LED Light Characteristics for Surgical Shadowless Lamps and Surgical Loupes

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Background: Blue light has more energy than longer wavelength light and can penetrate the eye to reach the retina. When surgeons use magnifying loupes under intensive surgical shadowless lamps for better view of the surgical field, the total luminance is about 200 times brighter than that of typical office lighting. In this study, the effects of 2 types of shadowless lamps were compared. Moreover, the effect of various eyeglasses, which support magnifying loupes, on both the light energy and color rendering was considered.
Methods: The light intensity and color rendering were measured on 3 variables: light transmittance, light intensity, and color rendering.
Results: Under shadowless lamps, the light energy increased with low-magnification loupes and decreased with high-magnification loupes. Filtering eyeglasses reduced the energy, especially in conditions where the low-magnification loupe was used. The best color-rendering index values were obtained with computer eyeglasses under conventional light-emitting diode shadowless lamps and with no glass and with lightly yellow-tinted lenses under less-blue light-emitting diode.
Conclusions: Microsurgeons are exposed to strong lighting throughout their career, and proper color rendering must be considered for easier recognition. Light toxicity and loss of color rendering can be reduced with an appropriate combination of shadowless lamps and colored eyeglasses. *(Plast Reconstr Surg Glob Open 2015;3:e562; doi: 10.1097/GOX.0000000000000498; Published online 19 November 2015.)*

Blue light has more energy than longer wavelength light and can penetrate the eye to reach the retina. Phototoxic retinal damage is expected to occur with wavelengths in the blue-light spectrum, especially below 460 nm.[1–4] In medicine, surgeons use magnifying loupes under intensive surgical shadowless lamps or operating room (OR) lights for better view of the surgical field. For general surgeries, the luminance is 100,000–160,000 lx, which is 200 times brighter than typical office lighting.

In the past, the light sources for surgical lamps were incandescent or halogen lamps. These lights are being replaced by more energy-efficient light-emitting diodes (LEDs), leading to increased blue light exposure. However, the accumulated knowledge of blue light hazards has accelerated the use of less-blue LEDs (LBLEDs) in surgical lamps.

We hypothesized that the eyeglasses to which the surgical loupe is attached can affect the light spec-

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Received for publication March 4, 2015; accepted July 28, 2105.

The experimental site (The Medical Lighting Lab) as well as the light measuring hardware and software were provided by Yamada Shadowless Lamp Co., Ltd. The transmittance data for the eyeglasses used in this investigation were obtained from JIN CO., LTD.

DOI: 10.1097/GOX.0000000000000498

Disclosure: *The authors have no financial interest to declare in relation to the content of this article. The Article Processing Charge was paid for by Yamada Shadowless Lamp Co., Ltd.*

Fig. 1. A eyeglass sample used in this investigation: original eyeglasses with clear lenses (glass #1).

trum and intensity. In this study, we evaluated the light characteristics for the combination of different glass lenses with different LEDs in shadowless lamps.

MATERIALS AND METHODS

Shadowless Lamp

We employed 2 types of OR lights: CRYSTAL CR07 (CRYSTAL) and SKYLED R9 BR01 (SKYLED) (Yamada Shadowless Lamp, Tokyo, Japan).

Eye Glasses

The sample provided by the loupe manufacturer has clear lenses (Fig. 1), whereas the other 4 samples have colored lenses (Fig. 2). The visible light (380–780 nm) transmittance and blue light (380–480 nm) transmittance were calculated based on the British Standard.

Surgical Loupes

The SurgiTel Miro350N (low magnification, 2.5×) and EVK650 (high magnification, 8×) (General Scientific Corporation, Ann Arbor, Mich.) surgical loupes were utilized.

Lighting Conditions and Measuring Methods

A spectral irradiance meter (ISM Lux, Isuzu Glass, Osaka, Japan) was placed 1-m below the shadowless light. The lighting conditions were as follows: the illuminance and color temperature were set to 95,000 lx and 3900 K (CRYSTAL), respectively, and 96,000 lx and 4400 K (SKYLED), respectively. The targeted samples were placed immediately above the irradiance meter.

Data Analysis

For each sample, measurements were repeated 3 times and averaged. Data analyses were performed using Microsoft Excel (Microsoft Corporation, Redmond, Wash.).

RESULTS

Glass Transmission Spectra

The transmission spectra curves showed distinct characteristics, even within the yellow-tinted lenses (Fig. 3).

The visible light transmittance (380–780 nm) and blue light (380–460 nm) cut rate are summarized in Table 1.

The blue-blocking capability was highest in glass #4, followed by #5, #2, #3, and #1 in descending or-

Fig. 2. Four more eyeglass samples used in this investigation (A) blue-light reduction eyeglasses sold as PC eyeglasses (glass #2), (B) light yellow-tinted eyeglasses (glass #3), (C) dark yellow-tinted eyeglass (glass #4), and (D) conventional dark-tinted sunglasses (glass #5).

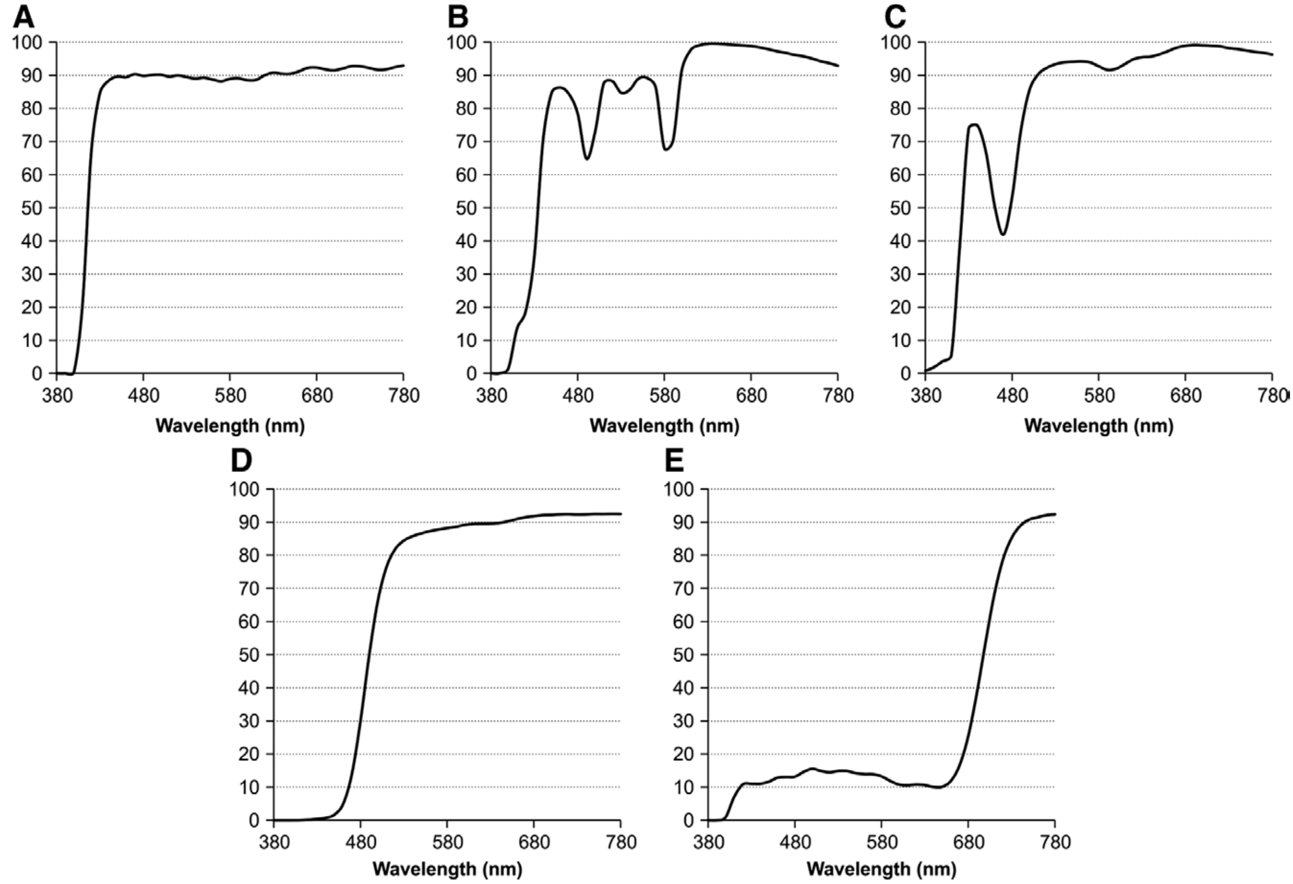

Fig. 3. The relative light transmittance curve (in %) for the 5 eyeglass samples: glasses #1–#5 (A–E, respectively). The lens spectrum curves were obtained from JIN Co., Ltd. Each curve indicates a large difference in the transmittance and in the blue-light cut rate.

der. The visible light transmittance is lowest in glass #5, followed by #4, #2, #1, and #3 in ascending order.

Effects of Combined Glass and Loupe on the Measurements

Our primary aim is to understand which surgical loupe has the highest light burden on the eye and to search for a way to reduce the light burden. The preliminary experiments showed that the high-magnification loupe transmitted significantly less light compared with either no loupe or the low-magnification loupe (Fig. 4). Therefore, in the following experiments, we excluded the high-magnification loupe.

In Figures 5, 6 and Table 2, the red curve (no eyeglass) and blue curve (conventional sunglass) had the highest and lowest intensity, respectively. The absolute and relative value of blue light is lower with eyeglasses. With the low-magnification loupe, the intensity tended to be higher than those cases with no loupe. In Table 2, although the percentage of the blue-light appears similar, the absolute value is higher with the low-magnification loupe, followed by the cases without the loupe and with the high-magnification loupe for both lamp groups.

In Table 2, the percentage of the blue-light area is lowest for glass #4, intermediate for glasses #2, #3, and #5, and highest in glass #1 and no glass in both lamp groups. However, the absolute value of the total visible light is lower with glasses, and the absolute value is lower for the apparent percentage of blue light.

Color-Rendering Properties

The color-rendering properties (Ra, R1–R15) are shown in Figure 7. Among them, Ra (average of

Table 1. Lens Characteristics for the 5 Eyeglass Samples

	Glass 1	Glass 2	Glass 3	Glass 4	Glass 5
Blue light cut rate (%)	51.08	65.93	64.72	99.1	92.8
Visible light transmittance (%)	89.2	84.0	91.0	82.1	13.5

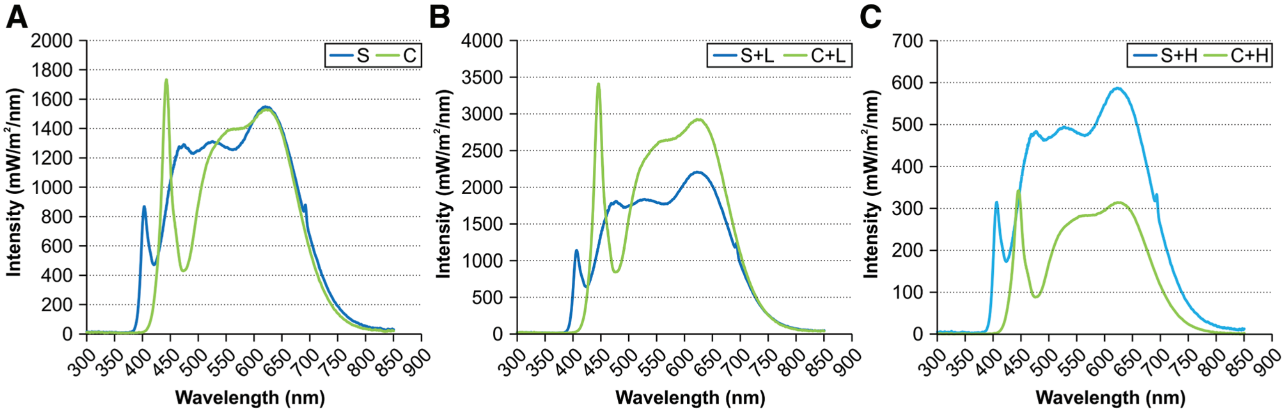

Fig. 4. Part I of the light intensity data (A) without the magnifying loupe, (B) with the low-magnification surgical loupe, and (C) with the high-magnification surgical loupe. C, CRYSTAL; S, SKYLED.

R1–R8), R9 (deep red), R13 (Westerners' skin color), and R15 (Japanese skin color) are important color indexes for medical use.

Under the CRYSTAL lamp, the personal computer (PC) glasses showed the best color rendering. Under the SKYLED lamp, however, the PC glasses had the second worst color rendering. The original clear glasses, light yellow-tinted glasses, and conventional sunglasses showed excellent color rendering. Under both surgical lamps, the dark yellow-tinted glasses showed consistently poor results.

DISCUSSION

The use of LEDs has been widely accepted in daily life and in the medical field. The Pacific Northwest National Laboratory report demonstrates an estimated 49% average energy reduction by switching to LEDs.[5]

Photoreceptors are damaged by light, but the severity of the injury depends on several factors, such as the intensity, duration, intermittence of light, and spectrum.[6] More than 45 years ago, blue light was recognized to induce retinal damage through photochemical processes.[7] Moreover, LED light contains higher proportions of blue light and is more likely to cause problems.[1] Other determining factors include the gaze direction, lens characteristics, iris pigmentation, and pupil diameter.[8–14] By pupil constriction, lid squinting, and eye movement, the eye naturally shields itself from intense light being focused onto the retina. Blue light illuminates our visual world and is also responsible for nonvisual functions such as circadian rhythms involved in sleep/wake cycles as well as cognitive performance and feelings of well being. Overexposure to blue light can also reportedly result in general diseases (eg, breast cancer).[15]

In medical fields, surgeons could be more influenced by lighting conditions because of irregular working schedules and intensive lighting. When the light is too bright, their eyes are no longer able to reduce their pupil size to protect the retina.

Moreover, surgeons have to focus on the intensely illuminated surgical field. The use of water can increase reflection and glare. Studies showed that cold LEDs emitted about 3–4 times as much energy in the blue-light spectrum as warm LEDs.[17] Lights with a relatively high content of blue light are more likely to generate glare-causing eye strain.[16,17] The accumulated knowledge of blue-light hazards has accelerated the use of LBLEDs in surgical shadowless lamps.

From our investigation, conventional LEDs (CLEDs) and LBLEDs have different spectra, energy distributions, and color rendering. The CRYSTAL lamp has CLEDs, which use blue LEDs with green and red phosphors, whereas the SKYLED lamp utilizes LBLEDs, which have purple LEDs with red, green, and blue phosphors to produce less-blue light and better color rendering. The percentage of blue light (380–460 nm range/380–780 nm range) has a similar value between the 2 lamps, but the peak and the absolute value are much higher under the CRYSTAL lamp.

We then compared the effects of the eyeglasses to which the loupe is attached. Both the illuminance (lx) and irradiance (W/m²) are higher with the low-magnifying loupe. Under the CRYSTAL lamp, from a color-rendering viewpoint, the PC glasses have the best performance. In particular, considering the light spectrum curve, the PC glasses lower the energy curve compared with other sample eyeglasses, excluding conventional sunglasses (Fig. 5).

Under SKYLED conditions, the original clear glass and light yellow-tinted glass seem to provide better options for better color rendering, though the energy curve is higher in the original than in light-yellow eyeglasses (Fig. 5). The conventional sunglasses have relatively good color rendering (Fig. 7), but they restrict too much light.

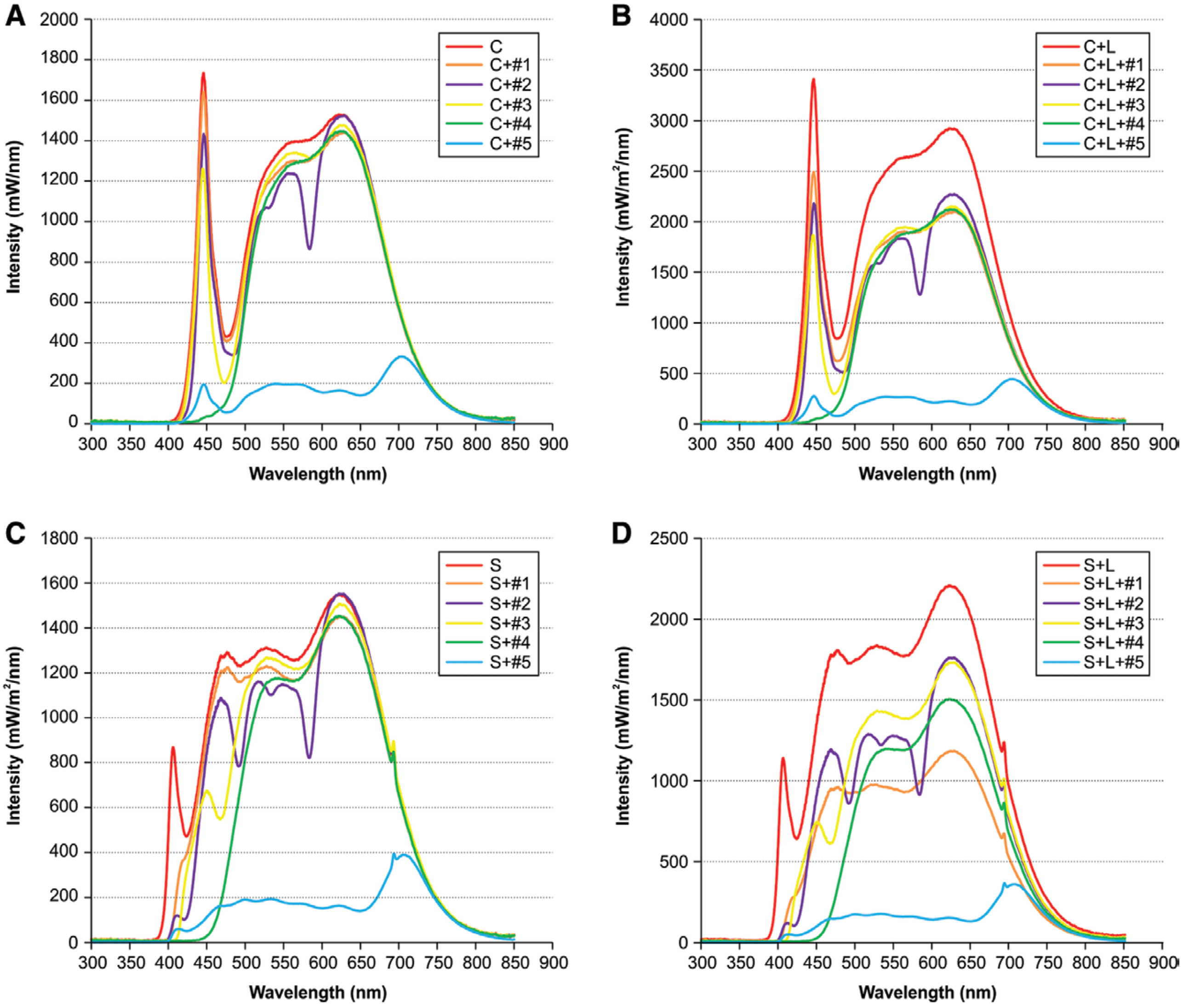

Fig. 5. Part II of the light intensity data for (A) the CRYSTAL surgical lamp with and without glasses (C + #1, 2, 3, 4, or 5), (B) the CRYSTAL surgical lamp and the low-magnification loupe with and without glasses (C + L + #1, 2, 3, 4, or 5), (C) SKYLED with and without glasses (S + #1, 2, 3, 4, or 5), and (D) SKYLED and the low-magnification loupe with and without glasses (S + L + #1, 2, 3, 4, or 5).

Even among eye professionals, the visual benefits of blue-blocking intraocular lenses (IOLs) are still under debate. Recent research found that contrast sensitivity and color vision improved with blue-blocking IOLs in diabetics,[18] whereas earlier research found that blue-blocking IOLs reduce scotopic sensitivity in aging individuals.[19] Bradnam et al[20] reported that when clear lenses were used with an indirect ophthalmoscope, the threshold limit values were exceeded after approximately 2.5 minutes. However, when a yellow lens was used, the ‘‘safe’’ operating period was increased by a factor of approximately 20.[20]

The Chesapeake Bay Waterman Study and the Beaver Dam Study found that advanced age-related macular degeneration was more common in men exposed to increased levels of blue light than those with increased levels of ultraviolet exposure.[21,22] On the other hand, the Pathologies Oculaires Lieesa l’Age study found no relationship between light exposure and age-related macular degeneration.[23]

Photochemical damage from blue light is proposed to emanate from a given amount of light, regardless of whether that amount of light is absorbed over a brief or extended period of time.[24] The effect of cumulative light exposure is not purely additive. Dose fractionation can produce a more severe effect than the same total duration of illumination without interruptions.[6] This fractionation is a possible concern for surgeons working under high luminance who operate on multiple patients during the work day.

On the other hand, recovery from phototoxic retinal damage has been shown in several

Table 2. The Light Spectrum Distribution (380–460–780 nm) Affected by the Light Source and Eyeglass Combinations

					SKYLED +	
A	**CRYSTAL**	**CRYSTAL + low magnification**	**CRYSTAL + high magnification**	**SKYLED**	**Low magnification**	**High magnification**
380–460 (mW/m^2)	37.54	75.77	7.73	46.01	62.42	1.77
Percentage of the 380–780 nm area	11.25	11.91	11.44	12.16	11.75	10.06
460–780 (mW/m^2)	296.15	560.44	59.85	332.33	468.8	15.83
Percentage of the 380–780 nm area	88.75	88.09	88.56	87.84	88.25	89.94
380–780 (mW/m^2)	333.69	636.21	67.58	378.34	531.22	17.6
B: CRYSTAL	**CRYSTAL**	**CRYSTAL + #1**	**CRYSTAL + #2**	**CRYSTAL + #3**	**CRYSTAL + #4**	**CRYSTAL + #5**
380–460	37.54	35.8	28.24	26.86	1.21	4.39
Percentage of the 380–780 nm area	11.25	11.39	9.55	8.83	0.46	7.37
460–780 (mW/m^2)	296.15	278.38	267.32	277.32	262.09	55.15
Percentage of the 380–780 nm area	88.75	88.61	90.45	91.17	99.54	92.63
380–780 (mW/m^2)	333.69	314.18	295.56	304.18	263.3	59.54
C: SKYLED	**SKYLED**	**SKYLED + #1**	**SKYLED + #2**	**SKYLED + #3**	**SKYLED + #4**	**SKYLED + #5**
380–460 (mW/m^2)	46.01	31.92	23.18	22.08	1.09	4.32
Percentage of the 380–780 nm area	12.16	9.25	7.17	6.74	0.39	6.38
460–780 (mW/m^2)	332.33	313.08	300.21	305.56	276.16	63.34
Percentage of the 380–780 nm area	87.84	90.75	92.83	93.26	99.61	93.62
380–780 (mW/m^2)	378.34	345	323.39	327.64	277.25	67.66
D: CRYSTAL + low magnification (C + L)	**C + L**	**C + L + #1**	**C + L + #2**	**C + L + #3**	**C + L + #4**	**C + L + #5**
380–460 (mW/m^2)	75.77	54.32	42.99	39.86	1.62	6.19
Percentage of the 380–780 nm area	11.91	11.82	9.80	9.03	0.42	7.69
460–780 (mW/m^2)	560.44	405.37	395.84	401.54	382.09	74.27
Percentage of the 380–780 nm area	88.09	88.18	90.20	90.97	99.58	92.31
380–780 (mW/m^2)	636.21	459.69	438.83	441.4	383.71	80.46
E: SKYLED + low magnification (S + L)	**S + L**	**S + L + #1**	**S + L + #2**	**S + L + #3**	**S + L + #4**	**S + L + #5**
380–460 (mW/m^2)	62.42	24.62	24.88	24.3	1.08	3.85
Percentage of the 380–780 nm area	11.75	8.94	6.91	6.55	0.38	6.18
460–780 (mW/m^2)	468.8	250.78	335.15	346.88	282.81	58.47
Percentage of the 380–780 nm area	88.25	91.06	93.09	93.45	99.62	93.82
380–780 (mW/m^2)	531.22	275.4	360.03	371.18	283.89	62.32

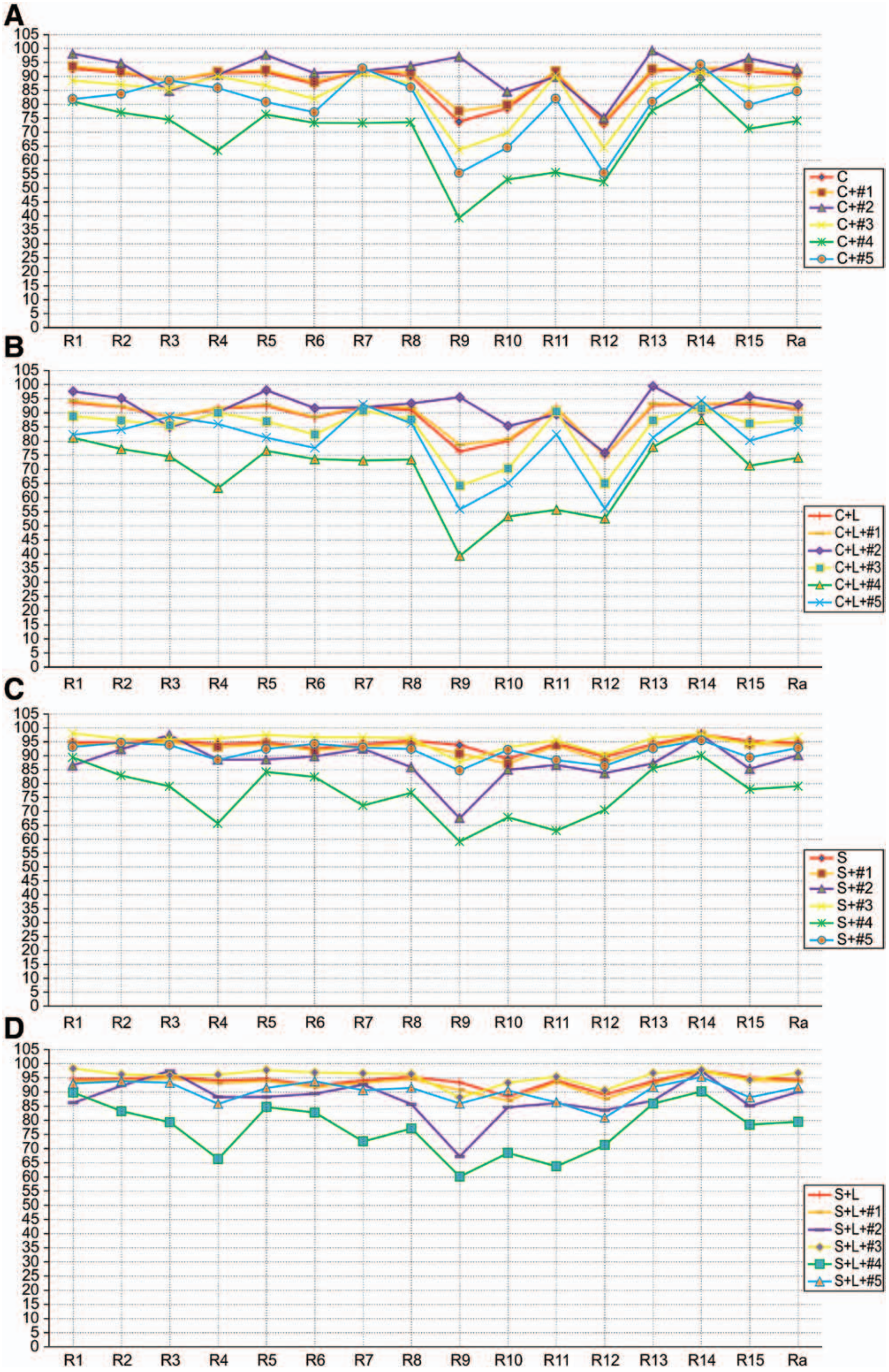

Fig. 6. The integral area of the high-magnification loupe groups is far lower than that from the other groups (no loupe and low-magnification loupe) (A). Therefore, in the following examinations, we only examined the no-loupe (B and C) and low-magnification groups (D and E). Compared with no-loupe groups B and C, low-magnification loupe groups D and E showed a sharp decrease between the no-glass and with-glass groups.

studies.[25–27] Other information suggests that damage to young and adult eyes by intense ambient light can be avoided because the eye is protected by a very efficient antioxidant system; however, after middle-age, there is a decrease in the production of antioxidants.[28]

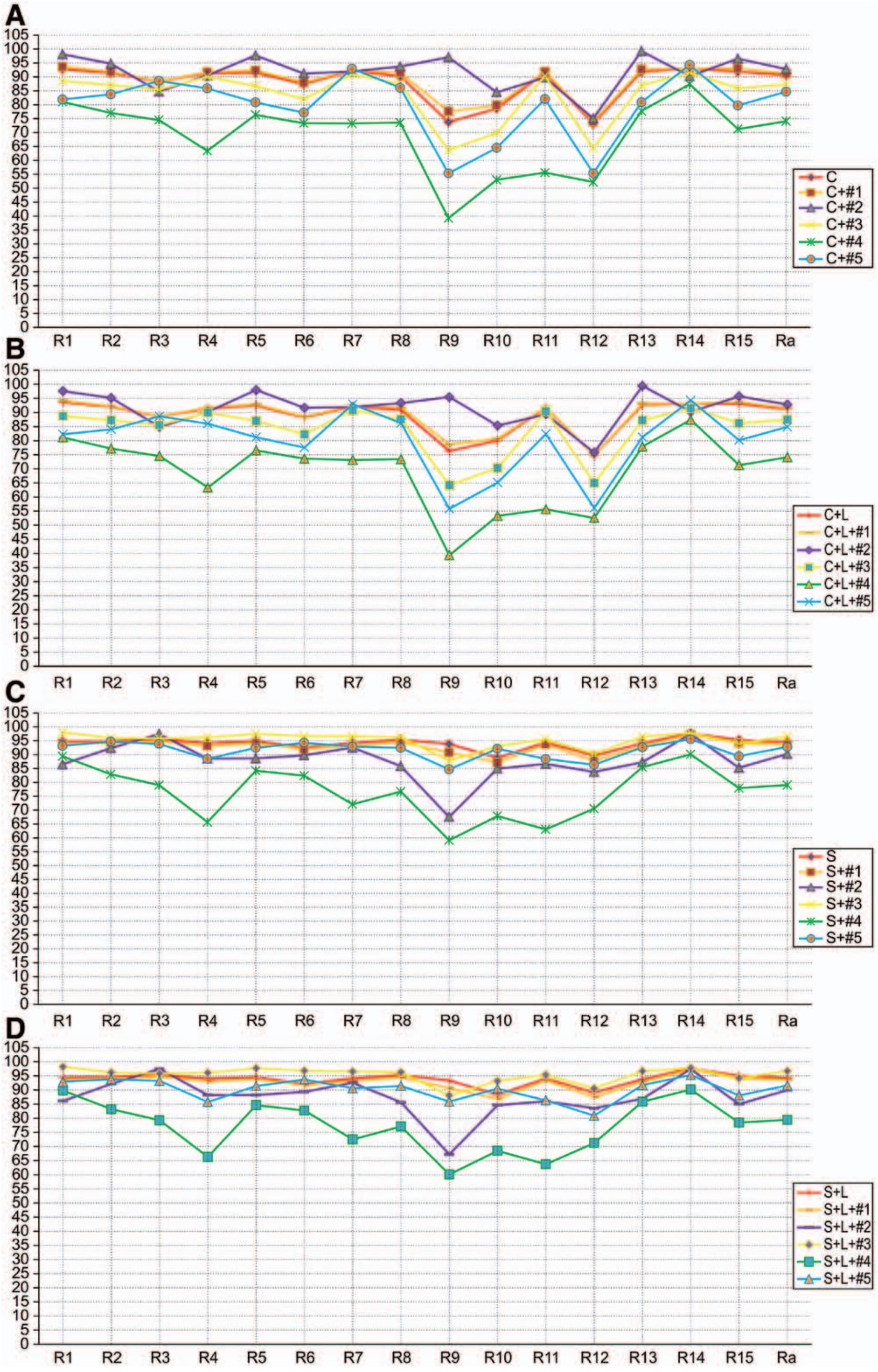

Fig. 7. The color-rendering index for (A) the CRYSTAL surgical lamp with and without glasses (C + #1, 2, 3, 4, or 5), (B) the CRYSTAL surgical lamp and the low-magnification loupe with and without glasses (C + L + #1, 2, 3, 4, or 5), (C) SKYLED with and without glasses (S + #1, 2, 3, 4, or 5), and (D) SKYLED and the low-magnification loupe with and without glasses (S + L + #1, 2, 3, 4, or 5).

The potential exists for light-induced retinal damage because of the (i) blue wavelength component, (ii) intensity of the light, (iii) duration of light use, (iv) magnification by surgical loupes, (v) glare and/or reflection, (vi) age of the practitioner, and (vii) cataracts (which can also function like sunglasses).[29]

Strictly, the light-field diameter, depth of illumination, color temperature, and nonvisible radiation likely differ between the 2 surgical lamps. Therefore, we admit this study may not provide a direct comparison between the 2 lamp types. In our study, we consider direct gaze to the light for easy comparison, which is rarely experienced in a clinical situation.

In conclusion, many medical professionals have been working under intensive OR lights. In this investigation, we compared the light characteristics and color rendering in 2 shadowless lamps (CLED and LBLED) and searched for an appropriate light filter for surgical loupes. We found that LBLED yielded better color rendering and less blue light. However, surgical lamps cannot be easily replaced because they are expensive and because the purchase is usually under the facility's control. Therefore, CLED users can use filtering glasses for little extra cost. There are many variables and unknown factors regarding blue light hazards, but we recommend that the medical community should err on the side of caution and make use of blue-light blocking eyeglasses and/or LBLEDs. In our future work, we want to find an appropriate and easily available method for surgeons to identify the appropriate combination of light source, magnifying loupe, and supporting filtering glasses.

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