# Factors Affecting the Efficiency of Phototherapy Devices for Treating Neonatal Jaundice

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## ABSTRACT

**Phototherapy devices play a crucial role in the treatment of neonatal jaundice in hospitals across Thailand. Adherence to appropriate standardized guidelines for phototherapy use is essential to ensure that treatment outcomes align with medical plans. This study highlights the importance of the engineering processes involved in preparing phototherapy devices prior to treatment. The findings reveal significant variations in irradiance levels of phototherapy devices during continuous use. It is recommended that the preparation process in hospitals should include regular monitoring of the irradiance levels from phototherapy devices. Establishing standardized protocols for preparation and ensuring strict implementation would not only enhance the overall effectiveness of phototherapy in treating neonatal jaundice but also contribute to the development of safer and more consistent treatment practices for infants.**

***Keywords-jaundice, phototherapy, irradiance from phototherapy***

## I. INTRODUCTION

Neonatal jaundice in Thailand can be divided into two main groups: term neonates, who make up about 60% of all term births, and preterm neonates, among whom jaundice affects up to 80%. Analysis of birth records shows that both groups have a significantly high risk of developing jaundice [1]. Jaundice arises due to the continuous breakdown of red blood cells, leading to the production of bilirubin, a yellow pigment processed by the liver into a more water-soluble form for excretion via feces or urine. However, in some neonates, hepatic immaturity impairs bilirubin clearance, resulting in its excessive accumulation in the bloodstream. The clinical manifestation of this accumulation is the yellow discoloration of the skin, a hallmark of neonatal jaundice. The principal concern regarding this condition is the potential neurotoxicity of bilirubin when it crosses the blood-brain barrier, leading to kernicterus, a severe form of bilirubin encephalopathy [2]. Neonates with jaundice often present lethargy, poor feeding, hypotonia, and an inability to maintain head control. If untreated, progressive symptoms include hypertonia, opisthotonus, persistent refusal to feed, fever, and seizures. Severe cases may culminate in respiratory failure and mortality, while survivors may suffer from long-term neurological impairments [3].

In Thailand, neonates diagnosed with jaundice or those at risk of developing the condition undergo initial clinical assessment by physicians based on physical examination. The appearance of jaundice on the face, sclera, trunk, and limbs prompts further laboratory investigation via serum bilirubin measurement. If bilirubin levels exceed the threshold for treatment, hospitalization is required for close monitoring and intervention. The primary objective of treatment is to prevent bilirubin neurotoxicity by maintaining serum bilirubin levels within a safe range. The most widely adopted therapeutic modality is phototherapy, which facilitates bilirubin degradation into a more excretable form [1-4]. Phototherapy is the first-line treatment due to its safety and efficacy. However, in cases of severe hyperbilirubinemia, exchange transfusion may be necessary to rapidly reduce bilirubin levels. Although transfusion is the most effective method for bilirubin clearance, it carries significant risks, including hemodynamic instability and infections. Pharmacological interventions are also available but require prolonged administration and are generally reserved for refractory cases. Among these three treatment modalities, phototherapy remains the preferred choice in Thai hospitals due to its non-invasiveness and high safety profile [5].

Although using light to treat jaundiced infants is an effective method, it still carries risks. Based on related research, there is a concept regarding the control of light energy that can be delivered into human tissue or the brain. This is especially important when considering the thinness of the skin or skull in both newborns and adults. If too much light energy is received, it can lead to side effects such as heat accumulation or skin irritation. This concept aligns with studies on the Specific Absorption Rate (SAR) of RF waves in human tissue layers such as skin, fat, bone, and the brain. The objective is to control the level of penetration of energy into the body to ensure that it remains at a safe level. This approach supports research into determining the appropriate light intensity for phototherapy devices used for infants [6]. To safely control the properties of light for biological effects, research has explored various materials, such as ZnO thin films. A study on ZnO thin films responsive to light in the 400-600 nm range demonstrated that nickel doping can significantly increase light absorption at 450 nm, and this effect diminishes at excessive concentrations [7]. This reflects the same concept as phototherapy, where light intensity must be controlled within an optimal range, neither too much nor too little.

Phototherapy utilizes specific wavelengths of light to convert bilirubin into photoproducts that can be excreted more efficiently. International research indicates that the efficacy of phototherapy begins at an irradiance level of 4 μW/cm²/nm and plateaus at 50 μW/cm²/nm [8]. The optimal wavelength range for phototherapy has been identified as 450-480 nm (blue-green spectrum), with recent advances favoring wavelengths around 476 nm over the conventional 460 nm due to superior bilirubin-reducing capacity. However, individual variations such as hematocrit (HCT) levels influence phototherapy effectiveness, as elevated hemoglobin concentrations can compete for light absorption, necessitating case-specific treatment adjustments [9]. Research in Thailand has primarily focused on developing prototype phototherapy devices and evaluating different light sources. A comparative study demonstrated that LED T8 (9W) phototherapy units deliver an average irradiance of 12.14 μW/cm²/nm, outperforming fluorescent T8 (18W) units, which provide 9.73 μW/cm²/nm [10]. Additionally, studies on high-intensity double-sided phototherapy for neonates with G6PD deficiency-associated jaundice indicate superior bilirubin reduction compared to single-sided phototherapy, with an optimal irradiance of approximately 30 μW/cm²/nm [11]. Further research on fluorescent and LED phototherapy devices has demonstrated that blue or blue-green light within the 400-520 nm range, positioned 10-15 cm from the neonate, enhances treatment efficacy. High-power LED devices with an irradiance range of 28.80-60.70 μW/cm²/nm have been developed, showing an average effective irradiance exceeding 30 μW/cm²/nm [12].

Neonatal jaundice remains a prevalent condition in Thailand, particularly among preterm infants. Phototherapy remains the cornerstone of treatment due to its safety and effectiveness. Continued research into optimizing phototherapy parameters and developing advanced light sources holds promise for improving neonatal outcomes and reducing the incidence of bilirubin-induced neurological dysfunction.

## II. DEVICE OVERVIEW

This research focuses exclusively on the study of phototherapy devices used for treating neonatal jaundice and does not involve direct interaction with neonates in any capacity. The phototherapy devices investigated include those utilizing various light sources, such as fluorescent lamps and LED (blue light) technology. Light emitted from the phototherapy lamp is directed onto the neonate's skin, with a typical distance between the light source and the infant ranging from 30 to 50 cm [8, 13]. Data collected on phototherapy usage in Thailand indicates a consistent trend, regardless of whether fluorescent or LED-based devices are used. The therapeutic wavelength range for neonatal jaundice treatment falls within the blue-green spectrum (450-480 nm) or at an irradiance level of 30-35 μW/cm²/nm, with an optimal lamp-to-infant distance of 25-50 cm, facilitating the most effective bilirubin reduction [1-5]. Conversely, phototherapy devices operating at a lower irradiance level of 4-8 μW/cm²/nm have also been documented. Although these lower irradiance levels can still contribute to bilirubin reduction, the process occurs at a significantly slower rate. However, when the irradiance level falls below 4 μW/cm²/nm, the treatment becomes ineffective in reducing bilirubin levels in neonates [13].

This study collected data on the levels of light wavelength (radiation emitted by the light bulbs used in phototherapy), the distance of the light source from the infant, and the operational hours of the phototherapy devices. The findings provide insights into the light intensity levels of phototherapy machines based on eight related research studies. Additionally, it reveals the light intensity levels used in ten hospitals across Thailand, highlighting any similarities or differences in the intensity or duration of phototherapy application. These findings help establish guidelines for appropriate light-intensity usage to enhance the safety of phototherapy treatments for infants with jaundice.

Eight research studies were identified to report light intensity levels. However, no studies specified the duration of phototherapy. Table I presents studies on infant phototherapy treatment that have determined the wavelengths of light and the height of the light therapy device. The recommendation is that the light intensities should not be lower than 8.80 μW/cm$^2$/nm [8]. The highest light intensities were found at 84.80 μW/cm$^2$/nm [14]. However, recommendations for the use of high light intensities have not been clearly specified, but there is one for the use of high radiation at 476 nm. If the radiation value is exceeded, the effectiveness of the light therapy device will gradually decrease [9]. Considering the safety, especially the possible risks to infants, it was found that the risk of encephalitis [15] and leukemia [10] is low. Therefore, it is recommended to use an appropriate value for light therapy to minimize unnecessary exposure.

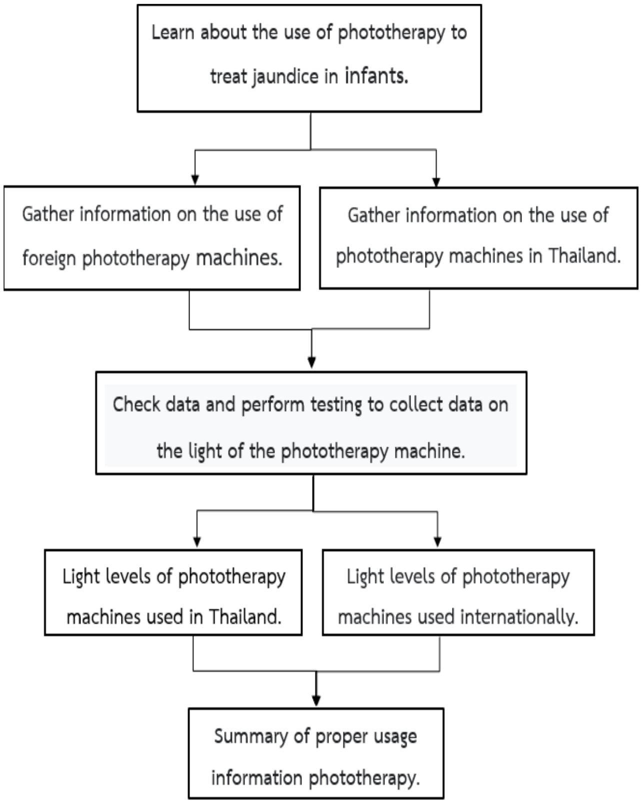


Fig. 1. Summary of the steps involved in studying the use of phototherapy machines.

TABLE I. DATA ON THE USAGE OF PHOTOTHERAPY

| Radiation (nm) | Irradiance (µW/cm²/nm) | Time used (hrs) | Reference |
|---|---|---|---|
| n/a | 30.00 | n/a | [8] |
| n/a | 23.00-84.80 | n/a | [16] |
| 460 | n/a | n/a | [17] |
| 476 & 460 | n/a | n/a | [18] |
| 459 & 478 | n/a | n/a | [19] |
| n/a | 6.80-41.00 | n/a | [20] |
| n/a | 4.30-32.60 | n/a | [20] |
| n/a | 3.30-30.00 | n/a | [21] |

Data regarding the usage of phototherapy devices for the treatment of neonatal jaundice were collected from ten hospitals in Thailand. No data related to neonates were collected. A preliminary analysis of phototherapy device usage focused on key parameters, including Radiation level (nm), Irradiance (µW/cm²/nm), and Time of use (hrs), as detailed in Table II. There are variations in the light intensity of the phototherapy devices, with light wavelengths ranging from 420-490 nm or irradiance levels between 23-60 µW/cm²/nm. Additionally, the lifespan of the light bulbs used in the phototherapy devices varies, ranging from 10,000 to 20,000 hours. It can be observed that the wavelengths and irradiance levels used in these hospitals align with existing research and guidelines for proper usage. However, there is insufficient data regarding the lifespan of the bulbs. As the bulbs are used over time, their efficiency may gradually decrease with age. Monitoring and controlling the lifespan of the bulbs will help ensure consistent light intensity, thus maintaining the desired therapeutic effects in line with the medical treatment plan.

TABLE II. DATA ON THE USAGE OF PHOTOTHERAPY (HOSPITALS IN THAILAND).

| Hospital / Location | Radiation (nm) | Irradiance (µW/cm²/nm) | Time of use (hrs) |
|---|---|---|---|
| Fang, Chiang Mai | 460-470 | 30.00-45.00 | 20,000 |
| Hod, Chiang Mai | 420-490 | 30.00 | 10,000 |
| Ban Thi, Lamphun | 450-480 | 40.00 | 10,000 |
| Wapi Pathum, Maha Sarakham | 420-480 | 40.00-60.00 | n/a |
| Khon Kaen, Khon Kaen | 420-480 | 60.00 | 20,000 |
| Maharaj, Nakhon Ratchasima | 420-480 | - | n/a |
| Charoenkrung Pracharak, Bangkok | 460-490 | 30.00-60.00 | n/a |
| Police General, Bangkok | 460 | 52 | n/a |
| Lerdsin, Bangkok | 450-470 | 40 | 10,000 |
| Hua Hin, Prachuap Khiri Khan | 430-480 | 23.00 | n/a |

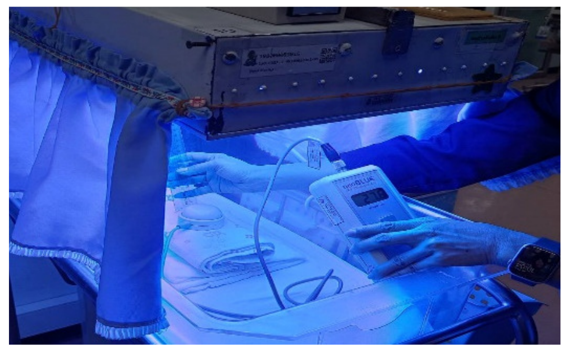

Fig. 2. Measurement of light emitted from a phototherapy device at a public hospital located in Bangkok, Thailand.

The collection and analysis of the light bulb lifespan data for phototherapy devices to treat neonatal jaundice was simulated with light measurements under controlled conditions. The environment and equipment used, such as bassinets, mattresses, and beds, were arranged to closely resemble those found in hospitals (without involving real neonates). The distance between the lamp and the measurement location was set between 30 to 50 cm. The measurement times followed the medical treatment plans, with measurements taken at 0, 7, 12, 24, 48, and 72 hours. Additionally, continuous measurements were taken to assess the lamp's performance after 720, 1,000, 2,000, 3,000, 4,000, and 5,000 hours of use [14]. For the light measurement process, six BLUE-LIGHT bulbs with a wavelength range from 425 to 475 nm or an irradiance level of at least 30 µW/cm²/nm were used. The lamps were positioned at a height of approximately 35 cm. The phototherapy device was cleaned and checked for readiness. A surrogate for the neonate was placed at the center of the bed, and the measuring device was positioned at its center. Measurements were taken for 5-10 seconds, and the recorded values were noted.

## III. RESULTS

A total of five phototherapy devices were utilized for preliminary data collection. However, only three devices successfully operated until the designated 5,000 hours mark, as one device experienced bulb failure during operation, while another encountered component malfunction. The light intensity measurements obtained from the three fully operational phototherapy devices are detailed as follows.

According to Table III, the light intensity measurements for phototherapy Device 1 remained unchanged during the initial 720 hours. A slight variation was first observed at 720 hours, and from 1,000 to 5,000 hours, a continuous decline in light intensity was recorded. Analyzing the overall trend of light intensity measurements for Device 1, it was evident that as the operating hours of the bulb increased, particularly from 720 to 5,000 hours, the device exhibited a progressive reduction in light intensity.

TABLE III. DATA ON LIGHT INTENSITY MEASUREMENTS FROM PHOTOTHERAPY DEVICE 1

| | Time of use (hrs) | Irradiance (μW/cm$^2$/nm) |
|---|---|---|
| 1 | 0 | 41.50 |
| 2 | 7 | 41.50 |
| 3 | 12 | 41.50 |
| 4 | 24 | 41.50 |
| 5 | 48 | 41.50 |
| 6 | 72 | 41.50 |
| 7 | 720 | 40.80 |
| 8 | 1,000 | 40.00 |
| 9 | 2,000 | 39.50 |
| 10 | 3,000 | 37.80 |
| 11 | 4,000 | 36.40 |
| 12 | 5,000 | 34.70 |

According to Table IV, the light intensity measurements for phototherapy Device 2 remained unchanged during the first 72 hours. A slight variation was first observed at the 720 hours mark, and from 1,000 to 5,000 hours, a progressive decline in light intensity was recorded. The analysis of light intensity trends in Device 2 indicates that as the lamp's operational duration increases, particularly from 720 to 5,000 hours, the device exhibits a noticeable reduction in light intensity. This suggests a correlation between increased operational hours and the decline in light intensity.

TABLE IV. DATA ON LIGHT INTENSITY MEASUREMENTS FROM PHOTOTHERAPY DEVICE 2

| | Time of use (hr) | Irradiance (μW/cm$^2$/nm) |
|---|---|---|
| 1 | 0 | 37.30 |
| 2 | 7 | 37.30 |
| 3 | 12 | 37.30 |
| 4 | 24 | 37.30 |
| 5 | 48 | 37.30 |
| 6 | 72 | 37.30 |
| 7 | 720 | 37.00 |
| 8 | 1,000 | 36.60 |
| 9 | 2,000 | 34.20 |
| 10 | 3,000 | 33.90 |
| 11 | 4,000 | 33.00 |
| 12 | 5,000 | 30.80 |

According to Table V, the light intensity measurements for Device 3 remained unchanged during the 0-72 hours period. A slight variation was observed at the 720 hours mark and from 1,000 to 5,000 hours, with a progressive decline in light intensity. The light intensity trends in Device 3 indicate that as the lamp's operational duration increases, particularly from 720 to 5,000 hours, the device exhibits a noticeable reduction in light intensity. This suggests a correlation between increased operational hours and the decline in light intensity.

TABLE V. DATA ON LIGHT INTENSITY MEASUREMENTS FROM PHOTOTHERAPY DEVICE 3

| | Time of use (hrs) | Irradiance (μW/cm$^2$/nm) |
|---|---|---|
| 1 | 0 | 39.70 |
| 2 | 7 | 39.70 |
| 3 | 12 | 39.70 |
| 4 | 24 | 39.70 |
| 5 | 48 | 39.70 |
| 6 | 72 | 39.70 |
| 7 | 720 | 38.20 |
| 8 | 1,000 | 37.10 |
| 9 | 2,000 | 36.50 |
| 10 | 3,000 | 34.00 |
| 11 | 4,000 | 33.40 |
| 12 | 5,000 | 32.30 |

TABLE VI. SUMMARY OF IRRADIANCE DECREASE IN PHOTOTHERAPY DEVICES OVER 5,000 HOURS

| Device | Irradiance Range (Initial - 5,000 hrs) (μW/cm$^2$/nm) | Decrease % | Variance (μW/cm$^2$/nm) |
|---|---|---|---|
| No.1 | 41.50-34.70 | 16.93% | 5.46 |
| No.2 | 37.30-30.80 | 17.38% | 4.96 |
| No.3 | 39.70-32.30 | 18.66% | 7.89 |

A statistical trendline analysis was performed on the light intensity values of phototherapy Devices 1 to 3 over time. Linear regression models revealed strong negative correlations between operating hours and irradiance levels. The trendline slopes were approximately -0.0014, -0.0013, and -0.0015 μW/cm$^2$/nm per hour for Devices 1, 2, and 3, respectively. The percentage decrease in irradiance over 5,000 hours was 16.93%, 17.38%, and 18.66%, respectively. The variance in irradiance levels was 5.46, 4.96, and 7.89 (μW/cm$^2$/nm)$^2$ for Devices 1, 2, and 3, respectively.

Figure 3 supports these statistical findings, indicating a gradual and predictable decline in irradiance as the lamps age. These results confirm the consistent degradation of light intensity and support the importance of routine maintenance and timely lamp replacement to preserve treatment efficacy. Based on this trend, lamp replacement procedures are recommended once a 15-20% reduction in irradiance is observed, typically after 4,000-5,000 operating hours.

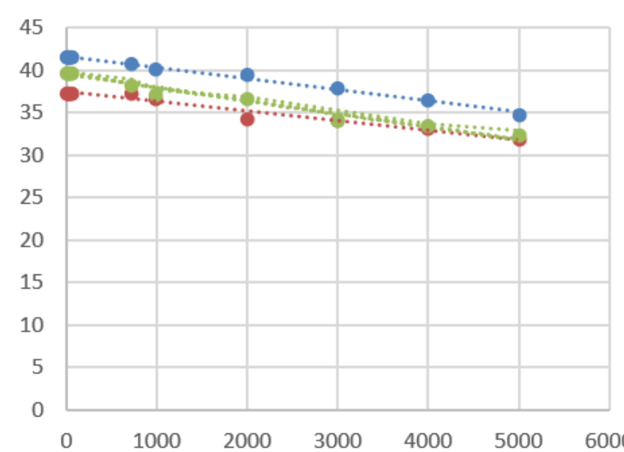


Fig. 3. Comparison of light intensity levels for phototherapy Devices 1-3.

## IV. CONCLUSIONS

The results of this study confirm that the irradiance levels of phototherapy devices decline progressively with prolonged use, particularly beyond 720 hours of operation. During the early phase, devices maintained stable light intensity with minor fluctuations; however, statistical and graphical analysis demonstrated a consistent downward trend over time. This decline may compromise the effectiveness of phototherapy in treating neonatal jaundice if not addressed through proper maintenance. These findings emphasize the importance of regular monitoring and scheduled lamp replacement, particularly when a 15-20% reduction in irradiance is observed, typically around 4,000-5,000 hours of use. Failure to maintain appropriate light levels could lead to insufficient bilirubin degradation, prolonging treatment or increasing the risk of complications. Conversely, excessive light exposure may pose health risks to neonates, such as ocular or skin damage [6, 7]. Therefore, ensuring optimal irradiance through routine inspection and timely intervention is essential for both safety and therapeutic efficacy. These insights support current clinical guidelines while also highlighting the need for improved energy control mechanisms in phototherapy systems, which could be addressed in future device development and clinical protocols.

Future research directions should focus on improving the control and optimization of the light energy delivered by the phototherapy lamp to achieve maximum efficacy and safety. This includes investigating methods such as coating the lamp glass surface with a specific thin film layer or designing an integrated light filter or radiation shielding material within the phototherapy device to further reduce the risk to the infant [7]. Research should explore the development of film-based light shielding materials [22] that allow precise light penetration to design eye protection devices for infants during jaundice treatment without compromising the overall efficacy of treatment. In addition, research should be conducted on the optimal absorption of light energy by the infant's skin to efficiently convert bilirubin while preventing excessive penetration that may cause heat accumulation in internal organs and possible harm.

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