Development of Safe UVB-LED Special Lighting to Support Daily Recommended Vitamin D Synthesis

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***Abstract*—**Vitamin D is an essential element for maintaining human health, most of which is met by skin exposure to UV rays in the sun. Some of the vitamin D in the body can be supplemented through diet, but the amount is known to be extremely limited. Vitamin D deficiency has become a social problem in many countries as modern people's indoor living time increases and their exposure to natural light shortens. In order to solve this problem, sun exposure is recommended. Outdoor activity guide service is provided by providing accurate UV-related information, while UV lighting technology is being developed in order to provide UV dose to indoor residents. However, these methods have limitations in directly supporting adequate UV doses for those who have difficulty in carrying out outdoor activities, whereas UV lighting does not provide accurate safety information about exposure. In this paper, a UVB-LED special lighting that supports indoor residents to meet a daily recommended UVB dose is proposed. First, the UVB-LED light source that can achieve an optimal UVB dose is selected. Its lighting characteristics are measured and analyzed and then a combination and control condition of the light source that can safely provide UVB dose are derived. After a stand type lighting equipment considering ease of use is designed, a UVB-LED special lighting that meets the photobiological safety standard of lighting (Risk Group 2) is developed. The expected amount of vitamin D synthesis by distance and use duration are calculated through a performance test for the proposed lighting. The test results show that when the proposed lighting is used at a distance of 20cm for 33-40 min, the daily recommended vitamin D synthesis can be achieved.

***Keywords*—** Daily Recommended Vitamin D, Safe UVB-LED, Special Lighting, UVB-LED, Vitamin D.

I. Introduction

As modern men aware more about health, interest in vitamin D, which is an essential element for maintaining human health, is also increasing [1]. Vitamin D plays a role in regulating the absorption of calcium and phosphorus in the body, thereby contributing to the development of the skeleton and muscles of the body [2]. Vitamin D is also important in the production and secretion of hormones [3]. Therefore, it is vital to maintain an optimum amount of vitamin D in the body to keep it healthy. This vitamin D, unlike general nutrients, is supplied by synthesis in the skin after exposure to the UV rays of sunlight [4] and can be supplemented by diet in a limited amount [3]. Hence, it is necessary to expose oneself to UV through outdoor activities in order to synthesize vitamin D which is essential to human health. Recently, however, the number of persons who stay longer indoors has been increasing due to changes in life patterns and working conditions and their exposure to the sunlight has become shorter [5]. Consequently, large numbers of populations having vitamin D deficiency are increasing in many countries [6]. In Korea, more than 70% of men and 80% of women have deficiency in vitamin D in winters and springs [7]. Various efforts are being made to resolve issues in UV exposure deficiency and consequent vitamin deficiencies. Some have proposed optimal time for outdoor activities according to UV intensity by region to prevent vitamin D deficiency [8]. Attempts to provide adequate UV dose through artificial lighting beyond the method of ultraviolet exposure under natural light have been also continued. Meanwhile, special purpose UV, such as treatment using fluorescent light type UV source, is proposed by P company [9], and skin treatment using lighting instruments and methods of providing UV dose are also introduced [10]. However, vitamin D synthesis from natural light cannot be a direct solution for the indoor residents who cannot easily afford outdoor activities. Previously developed UV luminaires also provide only uniform UV doses and cannot provide accurate information for the safety of UV luminaires and adequate exposure of UVB dose.

Therefore, this paper proposes a UVB-LED special lighting that supports meeting the daily recommended vitamin D for users indoors who lack exposure to UV in the natural light. First, a UVB-LD light source that can provide an optimal UVB dose is selected and the characteristics of light sources are measured and analyzed using a spectrometer. In addition, the design and control condition of the proposed lighting are derived through analyzing UVB dose and transmission rate according to different input currents and adoptions of cover for the light sources. Subsequently, a stand type UVB-LED special lighting, considering safety and use convenience, is developed and risk assessment is carried out for the UVB light source based on the photobiological safety assessment standard for the lighting. The possibility of supporting vitamin D synthesis by individual through the proposed lighting is also evaluated.

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II. Test for Characteristics of Light of UVB-LED Special Lighting

Lighting sources and an environment, wherein characteristics of light for the lighting can be measured, are established to develop the UVB-LED special lighting proposed in this paper. A test was carried out for determining Erythemal-weighted UV (EUV) according to input current and measuring the transmission rate of UVB dose to select the cover (diffuser) material to apply to the UVB-LED light source.

Basic Test for UVB-LED Light Source

In order to develop a UVB-LED special lighting that provides a safe and adequate amount of UVB light to indoor residents, a test for characteristics of light for the UVB-LED light source candidates was performed. The testing environment to measure and analyze the light sources was established as shown in Figure 1. In addition, equipment used for measuring characteristics of light and subjected light sources are described in Table 1.

Fig. 1 Testing environment

Table 1. Measuring equipment and subjected light sources

Image	Features(Detail)
 Spectrometer	CAS 140CT (Instrument Systems) Measurement Range: 200~800nm
 Light Source	UVB LED (6060,LG-Innotek) Output : 20mW Current : 350mA

Figure 1 shows the lighting cabinet (120cm×120cm×200cm) that can block the external light. In addition, the spectrometer used for the test as shown in Table 1 is capable of measuring a wavelength range of ultraviolet ray (200-400nm) related to human vitamin D synthesis and was installed at the bottom of the lighting box. The light source used in the test was a commercial product from L company and had an output capacity of 20mW. The UVB-LED that can control the intensity of output by adjusting input current (max. 350mA) was selected. During the measurement of UV light, the UVB-LED light source was installed at the top of the lighting box. The distance from the light source was maintained at 20cm, which is a standard measurement distance from the light source to the measuring equipment during assessment of photobiological safety for the special lighting. The optical characteristics of the UVB-LED light source was measured for a total of seven stages by increasing the input current by 50mA each in the range of 50-350mA using a power supplier. The measured values were used to calculate the intensity of Erythemal-weighted UV irradiance (EUV) reflecting the effect of UV on the human body. Equation (1) was applied to calculate the spectral irradiance of measured UV (200-400nm) waveband with erythrocyte weight [11].

$$EUV = \int_{250}^{400} E(\lambda) S_{er}(\lambda) d\lambda, \qquad (1)$$

$S_{er}(\lambda)$: Erythemal weighted function

In Equation (1), the weighted value defined in CIE was applied in the action spectrum in weight ($S_{er}(\lambda)$) [12]. The measurement results of the EUV by input current for the UVB-LED light source are as shown in Table 2.

Table 2. EUV by input current of the UVB-LED light source

Current[mA]	UV [W/m^2]	EUV [W/m^2]
50	0.029	0.005
100	0.057	0.011
150	0.086	0.016
200	0.113	0.022
250	0.14	0.027
300	0.165	0.031
350	0.19	0.035

From Table 2, it was confirmed that UVB dose can be controlled by adjusting the input current for the UVB-LED light source. In addition, the proposed UVB-LED special lighting should be able to provide UVB dose that meets the daily recommended vitamin D for the users within a limited time. Therefore, the output condition of UVB dose of the proposed lighting was derived by calculation equation for the expected vitamin D synthesis according to EUV as in Equation (2) [13]. Here, VitaminD is the amount of vitamin D synthesis and was set to 400IU which is the recommended vitamin D synthesis. MED is the skin type and was set to III considering Asians. The exposed area (Earea) was set to 20%, and the exposed time (Etimes) was set to 30 min. The required EUV in order to achieve the amount of vitamin D synthesis 400IU was calculated [13].

$$EUV[W/m^2] = \frac{VitaminD \times MED[J/m^2]}{Etime[s] \times Earea[\%] \times 40IU} \qquad (2)$$

The output condition of the proposed lighting calculated with Equation (2) indicated that the EUV was more than 0.083mW/m^2 and more than three UVB-LED light sources should be provided in order to support the daily recommended vitamin D synthesis. However, four 20mW UVB-LED light sources were found to be optimal in order to provide UVB dose for a broader area uniformly.

Experiment on Transmittance of UVB and Irradiance Angle of the Light Source

In general, when LED lighting is developed, a diffuser or cover shields the lighting source (or illuminators) to render light diffused and to protect the light source [14]. Therefore, an additional test was performed to select and fabricate the cover (or diffuser) of the proposed lighting. For this purpose, the transmittances of diffuser, general glass, and quartz glass, which are known to have excellent transmittance of UVB, were compared. The transmittances of various cover materials are illustrated in Figure 2.

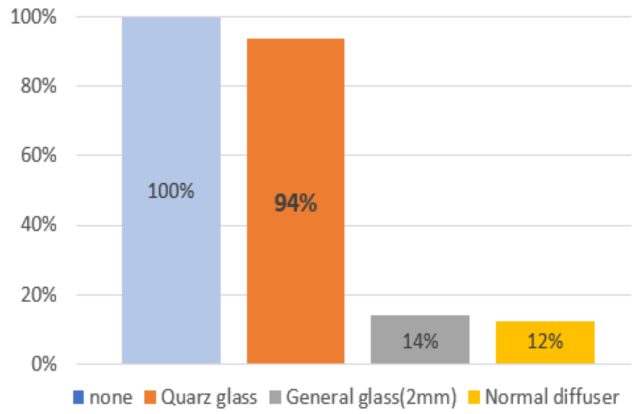

Fig. 2 Transmittance test for fabricating the cover

The results in Figure 2 indicated that the UVB transmittances of acrylic diffuser and general glass that are implemented in the general lighting were very low (below 5%). However, the UVB-LED output dose of more than 90% could be provided by using quartz glass. Furthermore, the UVB doses were measured at ranges of 15°, 30°, and 45° from the vertical bottom to provide uniform UVB dose by the proposed lighting. The irradiances were compared, and the results are illustrated in Figure 3.

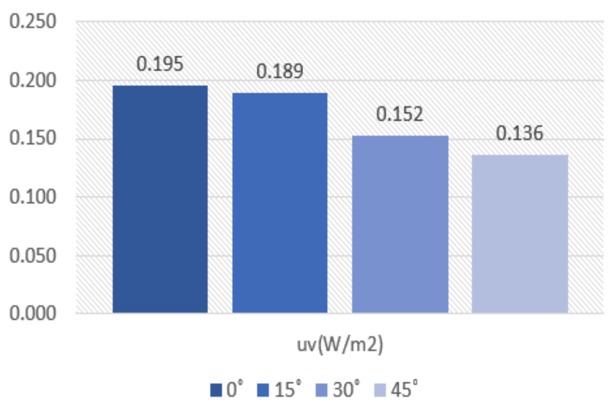

Fig. 3 Test for irradiance angles of UVB-LED lighting

From Figure 3, it was confirmed that the UVB-LED lighting can provide more than 90% of UVB-LED output dose within a range of ±15° of irradiance angle from the vertical bottom from the light source and more than 80% in a range of ±30°.

III. Development of UVB-LED Special Lighting

A UVB-LED special lighting that supports the daily required vitamin D synthesis was developed by exposing in a limited time the indoor residents based on the preliminary experiment for the UVB-LED light source conducted previously.

Design and Development of UVB-LED Special Lighting

After deriving a combination of the light sources through the test for characteristics of light according to input current for the UVB-LED light source, the test results of UVB transmittance by the cover materials, as well as irradiance angles, were applied to design the proposed lighting for supporting daily recommended vitamin D synthesis. The design result is as shown in Figure 4.

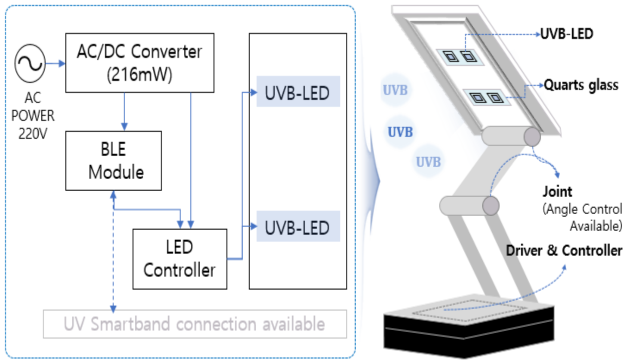

Fig. 4 Designing of the special lighting for supporting vitamin D synthesis

The proposed lighting to support vitamin D synthesis was fabricated with the UVB light source to provide a safe UVB dose, the power to drive the lighting, and the quartz glass cover that can transmit UVB wave in place of the diffuser of the general lighting as in Figure 4. UVB light sources were arranged two each at the top and bottom of the light sources of 20mW UVB-LED that was the combination of the light sources derived from the test in 2.1. BLE-based wireless modules were loaded to support communication with other devices like smart phone or smart band in the future. LED controller was also implemented for turning the UVB-LED light modules ON-OFF. In addition, quartz glass (45mm*18mm) that can transmit the UVB dose was made as a cover of the UVB light source. Multiple holes were processed at the rear case of the UVB-LED light source to enhance heat discharge. The UVB-LED light modules had two joints capable of moving up to 180° so that UVB could be easily irradiated on the skin of hands, back of hands, and upper body of the user. Figure 5 shows the front, as well as side, of the UVB-LED special lighting.

Fig. 5 Developed UVB-LED special lighting

Evaluation of Photobiological Safety of UVB-LED Lighting

Photobiological safety assessment for the lighting was conducted to check if safe UVB dose is provided by the special lighting developed in 3.1. The photobiological safety assessment of the lighting (IEC 62471 Photobiological Safety of Lamps and Lamp Systems) is a standard to classify hazardous level of lighting and to assess the safety for each item into four groups for seven risk items of the lighting based on the measurement and calculation results [15]. The safest grade is classified as “Exempt,” and “Risk Group 3” indicates high risk. The risk items, according to the implementation of UVB light source, include the Actinic UV hazard radiation (AUV) and Near UV hazard radiation (NUV). Table 3 shows the limit of emitting UV for each item.

Table 3. Classification standard for emission limit for UV-related items in IEC 62471

Risk group	UV risk item (W/m^2)		Details
	AUV	NUV	
Exempt	0.001	10	No photobiological hazard even with continuous use of lighting
Risk Group 1	0.003	33	No photobiological hazard under normal behavioral limitations except for very long exposure
Risk Group 2	0.03	100	Does not pose a hazard under limited exposure
Risk Group 3	0.03≤	100≤	Hazardous even for momentary exposure

In Table 3, Exempt, which is the safest grade of lighting, includes a range AUV $0.001W/m^2$ or -lower than NUV $10W/m^2$ while the riskiest grade Group 3 has a range of AUV $0.03W/m^2$ to higher than NUV $100W/m^2$. In “Exempt” and “Risk Group 1,” there is no limitation of use duration, but “Risk Group 2” is classified as safe if use duration is limited. “Risk Group 3” is classified as hazardous even for a momentary exposure. In this paper, the development of a special lighting equivalent to “Risk Group 2” is aimed so that vitamin D synthesis can be supported when exposed to the lighting for a specific duration. For that, the AUV and NUV that are UV-related items of photobiological safety standard for the lighting for the developed lighting modules were measured and calculated. As for AUV, it was integrated and then calculated by means of Equation (3) after application of the Actinic UV weighting function by wavelength to the spectral radiance in the wavelength range 200nm-400nm [16].

$$AUV = \int_{200}^{400} E(\lambda) S_{ac}(\lambda) d\lambda, \qquad (3)$$

λ: Wavelength, $E(\lambda)$: Spectral Irradiance

$S_{ac}(\lambda)$: Actinic UV hazard weighting function

NUV was calculated by integrating spectral irradiance in the wavelength range of 315nm-400nm as in Equation (4) [18].

$$NUV = \int_{315}^{400} E(\lambda) d\lambda \qquad (4)$$

However, spectral irradiance for the lighting modules in the experiment was measured under the testing environment as in 2.1. The input current into the UVB-LED light source was increased by 5mA in the range of 5mA-350mA while measuring the spectral irradiances. The AUV and NUV were calculated and the results are shown in Figures 6 and 7.

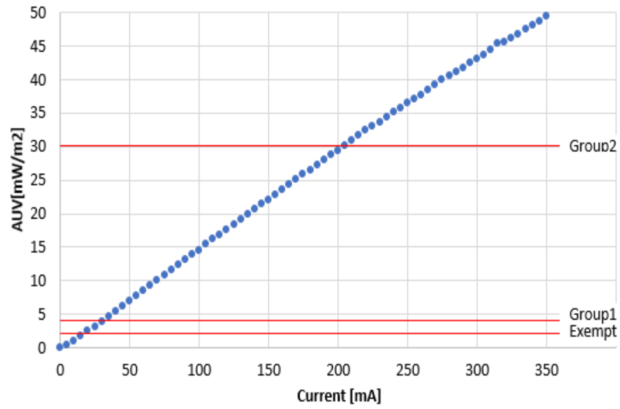

Fig. 6 AUV by input current for proposed lighting

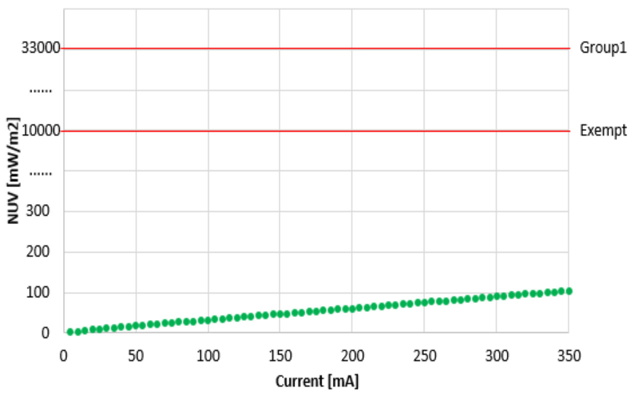

Fig. 7 NUV by input current for proposed lighting

In Figure 6, when the current was input at maximum (350mA) in the experimental lighting modules, the AUV was out of Group 2, but the NUV fell under the safest group (Exempt) in all the ranges. The results in Figures 6 and 7 were analyzed and input current method that complies with the exposure limit standard for each safety grade was derived. The results are tabulated in Table 4.

Table 4. Input current condition for UV hazardous items

Risk group	Input Current [mA]	AUV [W/m^2]	NUV [W/m^2]
Exempt	8	0.0009	0.0031
Risk Group 1	23	0.0028	0.0087
Risk Group 2	203	0.0299	0.0619

In Table 4, the proposed lighting fell under "Exempt" since AUV became 0.0009W/m^2 when the current 8mA was input, while AUV became 0.0299W/m^2 when the current of 203mA was input; therefore, it met "Risk Group 2." The NUV with all the current input condition met the condition of "Exempt." It could be concluded that the proposed lighting could realize "Risk Group 2" in the photobiological safety standard for lighting when the input current was set to 216mA(±5mA), considering the transmittance of quartz glass cover.

Performance Evaluation of UVB-LED Special Lighting

A test was conducted to check the supporting function of the proposed UVB dose for vitamin D synthesis during a limited time for indoor residents. The UVB dose was increased by 10 cm in a range of 20-50 cm in the lighting cabinet while measuring the spectral irradiance of the proposed lighting by distance. The results are shown in Figure 8.

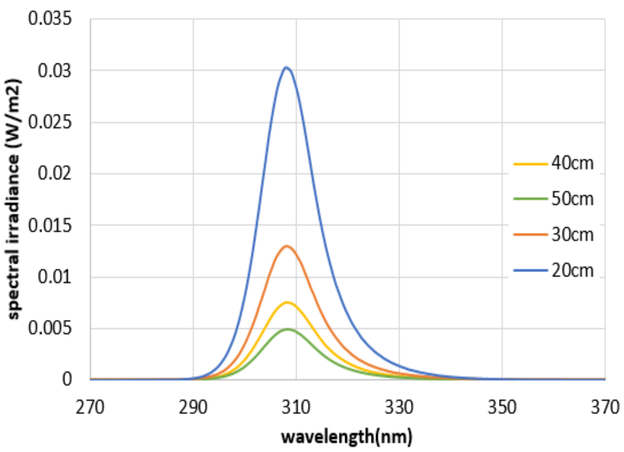

Fig. 8 Spectral Irradiance of proposed lighting by distance

Figure 8 shows the spectral irradiance of the proposed lighting by distance. The spectral irradiance values were converted to EUV whose effectiveness to the human body was reflected. The expected amount of vitamin D synthesis by distance and exposed time from the lighting were met (considering that an adult with skin type 3 had 20% of his/her skin exposed) and was calculated, with the results shown in Table 5. The expected amount of vitamin D synthesis was calculated using Equation (5) below [13].

$$VitaminD = \frac{EUV[W/m^2]\times Etime[s]\times Earea[\%]\times 40IU}{MED[J/m^2]} \quad (5)$$

Table 5. Expected amount of vitamin D synthesis by distance/time with the proposed lighting (Unit : IU)

Distance	EUV (W/m^2)	Exposure time(minutes)				
		20	30	40	50	60
20Cm	0.0756	242.02	363.02	484.03	605.04	726.05
30Cm	0.0323	103.44	155.16	206.88	258.6	310.33
40Cm	0.0184	58.91	88.36	117.81	147.27	176.72
50Cm	0.012	38.39	57.58	76.77	95.97	115.16

As indicated in the calculation results of expected amount of vitamin D synthesis in Table 5, the daily recommended vitamin D synthesis of 400IU for adult can be achieved when an adult is exposed from about 20 cm distance for 33-40 min. In addition, it was confirmed that it can support the synthesis of vitamin D at a distance of 30-50.

IV. Conclusion and Future Research Direction

Recently, many persons have been staying indoors and have been lacking exposure to sunlight, with vitamin D deficiency posing as an issue. In this paper, a UVB-LED special lighting that supports daily recommended vitamin D synthesis was developed through exposure to lighting for a specified duration for the person lacking in UV exposure. The characteristics of light for the UVB-LED light source from L company, which were capable of providing UVB dose according to different input currents, were measured and analyzed. The results were used to draw a combination of light sources for the proposed lighting. The transmittance experiment was conducted with different cover materials necessary to physically protect the light source and to diffuse the light. A stand type UVB-LED special lighting was designed so that UVB-dose could be easily provided to the indoor residents. Another experiment was performed to realize "Risk Group 2" that ensures the safety of users when the proposed lighting was used for a limited time in the photobiological safety assessment for providing safe UVB dose. The UVB-LED special lighting was then developed using an input current of 216mA (±5mA) drawn from the safety assessment. The expected amount of vitamin D synthesis was calculated according to the distance from the light source (20-50cm) and exposed time (20-60 min.) to check the effectiveness of the proposed lighting. The test results confirmed that when the UVB-LED special lighting was irradiated at a distance of about 20cm for 33-40 min., daily recommended vitamin D synthesis could be supported.

In the future, research should be carried out for systemization of the UVB-LED special lighting that can be linked with a smart band or smart phone capable of measuring and controlling UV. In addition, parties could pursue service improvement of the proposed lighting, enabling differentiated UVB-dose and considering the skin type of users or exposed body area.

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