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SCIENTIFIC INVESTIGATIONS

Blue-Light-Blocking Intraocular Lens Implantation Improves the Sleep Quality of Cataract Patients

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Study Objectives: To evaluate whether blue-light-blocking intraocular lens implantation affects the sleep quality of cataract patients.
Design: Pre-test/post-test experiment.
Setting: N/A.
Participants: 40 patients having bilateral cataracts with level higher than N3 (LOCS II) nucleus hardness, including 26 females (65%) and 14 males (35%).
Interventions: Cataract phacoemulsification followed by blue-light-blocking intraocular lens (IOLs, SN60WF, Alcon Laboratories, USA) implantation.
Measurements and Results: Patients were contacted in site before cataract surgery and followed by telephone at least 2 months later after second-eye surgery. Pittsburgh Sleep Quality Index (PSQI) questionnaires were administered to evaluate sleep quality. Median age of patients was 74 years (IQR 70 to 78). The median PSQI globe scores were 7 before surgery and 4 after surgery ($Z = -2.121$, $p = 0.037$). More specifically, there were significant differences on subjective sleep quality ($Z = -2.064$, $p = 0.045$), sleep duration ($Z = -2.037$, $p = 0.047$) and daytime dysfunction ($Z = -2.142$, $p = 0.034$) when compared between before and after surgeries. The ratio of poor sleepers (PSQI > 5) was reduced significantly after surgery ($\chi^2 = 14.532$, $p < 0.001$).
Conclusions: Blue-light-blocking IOL had a significantly beneficial effect on the sleep quality of cataract patients.
Keywords: Sleep quality, cataract, blue light, IOL, PSQI
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With aging, the human lens becomes a strong color filter attenuating light transmission, particularly for the short wavelengths.[1] However, light of short wavelength is important in the control of the sleep-wake cycle (circadian rhythm), which is well known as photo entrainment of circadian rhythm. Circadian rhythm is regulated by melatonin produced by the pineal gland. Photo entrainment of circadian rhythm is mainly mediated by intrinsically photosensitive retinal ganglion cells (ipRGC) containing melanopsin that allows melatonin suppression via the retinohypothalamic tract.[2] Even though the ipRGCs can function in the absence of rods and cones, their output is normally regulated by input from the rod and cone photoreceptors.[3,4]

Brainard et al.[5] reported the influence of various monochromatic lights on melatonin secretion and found that a peak of the action spectrum at 464 nm. Morita and Tokura[6] also indicated that a light with more short wavelengths reduced melatonin secretion and decreased the fall of core temperature in the evening and night, causing an inhibitory effect on nocturnal sleep.

In pathological conditions such as cataract, the reduction in light transmission in the eye can be very dramatic. Short wavelength light plays an important role on the inhibition of melatonin secretion. Therefore cataract patients, whose optical systems transmit light poorly (especially short wavelengths), would be likely to experience sleepiness in the daytime because there is not enough short wavelength light to reduce melatonin secretion. Consequently, they commonly have poor sleep in the night and are susceptible to sleep disturbances. For this reason, cataract surgery may improve not only their sight but also the quality of their sleep. Initially, intraocular lenses (IOLs) implanted during cataract surgery allowed the passage of all the visible light.[7] However, it was found erythropsia[8] (a temporary distortion of color vision where objects appear with an abnormal reddish hue), photic retinopathy (retinal dysfunction which induced by too much light exposure), and cystoid macular edema[9-12] (fluid accumulation in the outer plexiform layer and cyst formation, a common cause of decreased vision following cataract surgery) occurred in patients with these IOLs.

Previous works suggest that long time exposure in the blue range (approximately 475 nm) may injure an aging retina and cause photoreceptor damage and possibly lead to the development of other disease processes such as age-related macular

BRIEF SUMMARY
Current Knowledge/Study Rationale: For cataract patients, blue-light-blocking intraocular lens (IOLs) have beneficial effect on the retina, it can lower the risk of many retina diseases which are caused by too much light exposure. The ophthalmologist's only concern is whether blue-light-blocking IOLs affect the sleep quality of cataract patients because blue light is important in the control of the sleep-wake cycle.
Study Impact: Based on large sample size in Sichuan, China, our data indicate that blue-light-blocking IOL had a significantly beneficial effect on the sleep quality of cataract patients. Thus blue-blocking intraocular implants could be used routinely during cataract phacoemulsification surgery.

degeneration.[13-19] Therefore, in recent years, IOLs have been manufactured with a filter that blocks the passage of blue light. Although the filter can protect the posterior segment of the eye in theory, there have been few reports of its advantage, and many researchers still believed that a filter that blocks blue light may have detrimental effects.[20-22] Landers and colleagues[23] reported that compared to the conventional IOLs, blue-light-blocking IOLs had no detrimental effect on the sleep quality. However, Landers' study lacked assessment of the patient's sleep quality before surgery, and their study was conducted in a geographical region remarkable for its sunny climate. In order to confirm these initial findings in more patients and in a geographical region with less sunshine, we designed a study to evaluate whether cataract phacoemulsification (one kind of cataract extraction surgery, which uses ultrasonic power to emulsify the cataract in to aspirate it from two small incisions) combine blue-light-blocking IOL implantation has an effect on sleep quality based on large sample size in Sichuan, China.

METHODS

Participants

Considering that nucleus hardness is the most important factor for light transmission, 40 bilateral cataract patients with nucleus hardness > level N3 (Lens Opacity Classification System II, LOCS II) were recruited from the outpatient clinic of the Department of Ophthalmology, West China Hospital, Chengdu, China into this study. LOCS II is a grading system for cataract according to the transparency of the lens. Focusing on the nucleus hardness, it can be divided into 4 levels (level N0: transparent nucleus, colorless; N1: soft nucleus, yellow-white color; N2: medium hardness nucleus, yellow color; N3: stiff nucleus, dark brown color). Patients were chosen who required bilateral cataract phacoemulsification followed by blue-light-blocking intraocular lens (SN60WF, Alcon Laboratories, USA) implantation due to visual acuity less than 0.2. To evaluate the nucleus hardness more accurately, 2 doctors provided independent evaluations. If one of these two doctors was not sure the nucleus hardness was > N3, a third doctor provided evaluation. Informed consent was obtained from each patient prior to the beginning of the experiment. Exclusion criteria included: IOL could not implanted during surgery, retinal or optic nerve disorders that might interfere with light perception or color perception (e.g., retinitis pigmentosa, anterior ischemic optic neuropathy, diabetes, glaucoma), color blindness, and inability to complete a questionnaire due to confusion or dementia. Postoperative refractive error and visual acuity were not exclusions.

Study Design

Study design was a pre-test/post-test experiment.

Measurements

Transmission curve measurement

The transmission curves of the blue-light-blocking intraocular lens (+20.0D SN60WF IOL, Alcon Laboratories, USA) and the typical conventional intraocular lens (+20.0D AR40e IOL, Abbott Medical Optics Inc, USA) were obtained by using an UV/Vis Spectrometer Lambda 14 (Perkin-Elmer Lambda; Shelton, CT). The sources are 2 lamps, one halogen and the other deuterium, which can cover both the UV and the visible lights. The apparatus uses 2 monochromators to select the wavelength (λ) accurately. Light passes through the IOLs and is measured before entering the integrating sphere. A suitable cuvette is used to place the IOLs directly in front and covering the complete entrance hole of the integrating sphere. Spectral of the human lenses were adapted from Boettner and Wolter.[24]

Pittsburgh Sleep Quality Index (PSQI)

The questionnaire administered in this study was the Pittsburgh Sleep Quality Index (PSQI; **Table 1**). This 17-item questionnaire was designed to assess self-rated sleep quality and disturbances over a 1-month time period and to help investigators distinguish between "good" and "poor" sleepers. The PSQI included 7 component scores: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, daytime dysfunction, and a total global score. Each component was scored 0 to 3, with 3 indicating the worst score. The highest possible global score is 21; and a score > 5 indicates a poor sleeper. The PSQI has been in clinical use for almost 20 years and over that time has consistently shown robust validity and reliability.[25-28] The surgeries of this study were carried out between January 2012 to March 2012. All eligible patients completed the questionnaire within 3 days before their cataract surgery. Investigators did not tell subjects the supposed relationship between IOL and sleep quality. This was followed by a telephone call 2 months later after they completed bilateral surgeries. During the call, the same questionnaire was administered.

Statistical Analyses

Given that the data were not normally distributed, Statistical Analysis System software (SigmaPlot 12.2, SYSTAT) was used for statistical analysis, including Wilcoxon's signed rank test, chi-square test. Medians and interquartile ranges (IQR) were recorded. Odds ratios and 95% confidence intervals were also recorded.

RESULTS

Our study confirmed that in visible light, the shorter wavelength (380-480 nm) light's transmittance of the blue-light-blocking lens (SN60WF) was much lower than that of the conventional intraocular lens (AR40e), but interestingly, it is very close to that of the 53-year-old human's natural crystalline lens at short wavelengths range from 350 nm to 465 nm.

Of 40 patients who were eligible, 26 were women (65%) and 14 were men (35%). The data were not normally distributed, the median age of all patients was 74 years (IQR 70 to 78); of female patients, 73 years (IQR 67 to 79) and of male patients, 75 years (IQR 70 to 80). The median PSQI component score before surgery of all patients was 2 (IQR 0 to 3) for subjective sleep quality, 0 (IQR 0 to 1) for sleep latency, 2 (IQR 0 to 3) for sleep duration, 1 (IQR 0 to 1) for habitual sleep efficiency, 1 (IQR 0 to 2) for sleep disturbances, 0 (IQR 0 to 1) for use of sleeping medication, and 1 (IQR 0 to 1) for daytime dysfunction. The median global score of all patients was 7 (IQR 3 to 13); 30 patients (75%) had a global score > 5 and were considered to be poor sleepers (**Table 2**).

Table 1—The Pittsburgh Sleep Quality Index Questionnaire

PITTSBURGH SLEEP QUALITY INDEX (PSQI)

1. During the past month, when have you usually gone to bed at night?
2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?
3. During the past month, when have you usually gotten up in the morning?
4. During the past month, how many hours of actual sleep did you get at night? (This maybe different than the number of hours you spend in bed.)
5. During the past month, how often have you had trouble sleeping because you…

(a) Cannot get to sleep within 30 minutes.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(b) Wake up in the middle of the night or early morning.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(c) Have to get up to use the bathroom.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(d) Cannot breathe comfortably.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(e) Cough or snore loudly.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(f) Feel too cold.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(g) Feel too hot.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(h) Had bad dreams.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(i) Have pain.	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week

6. During the past month, how would you rate your sleep quality overall?
   Very good | Fairly good | Fairly bad | Very bad
7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?
   Not during the past month | Less than once a week | Once or twice a week | Three or more times a week
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?
   Not during the past month | Less than once a week | Once or twice a week | Three or more times a week
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?
   No problem at all | Only a very slight problem | Somewhat of a problem | A very big problem

Two months after patients received bilateral cataract phacoemulsification and blue-light-blocking lens implantation, the median PSQI component score of all patients was 1 (IQR 0 to 2) for subjective sleep quality, 0 (IQR 0 to 1) for sleep latency, 1 (IQR 0 to 3) for sleep duration, 1 (IQR 0 to 1) for habitual sleep efficiency, 1 (IQR 0 to 2) for sleep disturbances, 0 (IQR 0 to 1) for use of sleeping medication, and 0 (IQR 0 to 1) for daytime dysfunction. The median global score of all patients was 4 (IQR 2 to 7); only 13 patients (32.5%) had a global scores > 5 and were considered poor sleepers (**Table 1**).

Between the two timepoints, there was a significant difference in global score (Z = -2.121, p = 0.037). More specifically, there were significant differences in subjective sleep quality (Z = -2.064, p = 0.045), sleep duration (Z = -2.037, p = 0.047), and daytime dysfunction (Z = -2.142, p = 0.034) before and after surgeries (**Table 2**). As a result of cataract phacoemulsification with blue-light-blocking intraocular lens implantation, 56.67% of subjects went from having an abnormal PSQI (> 5) to normal < 5 PSQI. The ratio of poor sleepers (PSQI > 5) reduced significantly after surgery ($\chi^2 = 14.532$, p = 0.000); the odds ratios were 6.231 and 95% confidence intervals were (2.351, 12.513).

Table 2—Pittsburgh Sleep Quality Index scores before and after surgery

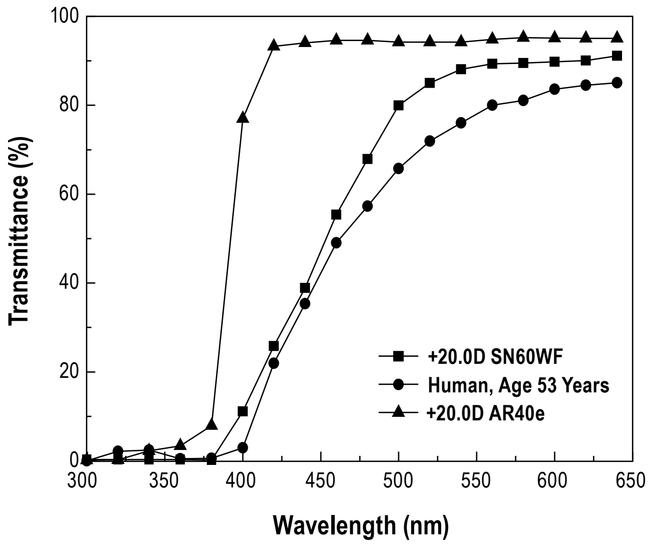
	Cataract Phacoemulsification with IOL Implantation (SN60WF)		
Parameter	**Before**	**After**	**p value**
PSQI scores			
Global			0.037
Median score	7	4	
IQR	3-13	2-7	
Median component scores			
Subjective sleep quality	2	1	0.045
Sleep latency	0	0	0.479
Sleep duration	2	1	0.047
Habitual sleep efficiency	1	1	0.644
Sleep disturbances	1	1	0.697
Use of sleeping medication	0	0	0.921
Daytime dysfunction	1	0	0.034
Poor sleepers > 5 global score, n (%)	30 (75)	13 (32.5)	0

IQR, interquartile range; PSQI, Pittsburgh Sleep Quality Index.

DISCUSSION

Any medical device must be evaluated to ensure that it has no adverse effects. Our study found there is beneficial effect to cataract patients on sleep quality after cataract surgery and blue-light-blocking IOL implantation. Patients in our study who with the nucleus hardness over than level N3 (LOCS II) typically slept for a median of 5.5 hours per day, and they slept for 6.5 hours per day after cataract surgery combined blue-light-blocking IOL implantation. Very high ratio (75%) patients before surgery were considered to be poor sleepers as their PSQI

Figure 1—Spectral transmittance curves of the human natural lens at age 53 years, a +20.0D blue-light-blocking IOL(SN60WF) and a +20.0D conventional IOL(AR40e)



Spectral of the human lenses were adapted from Boettner and Wolter.[25]

scores were greater than 5 and their median PSQI scores were similar with those in a previous population-based assessment of patients of the same age.[29]

The circadian rhythm is controlled by suprachiasmatic nucleus inhypothalamus[30,31] whose activity increases and decreases over a period of nearly 24.5 hours.[32] One of its target organs is the pineal gland which secretes melatonin in a cyclical fashion. The secretion of melatonin could induce sleep.[32] As mentioned above, the light-triggered melatonin suppression is most sensitive to blue light, and it has also been proved theoretically that short-wavelength light is important in maintaining a balanced circadian rhythm and a regular sleep-wake cycle.[33-36] This suggests that the patients with blue-light-blocking IOLs may be susceptible to sleep disturbances, daytime sleepiness, and insomnia or depression because of the blue light-blocking effect.[37] However in stark contrast, our results clearly indicate this is not the case, blue-light-blocking IOLs actually improve the sleep quality of cataract patients. One reason for this phenomenon is that blue-light-blocking IOLs block blue lights only partially. Indeed, based on the spectral transmittance spectral curve as shown in **Figure 1**, though the blue light transmittance of the blue light-blocking IOL is much lower than that of conventional IOL, but it is very close to that of a 53-year-old human natural lens, which still allows 10% to 70% of 400-500 nm light go through. It seems that this amount of blue lights is sufficient to suppress the melatonin production, and thus keep the circadian rhythm. Another possibility is that patients with blue light-blocking IOL may have more rods, cones, and ipRGCs (as this type of IOL can protect retina from light damages), thus are more sensitive to blue light. This will compensate for the lost blue lights by this type of IOL. This conclusion is consistent with Landers' finding that the sleep quality is the same in cataract patients with conventional IOLs and blue-light blocking IOLs.[23]

Blue-light-blocking IOLs have beneficial effect on the retina of cataract patients. They could lower the risk of erythropsia,[8] photic retinopathy, and cystoid macular edema.[9-12] Blue light-blocking IOLs do not reduce visual acuity, contrast sensitivity, color vision,[38-41] or scotopic sensitivity[42-44] of cataract patients. The ophthalmologist's only concern is whether blue-light-blocking IOLs affect the sleep quality of cataract patients. Based on our data and Landers' results, blue-light-blocking IOL is a good choice for cataract patients because thy have beneficial effects not only on retina, but also on sleep quality.

There are still several limitations of this observation. First, there is no control group, so we cannot compare the sleep quality between conventional IOL and blue-light-blocking IOL implantation. Second, we did not measure other circadian rhythm indicators such as the Horne Ostberg morningness-eveningness questionnaire or core temperatures. While our patients have improved sleep quality, we have no idea if they have a normal circadian rhythm. Third, it is difficult for us to be double-blinded to the treatment, so there might be bias. Nevertheless, our data indicate that blue-light-blocking IOL had a significantly beneficial effect on the sleep quality of cataract patients. Thus blue-blocking intraocular implants could be used routinely during cataract phacoemulsification surgery.

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