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Design of a Portable Phototherapy Unit for Hyperbilirubinemia using Surface Mounting Device Light Emitting Diodes

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Abstract

Hyperbilirubinemia is a condition of a high bilirubin level in newborns causing a yellowish color on newborns' skin and sclera. One of the treatment methods commonly used for hyperbilirubinemia is phototherapy in which newborns are exposed to visible light, especially within the green-blue spectrum. This study aimed to design a prototype of a portable phototherapy unit for newborns with hyperbilirubinemia. The phototherapy unit was designed by using a Surface Mounting Device Light Emitting Diode (SMD LED) with a wavelength of 400-520 nm as a light source which was attached to a fabric inside a box made of acrylic. The SMD LED strips were arranged with a spacing of 5 cm between the SMD LED arrays. The system was equipped with a monitoring system using SHT11 as a temperature and humidity sensor as well as a timer to adjust the duration of exposure and the LCD. The prototype was tested by irradiating various concentrations of artificial bilirubin solutions with a blue light produced by the phototherapy unit. The results show that the system can reduce the concentration of artificial bilirubin solution with an average reduction of 30.8%. The system shows the potential to be used as a portable phototherapy unit, further improvement on the efficacy, safety, and comfort of the unit is required.

Introduction

Hyperbilirubinemia is a condition commonly found in infants, where high-level bilirubin accumulates in the skin layers and mucous membranes. The buildup of bilirubin causes a yellowish color on the newborn's skin and sclera [1], [2]. Hyperbilirubinemia is mostly found in pre-term babies, although the condition can be also found in full-term babies [2]. The severity of hyperbilirubinemia depends on the bilirubin level, however, if it is left untreated might cause permanent damage in the central nervous system, known as kernicterus [3]. The total bilirubin serum (TBS) of ≥ 12 mg/dL indicates a significant hyperbilirubinemia, the TBS of ≥ 20 mg/dL indicates severe hyperbilirubinemia, and the TBS of ≥ 30 mg/dL indicates a hazardous hyperbilirubinemia [4].

The most common method used to treat hyperbilirubinemia is phototherapy [5], [6], [7], [8]. The treatment makes use the visible light within the green-blue spectrum to reduce the bilirubin level in newborns. Light exposure triggers the transformation of unconjugated bilirubin which is toxic to its non-toxic isomer. The change of bilirubin structure enables the excretion of an excessive amount of bilirubin from the body without further processes in the liver [5]. Phototherapy equipment usually is available in hospitals to treat newborns.

Four factors determine the success of phototherapy. The first factor is the spectral quality of the light source used in the treatment. The light source used in the phototherapy should have a wavelength interval from 400 nm to 520 nm, with a peak of 460±10 nm [5], [9]. The next factor is the light intensity produced from the light source. The minimum intensity required for intensive phototherapy is 30 $\mu W/cm^2/nm$ [5]. The distance of the light source to the baby's skin also determines the success of the phototherapy. As the distance gets closer, the light intensity received by the baby is higher, therefore the reduction of bilirubin level is also higher. The last factor is the area of the baby's skin surface exposed to the light. The larger area of the baby's skin exposed to the light the reduction of the bilirubin level is higher [10].

The phototherapy units are available as a conventional phototherapy which uses an overhead light source and a biliblanket which offer a portable phototherapy. The selection of light source in the phototherapy unit is important part determining the success of the phototherapy for hyperbilirubinemia treatment. The light source commonly used in the conventional phototherapy is a halogen lamp or fluorescent tube [11]. However, the halogen lamp has the disadvantage of causing excessive heat, therefore should be placed at a certain distance from the baby to prevent skin burn [5]. A fluorescent tube lamp can maintain a stable temperature but should be placed closer to the baby to be effective. Another issue with these light sources is the need to frequently replace the light to maintain required light irradiance [10]. Biliblanket is one form of the portable phototherapy unit, enabling it to wrap the baby's body, therefore the mother could breastfeed the baby during the phototherapy procedure [12]. The light is produced by a tungsten-halogen bulb and delivered to baby's skin through a cable into a transparent pad containing fiberoptic fibers. The drawback of the biliblanket is it has a low level of irradiance and, therefore should be combined with conventional phototherapy [5]. Light emitting diode (LED) lamp is another alternative light source for the phototherapy unit, offering the advantages of avoiding overheating production and having a longer duration of use [10], [13], [14], [15].

In Indonesia, the occurrence of hyperbilirubinemia in newborns is relatively high [16]. This condition is one of the factors causing high mortality rate in neonates. Sampurna et al. (2019) reported that phototherapy for hyperbilirubinemia treatment in Indonesia is less effective due to the low level of irradiance given to the baby during the phototherapy. Lack of access to phototherapy treatment is another factor causing a high mortality from hyperbilirubinemia, which is similar to the condition in other developing countries due to remote location and the high cost required for phototherapy treatment [17], [18]. This situation gets even worse in the COVID-19 pandemic, where people minimize their visits to the hospitals as almost all of the hospitals are used for Covid 19 treatment [19]. This shows the importance of the availability of the phototherapy unit which can be used at home therefore the newborns with hyperbilirubinemia could be treated quicker without separating the baby from the mother. It requires a compact, long-life, and cheap light source enable for a portable design of the phototherapy unit and reducing the cost spent for the treatment.

Previously, we have investigated the blue light emitted from the fluorescence light tube [20]. However, its bulky size is unsuitable for portable phototherapy unit. The LED seems to be more promising and potential to be used as a light source in a portable phototherapy. The use of LED for hyperbilirubinemia treatment has been explored in several studies. There are some commercial LED-based phototherapy units such as PTV300 (MTTS, Hanoi, Vietnam), Lullaby (GE Healthcare, Maryland, USA), and Firefly (MTTS, Hanoi, Vietnam) [10]. However, these devices used a LED bulb type. This work aims to design a portable phototherapy unit based on a surface mounting device light emitting diode (SMD LED). The SMD LED offers a small and flat chip, thus easily mounted onto a circuit board. A previous study by Addi et al. [17] made use the SMD LED for portable phototherapy, however the dimension size in their design was relatively small which were 4 cm x 4 cm which might not adequate for severe hyperbilirubinemia or bigger size of newborns. Therefore, this study will further explore the use of SMD-LED as a light source in a cheap portable phototherapy to be used in home treatment for neonatal jaundice.

Experimental Method

Materials. The materials used in this study could be classified into materials for the phototherapy unit, materials for the monitoring and control systems, and materials for testing. The main materials for the phototherapy units were light source to produce blue light and the box to place the object that would be irradiated by the blue light. The light source used in this study was SMD LED 5050 strips, due to its ability to produce a blue light with the suitable wavelength ranges for hyperbilirubinemia phototherapy (i.e, 400 – 495 nm). In addition, this SMD LED strip offers a smaller size compared to the regular LED and a brighter light as well as cheap, compact, and widely available. The SMD LED are designed to be mounted directly onto surface of material. A single SMD LED produce around 18-22 lumens. The SMD LED have a wide beam angle, around 120 degrees. The spectrum of blue light emitted from the SMD LED strips was measured using a Firefly 4000 spectrometer (Photontec, Berlin) to investigate the peak wavelength.

For the monitoring and control systems, the materials used were SHT11 as the temperature and humidity sensor, RTC DS1307 as the timer, step-down LM2596 to divide the voltage, Arduino Mega 2560 microcontroller for the signal processing, keypad, and LCD screen for the display. The SHT11 sensor was selected due to its high accuracy, compact size, fast response time and low power consumption. It delivers a digital output, simplifying integration with microcontrollers and other digital systems. It has a wide range of humidity measurement from 0% to 100% relative humidity (RH). It has an accuracy of ±3% RH. It has 12-bit digital resolution and approximately 8 seconds for a 63% change in humidity. The range of temperature measurement is from -40°C to +123.8°C, typically ±0.4°C accuracy, 14-bit digital resolution, allowing for precise temperature readings.

The materials used for testing were methyl red powder and acetic acid to prepare the artificial bilirubin solution, and 10 ml reaction glass tubes with seal.

System Design. The design of the portable phototherapy unit consisted of the hardware and software designs of the system. The hardware design included the development of a timer, a temperature and humidity sensor circuit, and ancillary components such as an LCD screen, keypad, step-down LM2596, and RTC DS1307 as a whole integrated system. The SMD LED used a voltage of 12 V. The SMD LED strip consumes 14.4 W/m, with a total length of 3.84 meter, the current drawn by the SMD LED was a 4.6 A. The step-down LM2596 was used to divide the voltage to 7 V. RTC DS1307 was used as a timer to adjust the duration of the treatment. The block diagram of the temperature and humidity monitoring system is shown in Figure 1.

The software design included the development of a monitoring and control system program to monitor the temperature, humidity, and duration during light exposure in the portable phototherapy box. Arduino was used to process the signal from the SHT11 sensor to be displayed on an LCD screen with a dimension of 20 cm x 4 cm. The set point for the temperature was 35°C. The buzzer was added to the system to create a warning system when the temperature inside the phototherapy unit exceeded 35° C.

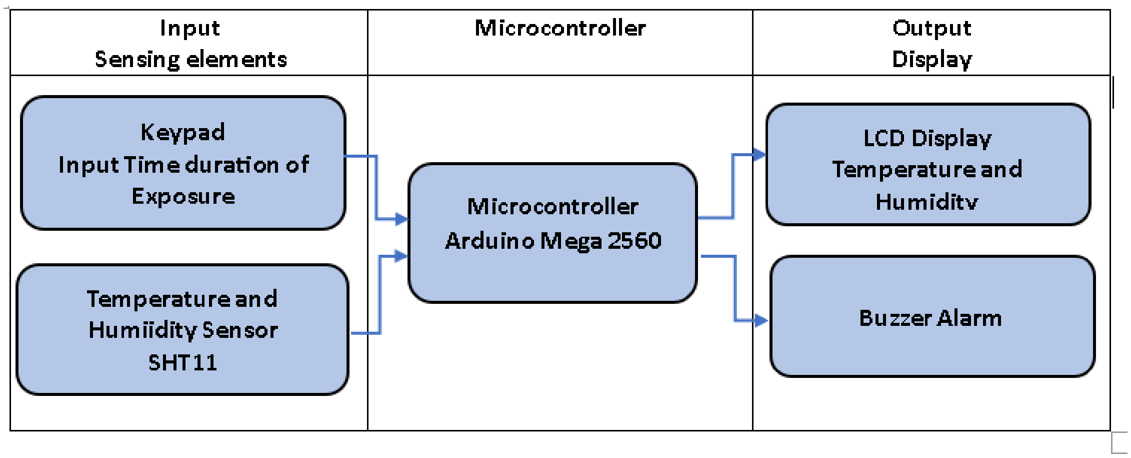


Figure 1. Block diagram of the system

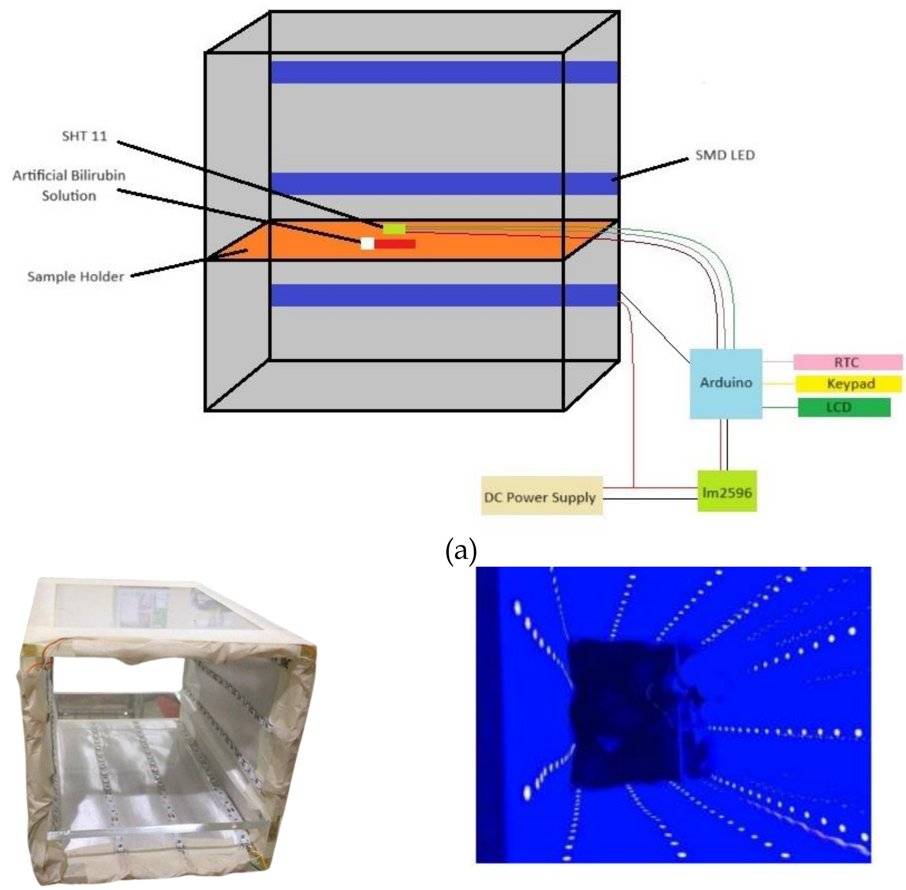
The phototherapy unit was designed in a box made of acrylic with a dimension of 32 cm x 20 cm x 20 cm (Figure 2). The thickness of acrylic was 8 mm. The acrylic was used because it is easier to handle than glass. The SMD LED strips were attached to a reflective fabric sheet with a distance of 5 cm between the LED strips. The use of reflective fabric aimed to optimize the irradiance to the sample by using the reflected blue light. There were 3 LEDs in every 5 cm length of the strips. The SMD LED strips were then placed in the inner side of the acrylic box with two openings in the front and back of the box, thus all the inner sides of the box were covered by the SMD LED strips. There were three rows of the SMD LED strips for each side resulted in a total of twelve LED strip rows in the inner side of the box.

System Testing. The unit was tested to ensure each part of the system functioned properly. The unit was also tested by exposing various concentrations of the artificial bilirubin solution made of methyl red powder and acetic acid to blue light emitted from the SMD LED light source for 90 minutes. This method was adopted from the study by Addi et al [15]. The artificial bilirubin was used since it has a great absorbance at the range of 400 nm to 550 nm, similar to the real bilirubin serum. The concentrations of the artificial bilirubin solution were 5, 10, 15, 20 and 30 mg/dL to mimic various severity levels of hyperbilirubinemia. In order to create a 5 mg/dL solution of artificial bilirubin solution, 5 mg of methyl red powder was dissolved in 1 dL of acetic acid [17]. The increase in the concentration of solution represents an increase in severity of the hyperbilirubinemia. The control solution was made from acetic acid only. The sample was placed at distance of 10 cm from the upper and the bottom of the box to ensure optimal irradiance from the light sources at the upper and lower sides. The illuminance of the blue light at this distance was measured using a luxmeter.

The absorbances (A) of the sample solution before and after irradiation were calculated using the Lambert-Beer Law (1) to evaluate the effect of the blue light to the solution during irradiation. The incident intensity (I_0) and the transmitted intensity (I) were measured using the Firefly 4000 spectrometer (Photontec, Berlin).

$$A = log_{10}(\frac{I}{I_0}) \tag{1}$$

To evaluate the effect of duration time to the temperature and the humidity within the unit, the duration of light exposure was varied from 30 to 120 minutes. The temperature and the humidity detected by the SHT11 sensor were recorded.



(b) (c)

Figure 2. The prototype of the phototherapy unit based on SMD-LED. a) The schematic of the phototherapy unit, b) The phototherapy unit when the LED is switched off, c) the phototherapy unit when the LED is switched on.

Results and Discussion

The spectrum of blue light emitted from the SMD LED strip is shown in Figure 3. The spectrum of blue light ranges from 400 – 520 nm, with a peak wavelength of 450 nm. This value has met the requirement for hyperbilirubinemia treatment, which is suggested by Stokowski (2011) the effective light source should have wavelength between 400 – 520 nm with a peak of 460±10 nm. The peak wavelength of the SMD LED strip used in this study is close with the dominant wavelength of the LED bulb used in the commercial LED-based phototherapy such as Lullaby and Firefly [10].

The exposure of the artificial bilirubin solutions to the blue light placed at 10 cm from the bottom of the box for 90 minutes shows a change in the absorbance of the solution as shown in Table 1. The illuminance of the blue light at this distance is 14300 lux. It shows that there is a reduction of the absorbance of the solution after being exposed to the blue light emitted from the designed phototherapy unit. The average reduction of the solution absorbance is 30.8%, with the highest reduction is observed in the solution with the concentration of 20 mg/dl. However, it should be noted that in this study the unit was only tested for the artificial bilirubin solution. The results might be different for the real bilirubin sample or the real patients. Since this study is still a pre-liminary study, it was not designed to be tested to the real patients. The optimization of the unit design is still required before it can be tested to the real patients.

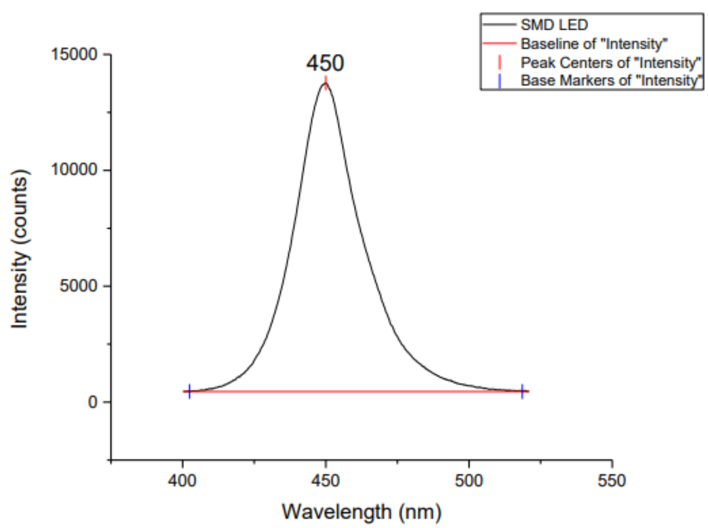


Figure 3. The spectrum of blue light emitted from the SMD LED. The wavelength ranges from 400 – 520 nm, with a peak wavelength of 450 nm.

Table 1. The exposure of the blue light from the phototherapy unit to the artificial bilirubin solutions.

Concentration of ABS (mg/dL)	Absorbance before irradiation	Absorbance after irradiance	Difference (%)
0	0.24	0.13	45.8
5	0.40	0.36	10.0
10	0.38	0.28	26.3
15	0.53	0.45	15.1
20	0.82	0.27	67.1
30	0.89	0.71	20.2

ABS: Artificial bilirubin solution

The selection of artificial bilirubin solution concentration from 5 to 30 mg/dL is to represent the severity level of the hyperbilirubinemia, as mentioned by Olusanya et al. (2018). The severity of the hyperbilirubinemia can be classified into significant hyperbilirubinemia with a total serum bilirubin (TSB) ≥ 12 mg/dL, severe hyperbilirubinemia with a TSB of ≥ 20 mg/dL, extreme hyperbilirubinemia with a TSB of TSB ≥ 25 mg/dL, and hazardous or critical hyperbilirubinemia with a TSB of ≥ 30 mg/dL.

Table 2 presents the recorded temperature and humidity in the phototherapy unit during the blue light irradiation at various durations of exposure. The temperature tends to increase as the exposure duration increases from 27^{0}C to around 33^{0}C, however, the temperature is still below the set point of 35^{o}C. A longer exposure duration causes a decrease in humidity within the phototherapy unit. The humidity drops to 67% after 30 minutes exposure and continues decreasing to 55.8% after 120 minutes exposure. The change in the humidity is not obvious after 60 minutes of exposure, as shown in Table 2.

Table 2. The temperature and humidity in the phototherapy unit during blue light irradiation.

Duration (minutes)	Temperature (^{o}C)	Humidity (%)
0	27.2	72.8
30	31.5	67.0
60	33.6	55.0
90	32.9	56.5
120	32.8	55.8

The reduction of bilirubin level obtained in this study is slightly higher compared to the result reported by Addi et al. [17]. In their study, they used LED as phototherapy garment which was attached directly to the object. It means there is no distance between the LED and the object. They reported that the reduction of artificial bilirubin solution concentration after 60 minutes LED's blue light irradiation ranged from 11.81% to 37.18%, for 30 mg/dL concentration of sample and 5 mg/dL concentration of sample respectively. In their study, as the concentration higher the reduction of the artificial bilirubin become smaller. In our study the temperature of the phototherapy is relatively stable although the duration increases, because there is two opening for heat transfer between the air inside the box with the air from its surrounding. The presence of the buzzer in the control system is aimed to give a warning alarm if the temperature inside the box exceeds 35^{o}C, so the LED light will be automatically turned off and the irradiation will be stopped.

The developed portable phototherapy in this study shows the potential of using the SMD LED as the light source in a phototherapy treatment for hyperbilirubinemia. Its compact design makes it easy to adjust with the phototherapy unit. The advantages of using SMD LED are compact design and reduction of the excessive heat produced in the phototherapy unit compared to over-head conventional phototherapy unit. Therefore, the SMD LED-based phototherapy unit is suitable to be used for home phototherapy settings, offering a cheaper hyperbilirubinemia treatment than hospital-based hyperbilirubinemia treatment. A study by Zanardo (2022) shows that home phototherapy using LED-based phototherapy transmitted to a small lighting area is effective, enabling a strong bond between the mother and the infants [19]. This is because phototherapy treatment in a hospital usually separates the mother and the infant, limiting the interaction between the two [6]. This situation is also relevant in low and middle-income countries such as Indonesia where access to medical facilities such as the phototherapy unit is limited, as well as implemented in Ethiopia [18]. The development of the portable phototherapy unit might contribute to reducing the death number of infants due to hyperbilirubinemia by treating the infant in their own home, offering a lower price and a more convenient treatment for the family. Although phototherapy using natural sunlight also recommended being used in low and middle-income countries [3], the broad spectrum of natural sunlight contains ultraviolet light which is dangerous for the skin of newborns. However, the improvement of the design is still required to ensure comparable efficacy and safety of this designed phototherapy with the commercial phototherapy units.

The mechanism of bilirubin reduction from blue light is due to the absorption of the blue light by the bilirubin, causing a transformation of a toxic unconjugated bilirubin to a non-toxic conjugated bilirubin. The conjugated bilirubin is water soluble and can be excreted from the body through the stool and urine without further processes in the liver. The mechanism has been explained by Stokowski (2011) [5]. The process of phototherapy involves the absorption of light by bilirubin molecules, leading to two main photochemical reactions. Initially, native 4Z, 15Z-bilirubin transforms into 4Z, 15E-bilirubin, also known as photobilirubin, along with lumirubin. Unlike its precursor, photobilirubin can be eliminated through the liver without conjugation, albeit slowly and with reversible conversion back to native bilirubin in the absence of light. Lumirubin, however, undergoes irreversible conversion. Despite its lower formation rate compared to photobilirubin, lumirubin is cleared more rapidly from the bloodstream, likely being the primary factor behind the decrease in serum bilirubin during phototherapy. Additionally, a fraction of native bilirubin is oxidized into monopyrroles and dipyrroles, which can be excreted in urine, although this process is relatively slow and contributes minimally to bilirubin elimination during phototherapy.

The effectivity of bilirubin reduction from the phototherapy treatment is highly dependence on the intensity of the blue light emitted from the light source. The use of a halogen lamp in conventional phototherapy usually should be kept at a certain distance from the baby's skin due to the excessive heat produced might cause damage to the baby's skin as well as dehydration [21]. The use of LED as a light source has been reported to minimize the heat produced during the treatment and is effective in reducing the bilirubin level [14]. To speed up the rate of bilirubin reduction, the intensity of the light source should be increased. It can be carried out by reducing the distance between the light source and the baby's skin or by adding more light sources. A study by Arnolda et al. (2008) comparing commercial single and double-sided LED phototherapy machines shows that the double-sided LED phototherapy unit increases the speed of total bilirubin serum reduction and shortens the treatment duration compared to the single-sided LED phototherapy unit [10]. In their study, they also increased the exposure area, causing more skin area exposed to the blue light, thus speeding up the decline of the bilirubin level. Another alternative to increase the intensity of the light received by the baby's skin is by using a reflective material placed on the side of the phototherapy units [22]. In our study, we used reflective fabrics placed on all inner sides of the treatment box, thus the intensity of the blue light in the box increases.

Although phototherapy has been widely adopted as the first treatment option for neonate hyperbilirubinemia, it also has adverse effects that need to be monitored regularly. As described by Shoris et al., the effects of phototherapy include hyperthermia and dehydration, hypocalcemia, hematologic effects, sleep disturbances, and hemodynamic change [21]. Even, the use of LED-based phototherapy has been also reported to cause hypocalcemia in treated babies [23]. The fiberoptic-based phototherapy might be used as an alternative to minimize the side effects of conventional phototherapy [24], [25], [26].

The developed prototype of the portable phototherapy unit in this study shows potential to be used in hyperbilirubinemia treatment. However, this study has several limitations that requires a further improvement and development in the future. First, this study only measured the illuminance of the blue light using a lux meter and not measured the irradiance of the blue light produced from the SMD-LED since the specific tool to measure the irradiance (i.e., radiometer) was not available. Second, the dimension of the box needs to be adjusted accordingly to give enough space for the treated infants during the treatment as the current design is too small for the placement of the real infants. The spacing of the SMD LED strips also needs to be investigated to obtain the required irradiance level without producing excessive heat within the unit. Lastly, since in this study the developed phototherapy unit was only exposed to the artificial bilirubin solution, exposure to the real bilirubin serum study might produce different results. Once the design has been matured, it opens the possibility to perform unit testing for the real patients.

Conclusion

The prototype of a portable phototherapy unit based on the SMD LED equipped with a temperature and humidity monitoring system has been developed. The blue light emitted by the SMD LED has a peak wavelength of 450 nm fulfilling the criteria to be used in the phototherapy of hyperbilirubinemia. The testing of the developed phototherapy unit can decrease the absorbance of the artificial bilirubin solution by 30.8% on average. However, further development of the system is required to improve the performance of the portable phototherapy to ensure the unit produces the required phototherapy dosage for hyperbilirubinemia treatment. In addition, the future development also can be focused on the safety and comfort of the designed phototherapy unit to be used in the real treatment situation.

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References

[1] D. K. Stevenson, P. A. Dennery, and S. R. Hintz, "Understanding Newborn Jaundice," *Journal of Perinatology*, vol. 21, no. S1, pp. S21–S24, Dec. 2001. [Online]. Available: https://www.nature.com/articles/7210628. [Accessed Feb 20, 2021].

[2] S. Ullah, K. Rahman, and M. Hedayati, "Hyperbilirubinemia in Neonates: Types, Causes, Clinical Examinations, Preventive Measures and Treatments: A Narrative Review Article.," *Iran J Public Health*, vol. 45, no. 5, pp. 558–68, May 2016. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/27398328. [Accessed Feb 20, 2021].

[3] D. Horn, D. Ehret, G. Suresh, and R. Soll, "Sunlight for the prevention and treatment of hyperbilirubinemia in term and late preterm neonates," *Cochrane Database of Systematic Reviews*, vol. 2019, no. 3, 2019. [Online]. Available: https://doi.wiley.com/10.1002/14651858.CD013277. [Accessed Dec 27, 2023].

[4] B. O. Olusanya, M. Kaplan, and T. W. R. Hansen, "Neonatal hyperbilirubinaemia: a global perspective," *The Lancet Child & Adolescent Health*, vol. 2, no. 8, pp. 610-20, Aug. 2018. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S2352464218301391. [Accessed: Sep 15, 2024].

[5] L. A. Stokowski, "Fundamentals of Phototherapy for Neonatal Jaundice," *Advances in Neonatal Care*, vol. 11, no. Supplement 5S, pp. S10–S21, Oct. 2011. [Online]. Available: https://journals.lww.com/00149525-201110001-00003. [Accessed: Feb 20, 2021].

[6] J. Wang, G. Guo, A. Li, W.-Q. Cai, and X. Wang, "Challenges of phototherapy for neonatal hyperbilirubinemia (Review)," *Exp Ther Med*, vol. 21, no. 3, pp. 231, Jan. 2021. [Online]. Available: http://www.spandidos-publications.com/10.3892/etm.2021.9662 . [Accessed: Dec 27, 2023].

[7] S. Ü. Sarici, F. Alpay, B. Ünay, O. Özcan, and E. Gökçay, "Comparison of the efficacy of conventional special blue light phototherapy and fiberoptic phototherapy in the management of neonatal hyperbilirubinaemia," *Acta Paediatrica, International Journal of*

Paediatrics, vol. 88, no. 11, pp. 1249-53, 1999. [Online]. Available: http://doi.wiley.com/10.1080/080352599750030374. [Accessed: Aug 1, 2024].

[8] K. Mreihil et al., "Phototherapy is commonly used for neonatal jaundice but greater control is needed to avoid toxicity in the most vulnerable infants," *Acta Paediatrica, International Journal of Paediatrics*, vol. 107, no. 4, pp. 611-19, Apr. 2018. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1111/apa.14141. [Accessed: Aug 1, 2024].

[9] V. K. Bhutani et al., "Phototherapy to prevent severe neonatal hyperbilirubinemia in the newborn infant 35 or more weeks of gestation," *Pediatrics*, vol. 128, no. 4, pp. e1046–e1052, Oct. 2011. [Online]. Available: https://publications.aap.org/pediatrics/article/128/4/e1046/30731/Phototherapy-to-Prevent-Severe-Neonatal. [Accessed: Feb 22, 2021].

[10] G. Arnolda et al., "A comparison of the effectiveness of three LED phototherapy machines, single- and double-sided, for treating neonatal jaundice in a low resource setting," *PLoS One*, vol. 13, no. 10, pp. e0205432, Oct. 2018. [Online]. Available: https://dx.plos.org/10.1371/journal.pone.0205432. [Accessed: Dec 27, 2023].

[11] H. Shirzadfar and K. Sheikhi, "Novel Design and Evaluation of an Automatic and Portable Phototherapy Device Using for Newborn Jaundice Treatment," *Recent Research in Endocrinology and Metabolic Disorder*, vol. 1, no. 1, pp. 22–31, Dec. 2019. [Online]. Available: https://rriemd.com/index.php/rriemd/article/view/18. [Accessed: Feb 22, 2021]

[12] K. K. Yenamandra, R. Kumar, A. K. Garg, V. Kumar, and D. Singh, "Comparison of effectiveness of light emitting diode phototherapy with conventional phototherapy and combination phototherapy of conventional with fiberoptic biliblanket, and light emitting diode phototherapy with fiber optic biliblanket for treatment of n," *Int J Contemp Pediatrics*, vol. 5, no. 6, pp. 2042, Oct. 2018. [Online]. Available: http://www.ijpediatrics.com/index.php/ijcp/article/view/2013. [Accessed: Feb 22, 2021].

[13] P. F. Sebbe, A. B. Villaverde, L. M. Moreira, A. M. Barbosa, and N. Veissid, "Characterization of a novel LEDs device prototype for neonatal jaundice and its comparison with fluorescent lamps sources: Phototherapy treatment of hyperbilirubinemia in Wistar rats," *Spectroscopy*, vol. 23. No. 5-6, pp. 243-55, Jan. 2009. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.3233/SPE-2009-0392. [Accessed: Feb 22, 2021].

[14] S. Gutta et al., "Light emitting diode (LED) phototherapy versus conventional phototherapy in neonatal hyperbilirubinemia: A single blinded randomized control trial from coastal India," *Biomed Res Int*, vol. 2019, No. 1, 2019. [Online]. Available: https://www.hindawi.com/journals/bmri/2019/6274719/. [Accessed: Dec 27, 2023].

[15] R. Purkait and M. Mondal, "Effectiveness of light emitting diode versus conventional phototherapy in neonatal hyperbilirubinemia: a hospital based observational study," *Int J Res Med Sci*, vol. 8, no. 3, pp. 1051, Feb. 2020. [Online]. Available:

https://www.msjonline.org/index.php/ijrms/article/view/7753. [Accessed: Aug 1, 2024].

[16] M. T. A. Sampurna et al., "Current phototherapy practice on Java, Indonesia," *BMC Pediatr*, vol. 19, no. 1, p. 188, Dec. 2019. [Online]. Available: https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-019-1552-1. [Accessed: Feb 22, 2021].

[17] M. M. Addi, N. A. Z. Abidin, and S. A. Daud, "Development of a portable phototherapy garment (PPG) for jaundice treatment," in IECBES 2016 - IEEE-EMBS Conference on Biomedical Engineering and Sciences, Kuala Lumpur, Malaysia, Dec 4-8, 2016, pp. 405-410. Available: https://ieeexplore.ieee.org/document/7843482.

[18] N. W. Gidi and M. Siebeck, "Neonatal Hyperbilirubinemia treatment by Locally Made Low-Cost Phototherapy Units," *Ethiop J Health Sci*, vol. 31, no. 1, pp. 55-62, Jan. 2021. [Online]. Available: https://www.ajol.info/index.php/ejhs/article/view/204104. [Accessed: Dec 27, 2023].

[19] V. Zanardo et al., "Pilot study of home phototherapy for neonatal jaundice monitored in maternity ward during the enforced Italy-wide COVID-19 national lockdown," *Eur J Pediatr*, vol. 181, no. 9, pp. 3523-3529, Jul. 2022. [Online]. Available: https://link.springer.com/10.1007/s00431-022-04557-x. [Accessed: Dec 27, 2023].

[20] S. Herwiningsih, D. Anggraeni, and M. Dewi, "The Effect of Blue Light Irradiation on Artificial Bilirubin Solution," in Proceeding International Conference on Innovation and Technology 2021, S. Suhartini, Ed., Malang: Journal of Innovation and Applied Technology, 2021, pp. 14–19.

[21] I. Shoris et al., "'Light' on Phototherapy—Complications and Strategies for Shortening Its Duration, A Review of the Literature," *Children*, vol. 10, no. 10, p. 1699, Oct. 2023. [Online]. Available: https://www.mdpi.com/2227-9067/10/10/1699. [Accessed: Dec 27, 2023].

[22] H. Van Rostenberghe, J. J. Ho, C. H. Lim, and I. J. Abd Hamid, "Use of reflective materials during phototherapy for newborn infants with unconjugated hyperbilirubinaemia," *Cochrane Database of Systematic Reviews*, vol. 2020, no. 7, 2020. [Online]. Available: http://doi.wiley.com/10.1002/14651858.CD012011.pub2. [Accessed: Dec 27, 2023].

[23] K. Panneerselvam et al., "Effect of Light-Emitting Diode Phototherapy on Serum Calcium Levels in Neonates With Jaundice," *Cureus*, vol. 14, no. 4, pp. e23938, Apr. 2022. [Online]. Available: https://www.cureus.com/articles/90713-effect-of-light-emitting-diode-phototherapy-on-serum-calcium-levels-in-neonates-with-jaundice. [Accessed: Dec 27, 2023].

[24] H. N. Joel, D. N. Mchaile, R. N. Philemon, R. M. Mbwasi, and L. Msuya, "Effectiveness of Fiberoptic phototherapy compared to conventional phototherapy in treating Hyperbilirubinemia amongst term neonates: a randomized controlled trial," *BMC Pediatr*, vol. 21, no. 1, pp. 32, Dec. 2021. [Online]. Available: https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-020-02458-2. [Accessed: Dec 27, 2023].

[25] M. Pettersson, M. Eriksson, E. Albinsson, and A. Ohlin, "Home phototherapy for hyperbilirubinemia in term neonates—an unblinded multicentre randomized controlled trial," *Eur J Pediatr*, vol. 180, no. 5, pp. 1603-1610, May 2021. [Online]. Available: http://link.springer.com/10.1007/s00431-021-03932-4. [Accessed: Aug 1, 2024].

[26] P. Nuntnarumit and C. Naka, "Comparison of the effectiveness between the adapted-double phototherapy versus conventional-single phototherapy," Journal of the Medical Association of Thailand, vol. 85, no. SUPPL. 4, pp. S1159-66, Nov. 2002. [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/12549790. [Accessed: Aug 1, 2024].