposure to phototoxic levels of blue light after cataract surgery and the development of age-related macular degeneration (ARMD),[6–11] experimental studies showed that exposure to blue light damaged retinal pigment epithelial cells.[12–15] As a consequence, some researchers suggested adding a yellow chromophore to the UV-blocking IOL.[16,17]

In North America, the first yellow-tinted IOL on the market was the AcrySof Natural (Alcon Laboratories, Inc.), which filters wavelengths between 300 nm and 500 nm to protect the retina from blue light damage.[18] This yellow-tinted IOL mimics the natural brunescence or yellowing of a single 53-year-old lens,[19] (C. Guttman,

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"Blue-Blocking Lens Performs Like Standard UV-Absorbing Model," Ophthalmology Times, July 1, 2003, page 20) examined by Boettner and Wolter,[20] that filters blue light, decreasing retinal illuminance.[21]

Given the absorption spectrum of the yellow-tinted IOL, some researchers raised concerns that the IOL may negatively affect some visual functions.[17,19] Initially, disturbances in color vision were suspected. However, no detrimental effects were found using traditional measures such as the Farnsworth-Munsell dichotomous test (D-15) or the Farnsworth-Munsell 100-hue test.[22–24] These measures, however, might lack the necessary sensitivity to detect subtle changes in color vision. The use of the Rayleigh and Moreland anomaloscope recently indicated tritan deficits with blue-blocking IOL simulation in younger individuals (R.M. Rubin, et al. "Impact of Blue-Blocking IOLs on Color Vision Performance," poster presented at the annual meeting of the American Academy of Ophthalmology, Las Vegas, Nevada, USA, November 2006). In the present study, the minimum-motion testing technique was used to evaluate the effect of a yellow-tinted IOL on luminance perception. Conceptually, a luminance task is comparable to arranging the caps of the D-15 by brightness, not by color.

The minimum-motion test measures the mean equiluminance point or the luminance contrast between the components of a chromatic grating,[25] in this case red and blue. The luminance contrast value has been shown to correlate negatively with the extent of lens brunescence.[21] In other words, as lens brunescence increases, the luminance contrast value decreases, reflecting the increase in light necessary for the same illumination. Nguyen-Tri et al.[21] tested older individuals with clear UV-blocking IOLs on this minimum-motion task. They found that after cataract surgery, elderly persons obtained scores similar to those of young adults with natural lenses. This suggests that clear artificial lenses allow older adults to perform at the perceptual level of younger adults. Based on this finding, the same minimum-motion task was used to assess whether the 2 types of IOLs yield different luminance perception results. It was hypothesized that patients with yellow-tinted IOLs would have lower luminance contrast values than patients with clear IOLs and would, therefore, require more blue light to perceive equal luminance.

PATIENTS AND METHODS

This study comprised 12 patients with a yellow-tinted IOL (AcrySof Natural SN60AT) and 13 patients with a clear IOL (SA60AT or LX10BD, Alcon Laboratories). Patients had no ocular disease or congenital color vision defects, assessed by their ophthalmologist, or flicker-sensitive epilepsy. All patients had a postoperative visual acuity of 20/40 or better (Early Treatment Diabetic Retinopathy Study, Lighthouse International) at the time of testing (mean 4 weeks $\pm$ 2 [SD] after surgery; range 2 to 9 weeks).

The study protocol was approved by the Institutional Review Board of the Sir Mortimer B. Davis Jewish General Hospital, Montreal, Quebec, and followed the tenets of the Declaration of Helsinki. Written informed consent was obtained from each patient after the nature of the study was explained.

Minimum-Motion Stimulus

Refraction was performed using the Nidek Autorefractor ARK-760A (Vision Medical), and all patients wore trial lenses for the minimum-motion test. The stimulus has been described in detail.[21] The stimulus was presented on a computer (Power Macintosh 7300/200, Apple Computer) equipped with a monitor (PT 813 CRT, ViewSonic). The monitor was calibrated using a Minolta photometer. The Commission Internationale de l'Éclairage (CIE) x and y coordinates of the monitor were 0.61 and 0.34, respectively, for the red phosphor; 0.29 and 0.58, respectively, for the green phosphor; and 0.14 and 0.06, respectively, for the blue phosphor.[21] The stimulus consisted of red and blue stripes (Figure 1). The vertical sinusoidal gratings were windowed within a circular aperture of 4 degrees of visual field in diameter. A black fixation point was located at the center of the gratings at all times during testing. The gratings had a temporal frequency of 2 Hz and a spatial frequency of 0.5 cycles per degree to minimize the impact of chromatic aberration.[26] The luminance modulation of the red–blue stimulus can thus be represented as

$$R(x,t) = 0.5 \times L_R \times \left\{ \begin{array}{l} [1 + m \times \sin(2\pi f_S x) \times \sin(2\pi f_T t)] \\ +[1 + \cos(2\pi f_S x) \times \cos(2\pi f_T t)] \end{array} \right\} \quad (1)$$

$$B(x,t) = 0.5 \times L_B \times \left\{ \begin{array}{l} [1 + m \times \sin(2\pi f_S x) \times \sin(2\pi f_T t)] \\ +[1 - \cos(2\pi f_S x) \times \cos(2\pi f_T t)] \end{array} \right\} \quad (2)$$

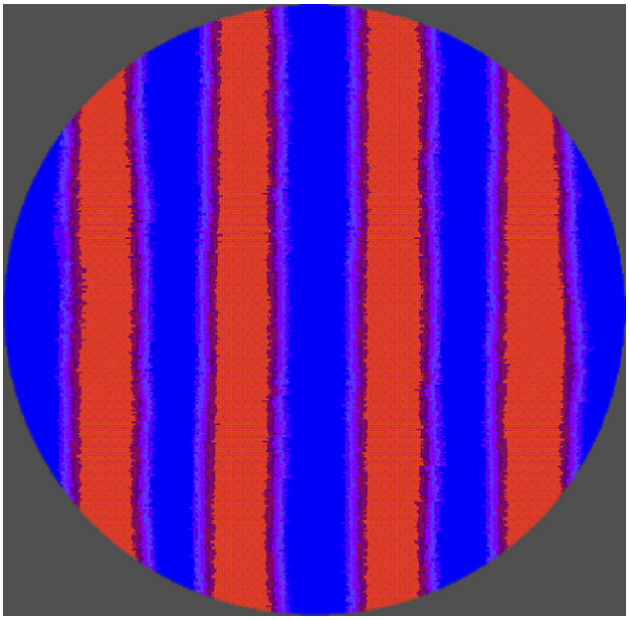

Figure 1. Representation of the minimum-motion stimulus.

where $R(x,t)$ and $B(x,t)$ are the luminances of the monitor's red and blue phosphors as a function of horizontal position (x) and time (t); L_R and L_B are the mean luminances of the red phosphor and blue phosphor, respectively; f_S and f_T are the spatial frequency and temporal frequency of the gratings, respectively; and m is the Michelson contrast of an achromatic grating. The luminance contrast of the achromatic grating was 10% Michelson contrast. The mean luminance of the blue grating component was held constant at 7 cd/m^2, whereas the experimenter adjusted the red luminance. The experimenter was masked to what type of IOL the patient had.

Depending on the relative mean luminances of the red and blue phosphors, the patient perceived motion toward the left, the right, or, at equiluminance, counterphase flicker. The luminance contrast value of the chromatic grating was recorded at the end of each trial, when patients indicated they saw no net direction of motion. This value was obtained by

$$LC = (R_{MOD} - B_{MOD})/(L_R + L_B)$$

where LC is the luminance contrast, R_{MOD} is the amplitude of luminance modulation of the red phosphor, and B_{MOD} is the amplitude of luminance modulation of the blue phosphor.[21]

Testing Procedure

Patients were contacted by telephone by the researcher 1 day before their routine postoperative follow-up appointment. The nature and purpose of the study, the tests, and the duration of the testing session were explained. Patients who decided to participate were met individually after their appointment with their ophthalmologist.

Patients were asked to sit in front of the screen and instructed to place their head in a chinrest, positioned 34 cm from the screen, to help maintain fixation. They were instructed to fixate on a black dot at the center of the display and to report the direction of the gratings' motion (left, right, or flicker) while the experimenter adjusted the luminance of the red grating component. When patients indicated perception of flicker (no net direction of movement), the experimenter recorded the luminance contrast value. Six trials were recorded, and the mean was calculated for statistical analysis.

Statistical Analysis

Statistical analysis was performed with SPSS for Microsoft Windows (version 10.0, SPSS, Inc). A P value less than 0.05 was considered statistically significant.

RESULTS

The mean age of the patients was 72 $\pm$ 9 years (range 55 to 89 years). In patients with a clear IOL, 8 received model SA60AT and 5, model LX10BD.

An independent-samples Student t test showed that the luminance contrast values of patients with yellow-tinted IOLs (mean 3.3% $\pm$ 11.4%) were significantly lower than those of patients with clear IOLs (mean 12.7% $\pm$ 9.4%) ($t_{(23)} = -2.25$, $P < .05$, $\eta^2 = 0.18$, observed power = .58). The results are shown in Figure 2.

DISCUSSION

Our results show a perceptual effect of the yellow chromophore. As expected, patients with yellow-tinted IOLs had significantly lower luminance contrast values than patients with clear IOLs.

Luminance contrast values have been shown to correlate negatively with the extent of lens brunescence.[21] These results are substantiated by the present data as the luminance contrast values of participants with yellow-tinted IOLs fell well within the predicted range of values for individuals in their sixth decade with their natural lenses. The manufacturer of the AcrySof Natural SN60AT describes the level of tint used in the implant as comparable to that of a 53-year-old natural lens (Alcon Laboratories, Inc. AcrySof® Natural Single-Piece IOL; Product Monograph, 2003). Our results support this claim from the psychophysical perspective. The findings regarding the luminance contrast values in the patients with clear IOLs support a study by Nguyen-Tri et al.,[21] who tested older patients with clear IOLs on this minimum-motion task. They found that after cataract surgery, older patients with clear IOLs obtained scores similar to those of young adults with natural lenses. This suggests that clear artificial lenses allow older adults to perform at the perceptual level of younger adults. These results also suggest a shift in the perception of equiluminance in patients with yellow-tinted IOLs compared with those with clear IOLs. Patients with yellow-tinted IOLs require more blue light to perceive their equiluminance point.

It remains to be determined whether this gain in luminance perception in patients with clear IOLs reverses the normal decrease in sensitivity to short-wavelength stimuli experienced with aging. Whether

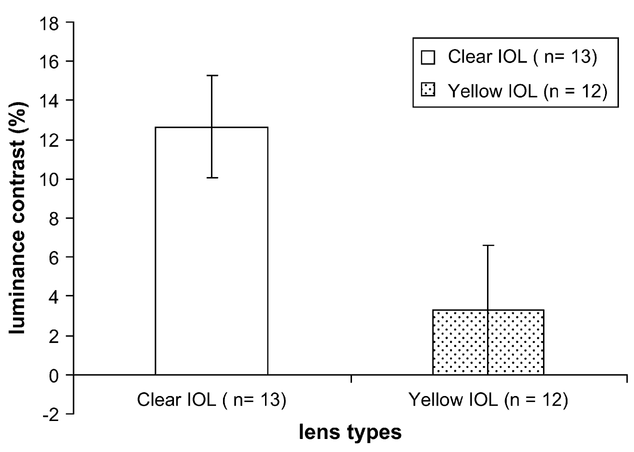

Figure 2. Mean luminance contrast values ($\pm$ SEM) in patients with clear IOLs (n = 13) or yellow IOLs (n = 12).

these results indicate a clinically significant impact on visual function should be investigated. As equiluminance judgments rely on luminance information, it is reasonable to conclude that yellow-tinted IOLs reduce the perception of brightness, in this case under photopic conditions. It is possible that under mesopic (low illumination) or scotopic (darkness) conditions, in which luminance is substantially reduced, the effect of yellow IOLs becomes even more pronounced. Preliminary investigations using a trial lens that replicated the transmission curve of an Alcon blue-blocking IOL have been inconclusive as 2 out of 3 studies suggest that blocking blue light might impair scotopic vision at 410 to 440 nm, while a third study indicates scotopic vision is not impaired (Jackson GR, Olson RJ. IOVS 2005; 46:ARVO E-Abstract 806; Baker PS, et al. IOVS 2005; 46:ARVO E-Abstract 805; Chiosi F, et al. IOVS 2006; 47:ARVO E-Abstract 304).

In addition, some researchers[27] argue that the loss in scotopic sensitivity is insignificant and not important for scotopic vision. Currently, a debate exists as to the extent to which the yellow-tinted IOL decreases scotopic vision compared with the clear IOL. Schwiegerling[28] showed that yellow-tinted IOLs decrease scotopic vision by 14.6% compared with clear IOLs. In contrast, Mainster[29,30] found that a yellow-tinted IOL of 20.0 diopters decreases scotopic sensitivity by 14% and offers 20% less photoprotection than a 53-year-old crystalline lens. Mainster concludes that the yellow-tinted IOL is less protective than the 53-year-old crystalline lens, which does not prevent ARMD. This contrasts with Werner,[27] who states that the benefit of the yellow-tinted IOL is more important than the insignificant 0.01 log unit loss in contrast sensitivity expected with this IOL. Additional research is required to demonstrate the relevance of a possible reduction in the perception of luminosity. Individuals with yellow IOLs may already experience scotopic vision under conditions that others experience as mesopic. This may affect visual function in the performance of daily activities such as driving.

Finally, our findings must be interpreted considering certain limitations. The sample size was small, and patients were tested fewer than 12 weeks after surgery. It would be preferable to test more patients before and at least 12 weeks after surgery, giving the visual system ample time to recalibrate.[31] Moreover, future research should investigate the relationship between the dioptric strength of the IOL and luminance contrast values. It is possible that as the power of the yellow-tinted IOL increases, the luminance contrast value decreases because increased dioptric strength implies increased IOL thickness. This, in turn, would increase the yellowness of the IOL and filter more blue light, making luminance judgments more difficult.

In conclusion, the present study found that yellow-tinted IOLs have a measurable effect on luminance judgment. It remains to be seen whether this finding reflects important functional limitations in daily visual activities such as driving at night. Finally, given our results and the findings of Mainster,[29,30] it remains to be established whether a yellow-tinted IOL is more practical or convenient than the use of sunglasses with the same blue-light filtering properties. Proper sunglasses can be removed when light filtering is neither desired nor required, which is most of the time. In addition, sunglasses have been compared with yellow lenses in their ability to protect the retina from possibly damaging phototoxicity and seem to be superior in all described transmission ranges.[29]

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