Is the blue light filter for spectacle and intraocular lenses helpful in improving ocular health? A systematic review of the literature

¿Es útil el filtro para luz azul de los lentes intraoculares y aéreos para mejorar la salud visual? Una revisión sistemática de la literatura

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Abstract

Introduction: Blue light can induce retinal damage. Nowadays, technological devices emit high levels of this light. Up to 90% of users experience symptoms including eyestrain, headaches, ocular discomfort, dry eye, and blurred vision. Some ophthalmic devices such as spectacle lenses and intraocular lenses (IOLs) absorb blue light. Benefits have been suggested as well as possible disadvantages. **Objective:** The objective of the study was to analyze if the use of blue light filters reduces ocular damage produced from blue light spectrum. **Method:** The databases used were PubMed, Biblioteca Virtual en Salud, Búsqueda de Información Global, Academic Search Complete, Science Direct, Wiley Online Library, SpringerLink, Medic Latina, OvidSP, Trip Database, Clinical Key, and UpToDate. A second query was performed to increase the number of studies that were analyzed with the OPMER scale. **Results:** Several studies show that blue light filter IOLs have benefits in ocular health with low adverse effects. For other ophthalmic devices such as spectacle lenses, evidence is lacking. Nevertheless, it seems to be beneficial. **Conclusions:** The studies suggest there are no significant harmful effects of blue-blocking IOLs on visual performance and could be an option to reduce the risk of development of age-related macular degeneration. With the use of spectacle lenses there was a reduction in eye fatigue, suggesting it may help to ameliorate visual impairment. It is known that the use of blue light filters in vitro minimizes the damage to retinal cells but data in humans are inconclusive, especially regarding spectacle lenses.

Key words: Macular degeneration. Macular changes. Visual acuity. Visual performance. Blue light filters.

Resumen

Introducción: La luz azul puede inducir daño retiniano. Hoy en día, los dispositivos electrónicos emiten altos niveles de este tipo de luz. Cerca del 90% de los usuarios experimentan síntomas como ojo seco, cefalea y visión borrosa. Algunos

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dispositivos oftalmológicos, como lentes aéreos e intraoculares, absorben la luz azul. Se han sugerido diversos beneficios y desventajas sobre su uso diario. **Objetivo:** Analizar si el uso de filtros de luz azul reduce el daño ocular inducido por este espectro de luz. **Metodología:** Se emplearon las siguientes bases de datos: PubMed, BVS, BIG, Academic Search Complete, Science Direct, Wiley Online Library, SpringerLink, Medic Latina, OvidSP, Trip Database, Clinical Key and UpToDate. Se realizó una recuperación secundaria para incrementar el número de estudios para su posterior análisis con la escala OPMER. **Resultados:** Diversos estudios demuestran que los filtros para lentes intraoculares tienen beneficios con pocos eventos adversos. En cuanto a los filtros para lentes aéreos, falta más investigación, pero parecen tener efectos beneficiosos. **Conclusiones:** Los estudios sugieren que no hay efectos perjudiciales en cuanto a desempeño visual con el uso de lentes intraoculares y pueden ser una opción para reducir el riesgo de desarrollar maculopatía degenerativa. Con el uso de filtros para lentes aéreos se observó una reducción en la fatiga ocular y pueden ayudar a mejorar la discapacidad visual. Es conocido que el uso de estos filtros in vitro minimiza el daño retiniano, pero la evidencia en humanos no es concluyente.

Palabras clave: Degeneración macular. Cambios maculares. Agudeza visual. Rendimiento visual. Filtro de luz azul.

Introduction

The usefulness of blue light blocking lenses to prevent retinal phototoxicity remains uncertain. Since the 1980s, light within the blue bandwidth of the visible spectrum as well as ultraviolet (UV) light have been speculated to cause damage to multiple eye structures, and so the desire to add specific filters to intraocular lenses (IOLs) increased^{1,2}.

Blue light has high photochemical energy and induces cell apoptosis in retinal pigment epithelial (RPE) cells due to its phototoxicity; retinal hazard by blue light stimulation has been well demonstrated using high-intensity light sources. Nowadays, our technological devices whose screens have light emitting diodes (LEDs) and compact fluorescent lamps emits relatively high levels of blue light. Although numerous studies have shown that lenses and IOLs that block light within the blue spectrum have multiple benefits in improving ocular health with minimum disadvantages; nevertheless, there are very few studies of spectacle lenses with a blue light blocking coat as a protective factor, and these types of filters can be significantly more expensive than the lenses without the blue light blocking coat^{1,2}.

Wavelengths in the blue portion of the electromagnetic spectrum (400-500 nm) can result in phototoxic retinal damage. With increased age, the life-long exposure of RPE cells to light, even ordinary everyday intensity, may have a significant impact on their degeneration. The cellular and molecular events underlying retinal photochemical light damage, including photoreceptor apoptosis, have been analyzed in experimental animal models. Two types of light-induced retinal damage have been described. Noell et al. explained the Class I retinal damage caused by low light levels and long exposures. The extent of the damage seen is

related to the duration of exposure and the wavelength of light used, with shorter wavelength (blue light) having a greater effect. Class II photochemical damage or blue-light hazard was described by Ham et al. relates to short retinal exposures of high intensity. In this case, toxicity decreases while increasing wavelength from UV through violet to the blue part of the visible spectrum. Retinal damage is related to exposure time and intensity in addition to the used wavelength with an excitation peak around 440 nm^{1,2}.

Both human and animal studies suggest that it is mainly the short wavelengths within the UV and blue light ranges that result in retinal damage and induce photochemical toxicity or oxidative stress to the RPE with the formation of reactive oxygen species^{3,4}.

Blue light is naturally emitted from the sun and helps regulate melatonin in the brain, which activates the natural sleep-wake cycle. However, technology has taken over because blue light is emitted by most electronic devices. Nowadays, the users of computers and other digital electronic devices up to 90% experience symptoms including, eyestrain, headaches, ocular discomfort, dry eye, diplopia, and blurred vision; despite the risks, the spectrally weighted irradiance from these devices does not reach international exposure limits, even for prolonged viewing; however, it has not been well studied. Moon et al. showed that display devices with a blue light peak at a shorter wavelength cause a more pronounced decrease in cell. Light damage as a possible contributing factor to the development of age-related macular degeneration (AMD) was first suggested in the 1980s. In the Chesapeake Bay study, there was a relationship between high levels of exposure to blue and visible light and development of AMD, especially later in life⁵⁻⁹.

Properties of the ocular media limit transmission of certain wavelengths. The cornea absorbs radiation of

Table 1. Keywords and terms

Keyword	MeSH terms	Synonyms	DeCS terms	Synonyms
Macular degeneration	Macular degeneration	Macular changes Age-related macular degeneration Age-related maculopathies Age-related maculopathy Macular degeneration, age-related Macular dystrophy Maculopathies, age-related Maculopathy, age-related	Degeneración macular	Maculopatía relacionada con la edad
Visual acuity	Visual acuity	Visual performance	Agudeza visual	Acuidad visual Rendimiento visual
Blue light filters	Title/abstract	Blue light blocking Blue light lenses	Filtro de luz azul	Lentes con filtro para luz azul

wavelengths below 300 nm but allows transmission of radiation of wavelengths between 300 nm and 400 nm. As the lens ages, it accumulates yellow chromophores, which results in a steady reduction in transmission of short-wavelength visible light. In aphakic or pseudophakic eyes, blue and UV radiation strikes the retina thus, in recent years, prophylactic measures against AMD have emerged. This resulted in the implantation of a “yellow” IOLs that absorb high-energy blue radiation and may be best suited for cases requiring special retinal protection¹⁰⁻¹³.

Benefits have been suggested including protection against retinal damage due to blue light hazard, with a possible role in preventing the development or exacerbation of AMD, improvement in contrast sensitivity (CS), reduced glare under photopic and mesopic conditions and reduction in disturbance of blue color vision. Possible disadvantages include disturbances of color perception, decreased scotopic sensitivity, and disruption of the timing of the circadian system. In addition, blue blocking spectacle lenses have also been claimed to improve sleep quality following the use of electronic devices at night and reduce eye fatigue and symptoms of eye strain during intensive computer tasks. Blue light blocking spectacle lenses claims they can alleviate eye discomfort for the use of digital devices, furthermore, improve sleep quality, eye-strain, and gives retinal protection. Nowadays, the use of digital devices is more than necessary in places such as schools, workplace, and domestic environments, spending a high number of hours per day with them¹⁴⁻¹⁸.

The aim of this study is to systematically analyze if the use of blue light filters reduces the ocular damage produced from short-wavelength light spectrum, helping colleagues take a decision to prescribe this type of spectacles considering the benefits and risks for each patient.

Methods

Search strategy

A search strategy was performed in different databases from January to February 2019, using the keywords, MeSH terms, and finally DeCS terms described in [table 1](#).

Data bases and information sources

The main databases and metasearch engines employed in this article were: PubMed, Biblioteca Virtual en Salud [BVS], Búsqueda de Información Global), Academic Search Complete, Science Direct, Wiley Online Library, SpringerLink, Medic Latina, Wolters Kluwer Health OvidSP, Trip Database, Clinical Key, and UpToDate. We also did a secondary recovery to increase the number of studies. With all the keywords, MeSH terms and DeCs terms, we created three different universes linked with the Boolean operator “AND,” also in each one of them the Boolean operator used to link the MeSH terms with their synonyms were “OR.” [Figure 1](#) to consult the complete search strategy.

Limits

In databases such as PubMed, BVS, and Academic Search Complete are multidisciplinary we used the filter studies in humans; with the other metasearch engines no filters were needed.

Selection criteria

First, one of the authors selected articles by titles, taking into consideration the ones who had a great number of keywords. Then, all the authors independently

Figure 1. Search strategy and methodology for databases.

reviewed the abstracts. Finally, potentially relevant studies were analyzed by one of the authors with full-text versions using a quality scale to take a final decision about inclusion. The evidence for original articles was evaluated with OPMER scale. This scale developed in the Epidemiology Department of Universidad Autónoma de San Luis Potosí based on PRISMA criteria is a checklist that includes five validity groups that address scientific soundness of original articles.

- Objective
- Population
- Methodology
- Statistics
- Results.

If an article had more than 14 points it was selected.

Exclusion criteria

We excluded all studies which title was not related to the main topic, before doing the review of every abstract. Finally, after the reading of selected articles, if the OPMER scale was below 14 points the study was excluded from the study.

Development of the topic

Twenty-nine original articles filled the criteria and were selected as the most important and reliable to include (Table 2) and its results are presented below.

Discussion

To make the analysis of the papers easier, we decided to distribute the articles in two groups; one about IOLs and its effects and the other one involving spectacles and eyeglasses; to make a comparison between both groups.

Owczarek et al. compared the amount of light transmission for two types of hydrophobic acrylic IOLs with the same refractive power of 20.0 dioptres, one containing a yellow chromophore (AcrySof® Natural SN60AT Alcon Lab, USA) and without chromophore (Alcon Labs). The light transmission was evaluated, in daylight, and in nighttime conditions. Presented results show significantly lower value of light transmission (74.41% and 92.14%) for IOL containing blue light filter as compare to non-modified IOL, respectively. On the other hand, it seems reasonable to suggest that blocking blue light radiation in twilight (mesopic) conditions potentially may improve the quality of vision¹⁹.

In 2006 a prospective, randomized study was designed to compare the post-operative visual outcomes: best-corrected visual acuity (BCVA), CS, and color perception of the blue light-filtering AcrySof® Natural (SN60AT) and AcrySof® single-piece (SA60AT) IOLs. The SN60AT group included nine eyes from nine patients and the SA60AT group ten eyes from ten patients. Post-operative evaluation included a complete clinical examination at 1, 3, and 6 months after the surgery including BCVA (Snellen chart), CS (Pelli-Robson CS chart), and color perception (Farnsworth-Munsell D-15 panel test) was measured at 1, 3, and 6 months postoperatively. Both groups showed improvement in log CS scores ($p = 0.08$) in mesopic and photopic conditions and color perception with no statistically significant differences between groups²⁰.

It has been reported that diabetic patients develop color vision alterations. Previous studies suggest that the short-wavelength-sensitive cone system or S-cones are more vulnerable to diabetes. Theoretically, the use of yellow filters may increase visual performance in this group of patients. Rodríguez et al. evaluated potential changes in CS and color discrimination in diabetic patients who had cataract surgery and implantation of the blue-light filtering AcrySof Natural SN60AT IOL compared with an UV-only filtering AcrySof SA60AT IOL. Forty-four eyes of 22 diabetic patients were enrolled in a blue light filtering fellow eye control study. Patients received AcrySof Natural in 1 eye and AcrySof SA60AT in the fellow eye. Three months after surgery, monocular CS function (CSF) was measured with the CSV 1000-E CS chart at distance and color discrimination was tested with the Farnsworth-Munsell 100-hue test. No statistically significant differences were found between IOLs ($p = 0.62$). Eyes implanted with the blue light filtering IOLs showed better CS values than fellow eyes implanted with non-yellow-tinted IOLs ($p < 0.05$). The blue light filtering IOL did not modify chromatic discrimination compared with the non-yellow-tinted IOL ($p = 0.62$). In diabetic patients, the AcrySof Natural IOL provides better CS than the AcrySof SA60AT. The blue light filter of the AcrySof Natural IOL did not cause chromatic discrimination defects based on total error scores (TES) and improved color vision in the blue-yellow chromatic axis in diabetic patients²¹.

Hammond et al. in 2010 compared visual performance in eyes with IOLs that filter blue light versus contralateral eyes with IOLs that do not filter visible blue light. Fifty-two subjects were evaluated and they found that mean glare disability was significantly less ($p = 0.04$) in the blue filtering IOL group than in the control group as well as heterochromatic contrast

Table 2. Results of articles

Title	Author	Year	Sample size	Objective	Kind of article	OPMER
Blue light filtering spectacle lenses: optical and clinical performances	Leung et al.	2017	80	To evaluate the optical performance of blue light filtering spectacle lenses and investigate whether a reduction in blue light transmission affects visual performance and sleep quality	Original	18
Short-wavelength light blocking eyeglasses attenuate symptoms of eye fatigue	Lin et al.	2017	36	To determine whether subjects who wear short-wavelength blocking eyeglasses during computer tasks exhibit less visual fatigue and report fewer symptoms of visual discomfort than subjects wearing eyeglasses with clear lenses	Original	17
Visual function improvement using photochromic and selective blue violet light filtering spectacle lenses in patients affected by retinal diseases	Colombo et al.	2017	60	To evaluate functional visual parameters using photochromic and selective blue violet light filtering spectacle lenses in patients affected by central or peripheral scotoma due to retinal diseases	Original	16
Psychophysical measurements of luminance contrast sensitivity and color discrimination with transparent and blue light filter IOLs	da Costa et al.	2017	15	To measure luminance contrast sensitivity and color vision thresholds in normal subjects using a blue light filter lens and transparent intraocular lens material.	Original	15
Sleep and mood changes in advanced age after blue blocking (yellow) intraocular lens implantation during cataract surgical treatment: a randomized controlled trial	Zambrowski et al.	2017	204	To demonstrate the superiority of yellow IOLs as compared with clear IOLs on sleep and mood changes before and after bilateral cataract surgery	Original	16
Protective effect of blue light shield eyewear for adults against light pollution from self-luminous devices used at night	Ayaki et al.	2016	12	To explore whether blue light shield eyewear can protect against the effects of blue light pollution from self-luminous portable devices used at night.	Original	16
The effect of blue blocking and neutral IOLs on circadian photoentrainment and sleep 1 year after cataract surgery	Brøndsted et al.	2016	67	To compare the long-term effect on circadian photoentrainment and sleep in patients implanted with neutral and blue blocking IOLs 1 year after cataract surgery.	Original	15
Reducing short-wavelength blue light in dry eye patients with unstable tear film improves performance on tests of visual acuity	Kaido et al.	2016	40	To investigate whether suppression of blue light can improve visual function in patients with short tear break up time dry eye	Original	17
Effect of blue light filtering intraocular lens on color vision in patients with macular diseases after vitrectomy	Mokuno et al.	2016	67	To evaluate the color vision of patients with macular diseases after implanting a blue light filtering intraocular lens during vitrectomy	Original	16
Light transmission through IOLs with or without yellow chromophore (blue light filter) and its potential influence on functional vision in everyday environmental conditions	Owczarek et al.	2016	-	To analyze the potential influence of light transmission through IOLs with or without yellow chromophore on functional vision in everyday environmental conditions	Original	15

(Continues)

Table 2. Results of articles (*Continued*)

Title	Author	Year	Sample size	Objective	Kind of article	OPMER
Blue light filtering IOLs and post-operative mood: a pilot clinical study	Leruez et al.	2015	54	To determine if implantation of blue filtering IOLs affects post-operative mood, inducing more depression, compared to patients undergoing implantation with conventional IOLs	Original	17
Effect of yellow filter on visual acuity and contrast sensitivity under glare condition among different age groups	Mahjoob et al.	2015	60	To investigate the effect of yellow filter on visual acuity and contrast sensitivity under glare condition for various ages.	Original	16
Nuevos lentes solares con certificado de seguridad retiniana: análisis de la función visual mediante la valoración de agudeza visual y estereoscópica, discriminación del color y sensibilidad al contraste	Bonnin et al.	2015	36	To compare the effect on the visual function of the new solar lenses with certificate of retinal safety versus traditional solar lenses	Original	15
Effect of blue light reducing eyeglasses on critical flicker frequency	Ide et al.	2015	33	To evaluate the effect of blocking short-wavelength light on critical flicker frequency	Original	16
Espesor macular medido con tomografía de coherencia óptica en ojos pseudoafáquicos con implante amarillo versus transparente	Chamorro et al.	2014	18	To evaluate by optical coherence tomography thickness variations in macular cells produced over time in pseudophakic patients implanted with a transparent intraocular lens compared to their respective contralateral eyes implanted with yellow IOLs	Original	15
Do blue light filtering IOLs affect visual function?	Lavric et al.	2014	30	To study different aspects of visual function, macular changes, and subjective differences between the eye with an ultraviolet and blue light filtering intraocular lens and the fellow eye with a ultraviolet-light filtering IOL	Original	14
Short-wavelength light filtering by the natural human lens and IOLs – implications for entrainment of circadian rhythm	Brøndsted et al.	2013	29	To examine the effect the aging human lens may have for the photoentrainment of circadian rhythm and to compare with intraocular implant lenses (IOLs) designed to block ultraviolet radiation, violet, or blue light.	Original	15
Influence of blue light filtering IOLs on daytime levels of melatonin (BluMel-study)	Kubista et al.	2013	8	To analyze the influence of those blue light filtering IOLs on daytime levels of melatonin in vivo	Original	14
Effects of blue light filtering IOLs on the macula, contrast sensitivity, and color vision after a long-term follow-up	Kara Jr. et al.	2011	30	To evaluate the possible side effects and potential protection 5 years after implantation of an intraocular lens with a blue light filter (yellow tinted)	Original	15
Effects of yellow filters on visual acuity, contrast sensitivity and reading under conditions of forwarding light scatter	Eperjesi and Agelis	2011	55	To compare the effects of three corning photochromic filters (450, 511 and 527) on visual acuity and contrast sensitivity with and without glare and on reading without glare under conditions of forwarding light scatter, to determine which provided the most beneficial effect on these aspects of visual function	Original	14

(Continues)

Table 2. Results of articles (*Continued*)

Title	Author	Year	Sample size	Objective	Kind of article	OPMER
Influence of blue light-filtering IOLs on retinal nerve fiber layer measurements by spectral-domain optical coherence tomography	Kim et al.	2011	39	To assess the influence of blue light-filtering IOLs on peripapillary retinal nerve fiber layer thickness measurements by spectral-domain optical coherence tomography	Original	15
Contralateral comparison of blue filtering and non-blue filtering IOLs: glare disability, heterochromatic contrast, and photostress recovery	Hammond Jr. et al.	2010	52	To compare visual performance in eyes with IOLs that filter short-wave blue light versus contralateral eyes with IOLs that do not filter visible blue light.	Original	17
Amber lenses to block blue light and improve sleep: a randomized trial	Burkhart and Phelps	2009	20	To demonstrate changes in overall sleep quality and positive/negative affect.	Original	15
Augmentation of macular pigment following implantation of blue light filtering IOLs at the time of cataract surgery	Nolan et al.	2009	42	To investigate whether the blue light filtering properties of the Alcon AcrySof natural intraocular lens implanted during cataract surgery affects macular pigment optical density	Original	16
Visual function and performance with blue light blocking filters in age-related macular degeneration	Kiser et al.	2008	22	To determine if a blue-blocking filter would affect performance during eye-hand coordination and mobility tasks in scotopic illumination, psychophysically measured scotopic sensitivity or color discrimination in age-related macular degeneration patients	Original	16
Blue blocker glasses impede the capacity of bright light to suppress melatonin production	Sasseville et al.	2006	14	To determine the capacity of blue blockers to prevent melatonin suppression during a 60-min light pulse at 4000×1 that is an intensity known to be sufficient to induce maximal melatonin suppression	Original	15
Visual outcomes with the yellow intraocular lens	Leibovitch et al.	2006	19	To compare postoperative best distance visual acuity, contrast sensitivity, and color perception with the blue light filtering AcrySof_ natural (SN60AT) and AcrySof_ single-piece (SA60AT) IOLs	Original	16
Blue light filtering intraocular lens in patients with diabetes: contrast sensitivity and chromatic discrimination	Rodríguez-Galietero et al.	2005	22	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 compared with an ultraviolet only filtering (AcrySof SA60AT) IOL	Original	16
The effects of colored light filter overlay on reading rates in age-related macular degeneration	Eperjesi et al.	2004	12	To determine the effect of colored light filter overlays on reading rates for people with age-related macular degeneration	Original	14

IOLs: Intraocular lenses.

threshold was significantly higher ($p = 0.0003$) also photo stress recovery was faster ($p = 0.02$) in the blue filtering IOL group, recovering visual function 5 s faster translates to 440 feet when driving at 60 miles/h²².

Da Costa et al. evaluated the CS of 15 participants; they compared the CS measure of the transparent and blue light filter and found that subjects had higher CS with the transparent filter when compared with the blue one ($p = 0.632$). Nevertheless, (87%) participants preferred to have a more comfortable vision under blue light filter lens condition ($p = 0.016$). The color vision had statistical higher significance for the blue light filter ($p = 0.003$). The subjective impression showed in all participants a better color vision under blue light filter condition. To summarize, no quantitative differences were found in the luminance sensitive between both types of lenses, although the blue light filter was reported to be more comfortable than the transparent filter²³.

In 2011 Kara Jr. et al. evaluated the possible side effects and potential protection of an IOL with a blue light filter (yellow tinted). Patients randomly received an UV and blue light filtering IOL (Acrysof Natural SN60AT) in an eye and an acrylic UV light filtering only IOL (Acrysof SA60AT) in the fellow eye. They measured CS, color vision, and macular findings 5 years after surgery under photopic and scotopic conditions, and a detailed macular examination was performed. There were no significant clinical or optical coherence tomography findings in terms of AMD in any eye nor statistically significant differences in central macular thickness between the 2 IOL groups ($p = 0.712$). There were also no significant differences under photopic or scotopic conditions at any spatial frequency studied or changes in color discrimination ($p = 0.674$). The potential advantage of the tinted IOL in providing protection to macular cells remained unclear²⁴.

In 2014 Lavric and Pompe developed a study to evaluate the effect of a blue light filtering IOL on visual function, macular changes, and subjective visual quality. In one eye, AcrySof SA60AT (a UV-light filtering IOL) was implanted, whereas, in the contralateral eye, AcrySof IQ SN60WF (a blue-light filtering IOL) was implanted. Each patient underwent VA testing, color vision testing (Ishihara and Farnsworth Munsell 100-hue tests), and CS testing; furthermore, the macula was evaluated with optical coherence tomography and clinical examination, finally subjective visual quality with the National Eye Institute Visual Functioning Questionnaire. As regard to color vision, no significant changes in Ishihara and Farnsworth-Munsell 100-hue error scores were detected between eyes ($p = 0.48$ and

$p = 0.59$, respectively). Analysis of CS showed no significant difference between both groups. Furthermore, no statistically significant differences in central macular thickness and total macular volume ($p = 0.72$ and $p = 0.61$, respectively) were found. This study showed no significant effects of a blue light filtering IOL on VA and no influence on color perception and CS²⁵.

In 2016, Mokuno et al. conducted a study to evaluate the color vision of patients with macular diseases after implanting a blue light filtering IOL. The Farnsworth-Munsell 100-hue test was used to determine TES and mean error scores under photopic and mesopic conditions in both groups. The TES under mesopic conditions were significantly higher than those under photopic conditions in both groups ($p < 0.05$). However, the TES in the macular disease group was not significantly different from that of the non-macular disease group under both photopic and mesopic conditions. The mean error scores under photopic conditions were significantly higher in the macular disease group than in the non-macular disease group, and under mesopic conditions, the mean error scores were significantly higher in the non-macular disease group than in the macular disease group ($p < 0.05$). These results indicate that blue light-filtering IOLs do not alter color discrimination in eyes with macular diseases²⁶.

Kiser et al. in 2008 studied whether a blue light blocking filter affects scotopic retinal sensitivity and visual performance (mobility, and eye-hand coordination) in patients with early AMD. Scotopic measures performed with and without a blue-attenuating filter included a mobility obstacle course, manipulation of cylindrical blocks, and a psychophysical dark adapted full-field flash test. A navy and blue sock color sorting task evaluated photopic color discrimination. On average with the filter, there was a 13% increase in time during the block test. The differences in time and number of bumps with versus without the filter were not significant for the mobility course. Performance with and without the filter was well correlated for the blocks ($r = 0.70$), flash test ($r = 0.83$), and mobility ($r = 0.66$), and the regression slopes were not significantly different from unity. About 77% of subjects misidentified at least one navy sock as black with the filter compared with 9% without, with a significant increase in such misidentifications with the filter. The difference in scotopic visual function or performance with versus without a blue blocking filter most likely does not produce a clinically significant effect or risk; however, detection of navy color may be impaired²⁷.

Brøndsted et al. examined the effect the aging human lens may have for the photoentrainment of circadian

rhythm and compared with IOLs designed to block UV radiation, violet, or blue light. The potential for photoentrainment of circadian rhythm was computed for donor lenses and five IOLs (one UV, two violet, and two blue light blocking) based on the transmission properties of the lenses and the spectral characteristics of melanopsin activation. The potential for melanopsin stimulation and melatonin suppression was reduced by 0.6-0.7 percentage point per year of life because of yellowing of the natural lens. The computed effects were small for the IOLs. Consequently, the aging process of the natural lens is expected to influence the photoentrainment of circadian rhythm, whereas IOLs are not expected to be detrimental to circadian rhythm²⁸.

In the other study of Brøndsted et al. in 2017, they investigated the effect of blue blocking and neutral IOLs on circadian photoentrainment 1 year after surgery, subjects were randomized to implantation with a neutral UV blocking IOL or a blue blocking IOL. The main outcome was activation of the intrinsically photosensitive retinal ganglion cells (ipRGC) measured by chromatic pupillometry. The circadian rhythm was analyzed by 24 h melatonin profiles and actigraphy; the latter was also used to determine objective sleep quality. One year after surgery, peak melatonin concentration was 3.3 pg/ml (95% CI, 2-5.5), corresponding to 50% lower for the participants allocated to blue blocking IOLs compared with participants allocated to neutral IOLs. Compared with pre-operative levels, the ipRGC response had increased by 13.7% (95% CI, 3.2-22.6) 1 year after surgery. Objective sleep quality was also improved as the time of wakefulness after sleep onset had improved by 5 min (95% CI, 1-10) for the entire population while sleep efficiency had increased by 2% points (95% CI, 0.42-3.65) although exclusively, for the participants allocated to blue blocking IOLs. Blue blocking IOLs improved the response of ipRGCs and sleep quality; however, the effect on sleep quality may be unrelated to circadian photoentrainment²⁹.

Kubista et al. analyzed the effect of blue light filtering IOLs and compared the change in melatonin daytime levels after implantation compared with IOLs without filter. Patients were randomized to receive either blue light filtering or white IOLs. Melatonin analysis, VA, complete slit-lamp examination, and sleeping habits, and quality questionnaire were performed before and 1 month after cataract surgery. The average amounts of wakes during the night increased postoperatively in subjects who received the blue light filtering lens. Subjects with the white lens only had < 1.0 pg/ml increase, while subjects with blue one had > 1.0 pg/ml increase of melatonin after surgery. Subjects who received blue

light filtering IOLs had an increase in uneasy sleep and more wakes during the night related to elevated levels of melatonin during day time³⁰.

Leruez et al. studied the mood in post-operative patients; the purpose of the study was to determine if implantation of blue filtering IOLs affects post-operative mood, inducing more depression, compared to patients undergoing implantation with conventional IOLs. The same type of IOLs was used in both eyes of each patient. Cognitively healthy patients (a mini-mental status examination score higher than 25) were assessed before and after surgery, using the 30-item geriatric depression scale (GDS) to seek symptoms of depression. Preoperatively, VA and GDS scores were comparable in the two groups. The post-operative GDS score was improved by 1.91 ± 3.10 points in the whole sample ($p = 0.002$), as well as in each subgroup of patients. Three months after surgery, the mean change in GDS score did not differ between groups ($p = 0.365$), nor did the mean VA ($p = 0.198$)³¹.

Zambrowski et al. compared the effects of yellow and clear IOLs on sleep and mood in advanced age patients undergoing bilateral cataract surgery. Subjects were randomized into yellow or clear IOLs groups. Patients completed a sleep diary, the pictorial sleepiness scale, and the Beck Depression Inventory (BDI) 1 week before and 8 weeks after the last surgical procedure. No significant difference was found between yellow and clear IOLs groups regarding sleep time, sleep latency, total sleep duration, quality of sleep, and BDI scores. However, surprisingly, the number of patients whose BDI score increased was significantly higher in the yellow IOL group $p = 0.02$. This suggests that patients receiving yellow IOLs could be at higher risk to develop depression or, at least, rather than being improved, mood may have been altered in patients who received yellow IOLs. Using yellow IOLs for cataract surgery do not significantly impact sleep but may induce mood changes in aging. As a possible explanation, the mood change may be the consequence of altered circadian rhythms that have been shown to have a significant impact on mood³².

Kim et al. in 2011 assessed the influence of blue light-filtering IOLs on peripapillary retinal nerve fiber layer (RNFL) thickness. Patients were randomly assigned to receive either a blue light-filtering IOL or a clear IOL. There was a significant increase in average RNFL thickness after cataract surgery in both IOL groups. No significant difference in perioperative changes of RNFL measurements was noted between yellow and clear IOL groups. The type of IOL did not affect the perioperative differences of RNFL thickness measurements ($p = 0.002$)³³.

Nolan et al. investigated whether the blue light filtering properties of the Alcon AcrySof Natural IOLs implanted during cataract surgery affects macular pigment optical density (MPOD). The patients were randomized to have either the standard Alcon AcrySof three-piece acrylic IOLs (controls) or the Alcon AcrySof Natural IOLs implanted at the time of cataract surgery. There was a highly significant and positive correlation between all MPOD recorded 1 week before and after surgery in eyes with an Alcon AcrySof three-piece acrylic IOLs implant ($p < 0.01$) and in those Alcon AcrySof Natural IOLs (blue filtering) implants ($p < 0.01$). Average MPOD across the retina increased significantly with time (after 3 months) in the Alcon AcrySof Natural IOLs (blue filtering) group ($p < 0.05$) but remained stable in the Alcon AcrySof three-piece acrylic IOLs group. This provides evidence that implanting an IOL that filters blue light is associated with augmentation of MPOD. However, further study is needed to assess whether the increase in MPOD is associated with reduced risk of AMD development and/or progression³⁴.

Macular thickness variations produced over time in pseudophakic eyes implanted with a transparent IOL compared to their respective contralateral eyes implanted with yellow IOL were evaluated in two sessions separated by a time interval of 5 years. Eyes implanted with transparent IOL showed a statistically significant reduction in macular thickness, $5 \pm 8 \mu\text{m}$ ($p = 0.02$) and reduction of the foveal thickness was $10 \pm 17 \mu\text{m}$ ($p = 0.02$) higher than expected due to the increase in age. However, the eyes implanted with yellow IOLs maintained their stable macular thickness³⁵.

In comparison with spectacle lenses, we summarized the following data.

Eperjesi et al. in 2004 determined the effect of colored light filter overlays on reading rates for people with AMD who often have difficulty with tasks involving reading, face recognition, and watching TV. Near word reading acuity was determined as the smallest word that could be read at 25 cm using the optimum refractive correction. The rate of reading tests showed that reading rate was not related to filter color ($p = 0.08$). Colored light filter overlays did not improve reading rate; it is unlikely that longitudinal chromatic aberration affects reading in AMD³⁶.

Leung et al. analyzed the impact of blue filtering spectacle lenses in visual performance and sleep quality. “BlueControl” (Hoya, Japan), “BlueProtect” (Zeiss, German), “Crizal Prevencia” (Essilor, France), and “StressFree” and “Noflex” (Swiss Lens, Hong Kong) were evaluated. The relative changes in phototoxicity,

scotopic sensitivity, and melatonin suppression were calculated based on their spectral transmittances measured by a spectrophotometer. The clinical performance of two blue light filtering spectacle lenses was compared with a regular clear lens serving as a control. CS under standard and glare conditions and color discrimination were measured. After each monthly wearing period, the participant's lens performance, night vision quality, and sleep quality were assessed subjectively using a questionnaire. All tested blue light filtering spectacle lenses theoretically reduced the phototoxicity by 10.6-23.6%. Although use of this filter also decreased scotopic sensitivity by 2.4-9.6% and melatonin suppression by 5.8-15.0%, over 70% of the participants could not detect these optical changes. Their clinical tests revealed no significant decrease in CS either. These lenses may serve as a supplementary option for protecting the retina from potential blue light hazard³⁷.

Arias et al. compared the effect of new sunglasses with the certification of retinal safety (RSC) and the traditional sunglasses on visual function. The sunglasses were characterized by means of the Humphrey spectrophotometer, and the main difference between the new RSC sunglasses and traditional ones is in the selective absorbance of short wavelengths. The visual function aspects assessed were: VA, stereo acuity (SA), color perception, and CSF. The VA and SA values with the RSC solar filter are similar to those obtained without the filter; however, with the traditional sun filter, both variables decrease significantly. Color discrimination decreases with both filters, which is a far superior loss with the traditional filter (45%) compared to the RSC filter (5%). Accordingly, these lenses improve visibility and comfort while maintaining sun protection and at the same time optimize VA, SA, and CSF and maintain color perception³⁸.

Ide et al. studied the effect of blocking short-wavelength light on critical flicker frequency (CFF). The study population was divided into three groups depending on the type of glasses worn during the study; these are as follows: blue light filtering lenses (lens 1, high blocking rate), blue light filtering lenses (lens 2, low blocking rate), or transparent lenses (lens 3, control). Before and after the experimental tasks were conducted, visual fatigue was assessed by calculating the CFF and by evaluating the answers to a 13-item questionnaire on visual complaints (dry eyes, irritated eyes, difficulty in refocusing the eyes, photophobia, itchy eyes, eye strain/fatigue, mental stress, and sleepiness when working, neck/shoulder/back/waist pain). The type of lens worn significantly affected the CFF; however, answers to the subjective questionnaires did not

differ significantly between the groups. Only two of the 13 question items (neck/shoulder/back/waist pain and eye strain/fatigue) showed a statistical difference between lens transparency. The higher the blocking effect of the lens, the lower the reduction in the CFF, suggesting that blocking short-wavelength light can reduce eye fatigue³⁹.

Kaido et al. investigated whether suppression of blue light can improve visual function in patients with short tear break up time dry eye (BUTDE). Twenty-two patients with short BUTDE and 18 healthy controls underwent functional VA examinations with and without wearing eyeglasses with 50% blue light blocked lenses. The functional VA parameters were starting VA, functional VA, and visual maintenance ratio. The baseline means values of functional VA and the visual maintenance ratio were significantly worse in the BUTDE patients than in the controls ($p < 0.05$), while no significant difference was observed in the baseline starting VA. The BUTDE patients had significant improvement in mean functional VA and visual maintenance ratio while wearing the glasses ($p < 0.05$), while there were no significant changes with and without the glasses in the control group ($p > 0.05$). Protecting the eyes from short-wavelength blue light may help to ameliorate visual impairment associated with tear instability in patients with BUTDE⁴⁰.

In 2010 Eperjesi et al. conducted a study to evaluate the effects of three commercial yellow filters on VA and CS measured with the Pelli-Robson test (with and without glare) and reading measured with MNRead charts (without glare) under conditions of forwarding light scatter (FLS). Statistically significant differences were found between the overall effect of glare and between corning photochromic filters (CPFs) for VA and CS. A gradual decline in VA, CS and reading with increasing CPF absorption was noted⁴¹. Furthermore, Mahjoob et al. evaluated the effect of yellow filter on VA and CS under conditions of FLS in different age groups. Their hypothesis was that yellow filter could change tested visual performance and has different results in older and younger adults. In general, there was no statistically significant difference in VA with and without glare ($p = 0.083$); also, no significant yellow filter effect was found in VA of the patients under glare ($p = 0.564$). On the other hand, there was a significant difference between mean of CS with and without glare ($p = 0.000$), and significant yellow filter effect was found in VA of the patients under glare ($p = 0.000$). CS in all age groups under glare condition was significantly lower than CS without glare. The results showed that scatter light effects increased with age and that could be reduced with the use of yellow filter⁴².

Burkhart in 2009 randomized 20 adults to wear either blue blocking (amber) or yellow-tinted (blocking UV only) safety glasses for 3 h before sleep. Participants completed sleep diaries during a 1-week baseline assessment and 2 weeks use of glasses. Outcome measures were subjective: change in overall sleep quality and positive/negative effect. The amber lens group experienced significant ($p < 0.001$) improvement in sleep quality relative to the control group and positive effect ($p = 0.005$). Mood also improved significantly relative to controls⁴³. In addition to the mood topic Sasseville et al. in 2006 tested the hypothesis that cutting the blue portion of the light spectrum with orange lens glasses (blue blockers) would prevent light-induced melatonin suppression. The amount of salivary melatonin change was compared with a melatonin baseline obtained the night before. Although both glasses transmitted the same illuminance the ANOVA performed found a non-significant increase of 6% (95% CI, 20%-9%) with the orange lens, whereas a significant ($p < 0.05$) reduction of 46% (95% CI, 35-57%) was observed with the grey lens. Blue blockers represent an elegant means to prevent light-induced melatonin suppression⁴⁴.

Researchers in Keio University School of Medicine investigated the sleep quality and melatonin in adults who wore blue-light shield or control eyewear 2 h before sleep while using a self-luminous portable device, and assessed visual quality for the two eyewear types, monitoring each patient sleep/wake cycle with a micro-motion logger, and making a validated questionnaire (which incorporated the Pittsburgh sleep quality index and Karolinska sleepiness scale) before and during the experiment. Overnight melatonin secretion was significantly higher after using the blue-light shield ($p < 0.05$) than with the control eyewear. Sleep efficacy and sleep latency were significantly superior for wearers of the blue-light shield ($p < 0.05$ for both), and this group reported greater sleepiness during portable device use compared to those using the control eyewear⁴⁵.

Another study with eyeglasses and electronic devices was performed by Lin et al. in 2017. Its purpose was to determine whether subjects who wear short-wavelength blocking eyeglasses during computer tasks exhibit less visual fatigue and report fewer symptoms of visual discomfort than subjects wearing eyeglasses with clear lenses. A masked grader measured CFF as a metric of eye fatigue. They found that the change in CFF after the computer task was significantly more positive (less eye fatigue) in the high-block versus the no-block ($p = 0.027$) group. Moreover, random assignment to the high-block group but not to the low-block group predicted a more

positive change in CFF (i.e., less eye fatigue) following the computer task ($p = 0.002$). In addition, subjects wearing high-blocking eyeglasses reported significantly less feeling pain around/inside the eye ($p = 0.0063$), less feeling that the eyes were heavy ($p = 0.0189$), and less feeling that the eyes were itchy ($p = 0.0043$) following the computer task, when compared to subjects not wearing high-blocking lenses. Results support the hypothesis that short-wavelength light-blocking eyeglasses may reduce eye strain associated with computer use based on a physiologic correlate of eye fatigue and on subjects' reporting of symptoms typically associated with eye strain; however, it seems that flicker frequency it is independent of blue light exposure⁴⁶.

Colombo et al. evaluated functional visual parameters using photochromic and selective blue-violet light filtering spectacle lenses in patients affected by central (Group 1) or peripheral scotoma (Group 2) due to retinal diseases. Black on white BCVA (BW-BCVA), WB-BCVA, Mars CS, and a glare test (GT) were performed to all patients. Test results with blue-violet filter, a short-pass yellow filter, and with no filters were compared. The mean BW-BCVA increased from 0.30 ± 0.20 to 0.36 ± 0.21 decimals in Group 1 and from 0.44 ± 0.22 to 0.51 ± 0.23 decimals in Group 2 ($p < 0.0001$). The mean WB-BCVA increased from 0.31 ± 0.19 to 0.38 ± 0.23 decimals in Group 1 and from 0.46 ± 0.20 to 0.56 ± 0.22 decimals in Group 2 ($p < 0.0001$). The letter count for the CS test increased from 26.7 ± 7.9 to 30.06 ± 7.8 in Group 1 ($p = 0.0005$) and from 31.5 ± 7.6 to 33.72 ± 7.3 in Group 2 ($p = 0.031$). GT was significantly reduced: the letter count increased from 20.93 ± 5.42 to 22.82 ± 4.93 in Group 1 ($p < 0.0001$) and from 24.15 ± 5.5 to 25.97 ± 4.7 in Group 2 ($p < 0.0001$). Higher scores were recorded with the blue filter compared to yellow filter in all tests ($p < 0.05$). No significant differences in any test results could be detected between the yellow filter and the no filter condition. The use of a combination of photochromic lens with a selective blue-violet light filter showed functional benefit in all evaluated patients⁴⁷.

The main strength of this systematic analysis is the rigorous assessment of the quality of the included studies and the comparison between IOLs and other ophthalmologic devices. A limitation of our study is the inclusion of published studies only, and therefore, publication bias is not excluded from the study.

Conclusions

Regarding the blue light blocking IOLs no studies show harmful effects on visual performance, including

VA, CS, and color perception even in eyes with macular diseases. There was overall improvement in CS in mesopic and photopic conditions. Patients reported less glare discomfort and color perception was reported to be more comfortable with these IOLs.

The potential advantage of the tinted IOLs in providing protection to macular cells remained unclear. Post-operative mood is improved in most patients after cataract surgery unrelated to the IOL filter. Blue blocking IOLs may improve sleep quality.

There is a lack of quality clinical trials that shows the benefits of using these filters in spectacle lenses in comparison with IOL's. All tested blue light filtering spectacle lenses theoretically reduced the phototoxicity and may serve as a supplementary option for protecting the retina from potential blue light hazard.

The short-wavelength emitting devices contribute to visual fatigue. In fact, prolonged use of these devices can result in a constellation of symptoms, which are now recognized as digital vision syndrome. Blocking short-wavelength light can reduce eye fatigue and may help to ameliorate visual impairment associated with tear instability in patients with dry eye. Taking into consideration the digital vision syndrome that involves eyestrain, headaches, ocular discomfort, dry eye, diplopia, and blurred vision, is a multifactorial condition with very different causes such as tear film abnormalities, systemic rheumatologic diseases, oculomotor disorders and even uncorrected refractive error. That is why delimitate the role of blue light in this syndrome is slightly difficult.

This kind of lenses has a slight increase in contrast sensitivity but with very low clinical impact. Some studies suggest an improvement in sleep quality with a non-significant increase in serum levels of melatonin.

Retinal damage induced by LEDs in animal models shows wavelength dependence. Since the discovery of the blue light hazard, blue light filtering lenses have been considered as a viable option for retinal protection, but the real impact of this procedure has not been definitely proven. Although human exposure to short-wavelength light generally is chronic and subthreshold rather than acute and suprathreshold, as is for most these animal models, the studies analyzed implicate short-wavelength light as pathologic. Even though increasing age, genetics, and smoking are well-established risk factors for AMD, it is still not clear whether other aspects, including long-term exposure to short-wavelength light, could contribute to the development of the disease.

In current medical literature only, few papers were identified reporting the effects of blue light blocking spectacle lenses in retinal health, and all of them

conclude that the irradiance from these devices does not reach international exposure limits for damage the retina even for prolonged viewing. With these considerations, wider use of blue light filtering spectacle lenses, especially old people with an increased risk of AMD progression, could play a complementary role in visual preservation and might be an option for further protection for retinal diseases.

One key aspect of blue light blocking filters is finding the balance between effectively reducing blue light hazards without compromising the essential visual functions in daily life. Well designed, long-term studies could unveil which spectrum of visible light should be filtered to minimize the health hazards permitting sufficient blue light transmission to allow it to perform its normal physiologic functions, moreover, define what is the real role of blue light in the pathogenesis retinal disease, both degenerative and dystrophic. Future studies not only will explore the effects of chronic exposure to blue light but also will identify the characteristics of blue light that yield these toxic effects.

It is difficult to generalize broadly based on our results, alone nonetheless, the authors hope that with the findings of this systematic review it could be useful for further clinical studies to improve methodology and statistical analysis for addressing better the benefits of these filters in general population.

Conflicts of interest

The authors do not have any conflicts of interest to disclose regarding this review.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that no patient data appear in this article.

Right to privacy and informed consent. The authors declare that no patient data appear in this article.

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