VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

AUTOMATIC PHOTOTHERAPY GARMENT (APG) USING BLUE LED FOR JAUNDICE TREATMENT - A PRELIMINARY DESIGN

Mitra Mohd. Addi[1], Siti Asmah Daud[2], Nurul Atiqah Abdul Ghani and Fauzan Khairi Che Harun[1]
[1]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[2] Faculty of Bioscience and Medical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
E-Mail: mitra@utm.my

ABSTRACT

Phototherapy is a form of treatment for skin conditions, using light sources which are regularly used to treat jaundice. Common light sources used in phototherapy systems include fluorescent lamp, halogen lamp, fibre optic and also light emitting diodes (LED). Currently, blue LEDs are found to be used in phototherapy devices due to its unique characteristics which include high sensitivity towards bilirubin reduction, power efficient, light in weight, less heat production, low in cost and a longer lifetime. Experiments were conducted to compare the efficiency of blue LEDs in reducing bilirubin level in bilirubin solutions, compared to fluorescent light which are commonly used in hospitals. A bilirubin level detector was designed using LabView to measure the bilirubin concentration. Results show that the blue LED were more efficient in reducing bilirubin compared to the fluorescent light (10% - 20% bilirubin degradation) for a time exposure of 30 minutes to 3 hours. In this paper, the design of an automatic phototherapy garment (APV) for infants, using blue LEDs and Arduino microcontroller for use in jaundice treatment is proposed. The proposed garment phototherapy device is portable, uses a small power supply and is easily operated.

Keywords: jaundice, blue LED, phototherapy treatment, bilirubin.

INTRODUCTION

Jaundice or hyperbilirubinemia is the yellow discoloration of the skin, sclera (white of the eyes) and other tissues due to excessive bilirubin in the blood. Almost 60 % to 70 % of infants at the age of 35 weeks to 38 weeks have a greater risk of encountering jaundice, which can either happen in premature or full-term infants [1]. Normally, most infants experience the physiologic jaundice which is a mild type of jaundice. Another type of jaundice is the pathological jaundice which causes damage to the infant's brain, known as kerticterus, due to the deposition of bile pigments in the brain stem. The condition can also cause loss of hearing, late development in growth and yellow staining of the basal ganglio which can lead to death. Factors that contribute to the development of jaundice include blood incompatibility between the mother and infant (different blood rhesus), lack of enzyme which causes unstable red blood cells when exposed to certain substances, virus infections in infant such as rubella, herpes simplex and also syphilis, and immature liver condition during breakdown of red blood cells [2].

Bilirubin is a normal part of the red blood cells. When the body breaks down the red blood cells, the old red blood cells will be removed by the liver from the system. Extra bilirubin will then be stored in the skin and when this happens, it causes the baby's skin to become yellow. A normal infant should have a bilirubin level of less than 35 μmol/L or 2 mg/dL [2,3]. When the bilirubin measurement exceeds the normal level, treatment is required to reduce the bilirubin level.

Traditional jaundice treatment

Conventionally, jaundice is treated by exposing the infant to sunlight, preferably in the early morning or late evening. It is important to not expose the infant directly to sunlight as it can cause burns to the infant's sensitive skin. In the early 1950's, sunlight was found to be able to reduce the yellowing effect on jaundiced infants after a certain period of exposure under the sun [3]. The observation has led future researchers to conduct an experiment using blue fluorescent tubes as light sources to treat jaundice. The results showed that bilirubin level in infants declined when they were exposed to the blue fluorescent tubes, which led to the introduction of phototherapy [3]. In a research by Fadhil M. Salih, it was reported that the absorbance of bilirubin was higher when sunlight was used compared to phototherapy unit for the same time interval [14]. The percentage of bilirubin degradation was close when using sunlight and a phototherapy unit. Sunlight can well be suggested as an alternative source of light in the treatment of neonatal jaundice in circumstances where phototherapy units are not available such as at third world countries or at developing countries. However, the time for sunlight exposure should be monitored very carefully as sunlight could impose biological hazards to the infants as it has considerable amount of ultraviolet radiation [14].

Phototherapy – blue LED vs. other phototherapy lights

Nowadays, the most common medical treatment to cure jaundice is through phototherapy. Infants will be exposed under the phototherapy light for a certain period of time until their bilirubin level decreases to a level that is safe for the infant. By exposing infants under the phototherapy light, bilirubin will discrete from the infants' bodies through their faeces and urine which changes the bilirubin to its break down compound. In phototherapy, when light penetrates the skin, bilirubin will be converted into its isomers (photobilirubin and lumirubin) and removed from the body without the involvement of the liver[2].

Design of phototherapy devices has been developing throughout the years, with the aim of reducing bilirubin level efficiently at shorter exposure durations. The available light sources used in phototherapy devices include fluorescent tubes, halogen spotlights, fibreoptic systems and LEDs, [1,5,6,7,8,12] each with their advantages and disadvantages depending on the specifications and requirements. There are several factors that determine the efficiency of these phototherapy lights which include spectral qualities, irradiance (light intensity), exposed body surface area, duration of exposure, skin thickness and pigmentation, and the amount of bilirubin degradation [1,12.13]. Researches were conducted to identify the best and effective light source for jaundice treatment. A research conducted by YS Chang *et al*. compared the percentage of bilirubin degradation for in vitro and in vivo experiment using LED and halogen bulb as the phototherapy light source [12]. Based on the result obtained, the percentage of bilirubin degradation was higher when using blue LED compared to the conventional phototherapy (using halogen bulbs). It was proven that after the exposure time, the percentage of bilirubin degradation when using blue LED increased to 44% for in vitro and 30% for in vivo meanwhile when using conventional light source the percentage of bilirubin was 35% and 16% for both in vitro and in vivo respectively. The study concluded that blue LED as a light source was more efficient than conventional light source for degradation of bilirubin. The efficacy was determined by two major factors which was the wavelength and the intensity of the light emitted during phototherapy.

Bilirubin was found to be more sensitive to blue and blue-green regions of the visible spectrum as it is closer to the bilirubin absorbance spectrum [4]. The most suitable wavelength ranges between 400 nm – 520 nm with a peak of 460 nm ± 10 nm [1]. A research by Vreman *et al.* compared the efficiency between different color of the LEDs and also compared the efficiency of other phototherapy light sources (Mini Bili Lite, BiliBlanket, Photo-Spot, and Bili Lite) [8]. Results from the experiments showed that blue LED was proven to be able to reduce bilirubin level by 28 % followed by blue-green LED, white light and green LED with the percentage of bilirubin degradation of 18 %, 14 % and 11 % respectively. The in vitro efficacy of bilirubin degradation was then compared between blue LEDs and several conventional phototherapy devices. The greatest irradiance and the most effective light source for bilirubin degradation were when using blue LED (60 % bilirubin degradation). Both Mini Bili-Lite and BiliBlanket were able to degrade 44 % - 45 % of bilirubin. In another research, Vreman *et al.* found that Portabed and neoBlue (which uses blue LED) took shorter time to reduce bilirubin level in both preterm and tern neonates [13]. Important factors that were found to determine the potential efficacy of a device include the quality of light, size of the subject, mean irradiance of the treatable body surface area (BSA) and percentage treatable BSA.

The conditions for phototherapy treatment in hospitals require infants to be uncovered, to expose as much skin to the light. In order to maximize exposed body surface area, an infant's posture needs to be changed in every 2 hours to 3 hours [5]. The greater the exposed surface area the greater the rate of total bilirubin declination [14]. Infants with thick and highly pigmented skin may prevent the effectiveness of phototherapy [1]. Infants need to wear eye patches as well to protect their eyes from the lights. These conditions are not preferable as infants tend to remove the eye patches and can easily get cold. Besides that, it is also not encouraging for breastfeeding mothers as the phototherapy treatment needs to be continuous and not interrupted. Breastfeeding mothers may not be able to feed their babies naturally on time and need to pump out their milk in the bottle for the nurse to feed the babies.

Portable phototherapy light was designed to make phototherapy treatment possible anywhere. However, there are still several weaknesses on the design as it does not have any indicator or protection for the infant in case when the infant's temperature increases [1,5,8]. The Automated Phototherapy Garment (APV) is proposed as an alternative phototherapy device for infant. By using the APV, mothers no longer have to leave their babies at the paediatric wards and they are able to monitor their own baby's condition. Mothers can also breastfeed even during the treatment. The device is proposed with safety features which prevent infants from getting over exposure. The APV may also be an alternative for users who have difficulties or limited access to the hospital.

METHODOLOGY

Bilirubin degradation experiment (blue LED vs. fluorescent light)

Bilirubin (Sigma Aldrich) solutions were prepared by dissolving 5 mg of bilirubin in 10 ml of a 0.05 M Sodium Hydroxide (NaOH). Several dilutions of standard bilirubin solution were prepared (50 mg/dL to 500 mg/dL*)* by diluting the concentrated solution with saline to obtain a calibration curve of absorbance versus bilirubin concentration.

An experiment was conducted to compare the efficiency of blue LED in reducing bilirubin compared to the conventional method, using fluorescent light which is commonly used in hospitals. Eighteen (18) 10 mm high intensity super bright blue LEDs (China Young Sun LED Technology Co. Ltd) were used in the experiment. The dominant wavelength of the blue LED is between 465 nm – 470 nm which is suitable in reducing bilirubin. To compare the performance of the blue LED and conventional phototherapy light source, a fluorescent tube (Philips TL/52 20 W) was used in the experiment. The wavelength of the fluorescent light is 400 nm to 500 nm with its maximum wavelength at 450 nm.

VOL. 10, NO. 21, NOVEMBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-1 illustrates the bilirubin degradation experiment using blue LED and fluorescent light. Two (2) sets of five (5) samples of 100 mg/dL bilirubin solution were prepared (each in a clear cuvette). The first set of bilirubin solutions were exposed to blue LEDs and the other set were exposed to fluorescent light at five different time intervals; 10 minutes, 30 minutes, 60 minutes, 120 minutes and 180 minutes. The absorbance value for each sample was measured before and after the light exposure using a spectrophotometer (Spectrum lab 752s). A bilirubin level detector system was developed using LabView, to measure the bilirubin concentration by converting the absorbance data from the spectrometer into bilirubin concentration. The graphical user interface enables user to compare bilirubin measurements of several samples which can be saved into Microsoft Excel for future reference.

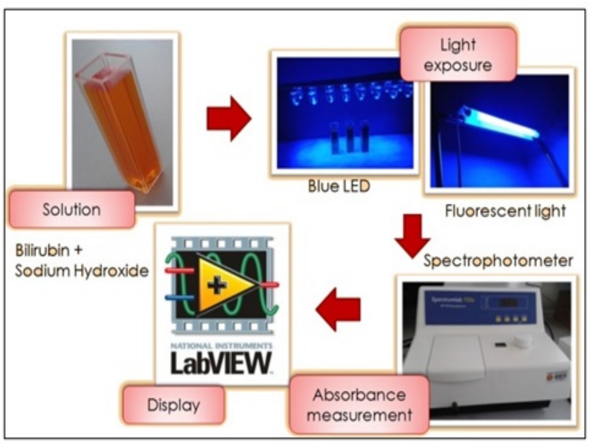

Figure-1. Bilirubin degradation experiment set up.

Design of the automatic phototherapy garment (APG)

There are several factors that need to be considered to determine the LEDs' arrangement on the garment. These include the effective light field, light wavelength and also maximum power dissipation of the UV LEDs[1]. The irradiance of the blue LEDs was determined as in Equation. (1) and Equation. (2). The LED peak wavelength, λ_{peak} and maximum power dissipation, P_{max} were obtained from the data sheet with the values as below.

LED Peak Wavelength, λ_{peak} = 465nm – 470nm
Maximum Power Dissipation, , P_{max} = 180mW

$$L = l \times w = 3cm \times 3cm = 9cm^2 \quad (1)$$

where L is the effective light field, l is the length and w is the width of LED exposure are. From the data obtained above, irradiance of the LEDs can be calculated.

$$E = \frac{P_{max}/L}{\lambda_{peak}} = \frac{180\ mW/9cm^2}{467.5nm} = 42.78\ \mu W \bullet nm\ /\ cm^2 \quad (2)$$

where E represents irradiance, P_{max} is the maximum power dissipation, λ_{peak} is the peak wavelength.

According to the American Academy of Paediatrics (AAP), the required irradiance for phototherapy to be delivered to infants should be at least 30 µW/cm^2/nm to the greatest surface area available [9]. The calculated irradiance obtained is 42.78 µW/cm^2/nm which fulfils the AAP requirement.

Figure-2 illustrates the component layout of the proposed APG. The system is controlled by the Arduino Uno microcontroller, an open source electronics prototyping platform which is commonly used in designing interactive devices. All the blue LEDs were sewn on the garment using conductive threads which allows current flow. The push button is used to set the duration of treatment which will be only enabled when the infant's body temperature is within the normal range (36 °C -37 °C).

The operation of the system is described in Figure-3. The timing circuit and the blue LEDs will be switched on once the time selection is set. The temperature detector sensor continuously measures the infant's body temperature throughout the treatment period. All temperature readings and set time for the treatment will be displayed on the liquid crystal display (LCD). The device will automatically turn off and trigger the buzzer once the treatment period is complete.

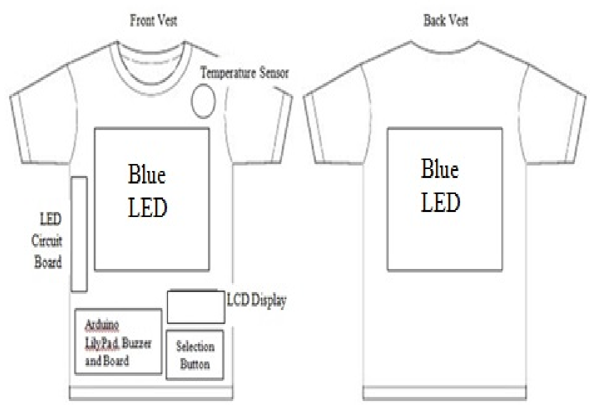

Figure-2. Automatic phototherapy garment (APG) component layout.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

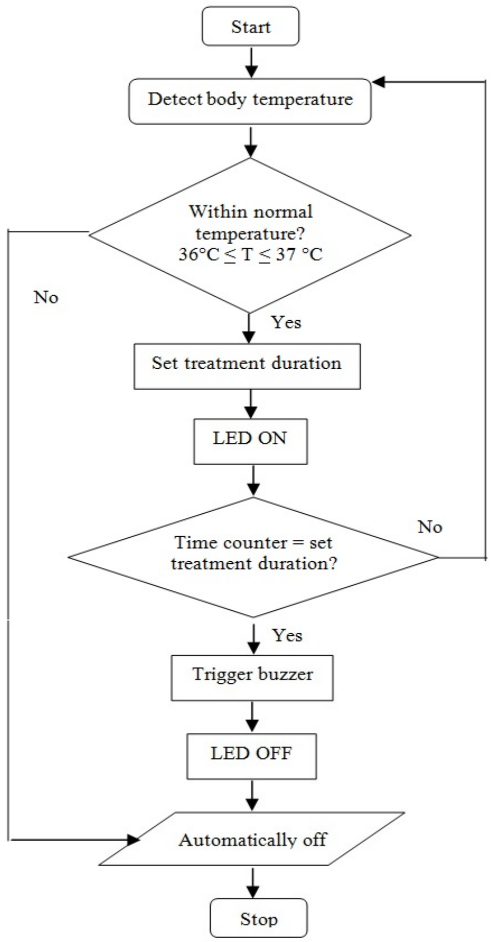

Figure-3. Automatic phototherapy garment (APG) operational flow.

RESULTS & DISCUSSION

Relationship of absorbance and bilirubin concentration

From the bilirubin concentration and absorbance calibration experiment, the relationship shown in Figure-4 was obtained. It is proven that absorbance and bilirubin concentration is linearly proportional with a high correlation value. Absorbance increases with higher values of bilirubin concentration.

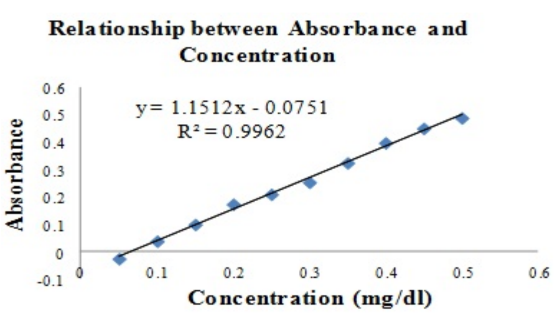

Figure-4. Calibration curve of absorbance and bilirubin concentration.

Blue LED vs fluorescent light – A comparison

Figure-5 illustrates the user interface of the bilirubin level detector using LabView as a platform to measure bilirubin samples in samples of bilirubin solutions. The system is able to automatically convert absorbance data from the spectrometer into bilirubin concentration. The LabView interface shown in Figure-5 is able to display up to four measurements simultaneously on the screen, making it easier for the user to compare between several data measurements. The data can also be saved in Microsoft Excel for future reference.

Figure-6 shows the percentage of bilirubin degradation after light exposure for both blue LED and fluorescent light. Results from the bilirubin samples that were exposed to blue LEDs gave a higher concentration difference, before and after light exposure, as shown in Table-1. These samples also showed a higher percentage difference (between 2 to 10 times more) in bilirubin degradation compared to the samples which were exposed to the fluorescent light. The experimental findings proved that blue LEDs are more efficient in reducing bilirubin compared to fluorescent light. Results also exhibit that bilirubin degradation was higher with longer time of exposure for both light sources [1,13]. For an effective treatment, serum bilirubin concentration should show a decrease of more than 2 mg/dL (34 µmol/L) within 4 to 6 hours of initiation and treatment should be stopped once bilirubin level is below 200 µmol/L [10].

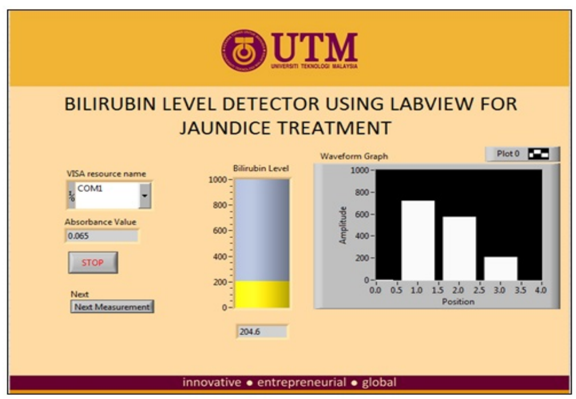

Figure-5. User interface of bilirubin level detector.

Table-1. Percentage difference in bilirubin degradation (Blue LED vs fluorescent light).

Time (mins)	Concentration (mg/dl)					
	Blue LEDs			Fluorescent Light		
	Before	After	Difference (%)	Before	After	Difference (%)
10	0.117	0.116	0.85	0.119	0.119	0
30	0.115	0.103	10.43	0.117	0.116	0.87
60	0.113	0.098	13.27	0.114	0.112	1.75
120	0.113	0.095	15.92	0.111	0.106	4.39
180	0.107	0.086	19.63	0.101	0.092	8.91

ARPN Journal of Engineering and Applied Sciences

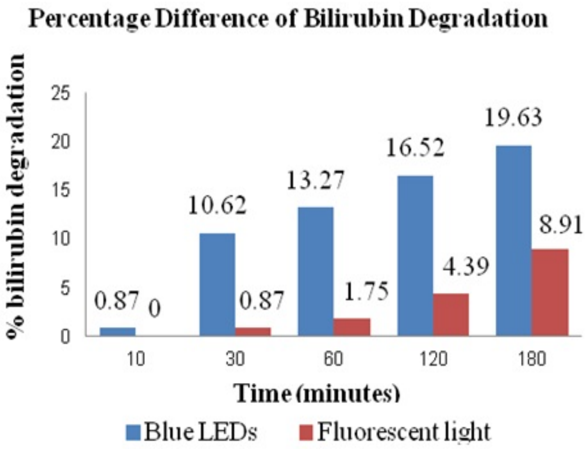

Figure-6. Comparison of bilirubin degradation in blue LED and fluorescent light (in percentage, %).

Operation of the automated phototherapy garment (APG)

When the APG is switched on (as in Figure-7), it will greet the user with a welcome note (Figure-8(a)) and display the current infant's body temperature (Figure-8(b)). The device will only enable user to set the duration of treatment if the detected body temperature is within the range of the set temperature (36°C - 37°C).

To start the treatment, a user needs to choose and set the appropriate duration of treatment (Figure-8(b)). Once the duration is set, the user needs to press the ON push button and the treatment will start automatically. All the blue LEDs will be switched on for the desired duration, as shown in Figure-7 and Figure-8(c). The temperature sensor will measure the infants' body temperature in every one (1) second and will be displayed on the LCD. Once the treatment is complete, the buzzer will be triggered to alarm the user and a complete notification message will be displayed on the LCD (Figure-8(d)).

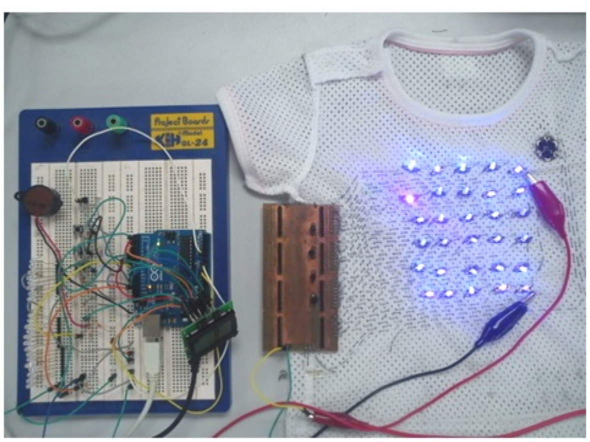

Figure-7. APG full set up (switched ON).

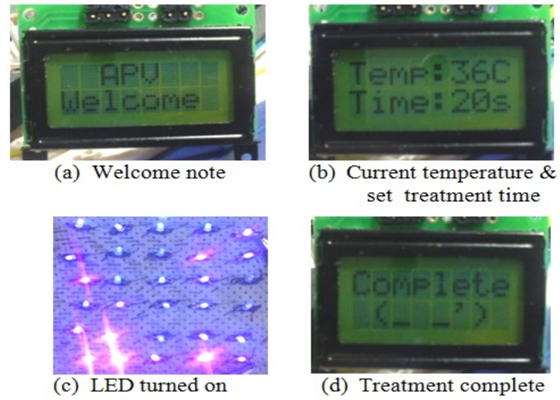

Figure-8. Complete operation of APG.

CONCLUSIONS

Blue LEDs which are proposed to be used as the light source in the APG was proven to be able to reduce bilirubin level more effectively (2 to 10 times more) compared to the conventional phototherapy device, such as the fluorescent light.

A simple spectrophotometric method was used to measure the bilirubin level as it is easy to operate, highly sensitive and is widely used for data analyzing in industrial applications. A bilirubin level detector system using LabView was developed to measure bilirubin concentration by converting absorbance readings from the spectrometer into bilirubin concentration. The graphical user interface enables user to compare bilirubin measurements of up to four samples which can be saved into Microsoft Excel for future reference.

The design of the Automated Phototherapy Garment (APG) was proposed as an alternative phototherapy device for infants. The emitting blue LEDs from the phototherapy garment is able to emit the desired power which will help in reducing bilirubin level in an infants' body. The device is also able to monitor the infants' body temperature and automatically turns OFF when the detected temperature exceeds the limit temperature set in the device. The required power supply is small and the garment is easy to wear and comfortable to be operated at the hospital or even at home. The battery for the device can be easily replaced and the cost is of the device is also low. By using the APG, user/guardians no longer have to leave their babies at the paediatric wards for phototherapy treatment and they are able to monitor their own baby's condition. Mothers can also breastfeed even during the treatment. The device will automatically turn OFF once treatment is complete and this prevents, the infants from getting an over exposure of the blue LED light even when the user/guardian is unaware of it. The buzzer will also acts as an alarm to remind the user/guardian that the treatment period has end and for them to attend to their babies.

ACKNOWLEDGEMENTS

This work has been supported by the Centre for Student Innovation (CSI) of Universiti Teknologi Malaysia (UTM).

REFERENCES

[1] Vreman H. J., Wong R. J. and Stevenson D. K. 2004. Phototherapy: Current Methods and Future Directions. Seminars in Perinatology. Vol. 28, No. 5, pp. 326-333.

[2] Academy of Medicine, Ministry of Health Malaysia. 2003. Management of Jaundice in Healthy Term Newborns. Clinical Practice Guideline. MOH/P/PAK/62.03 (GU).

[3] M. Jeffrey Maisels and M., BCh. 2001. Phototherapy - Traditional and Nontraditional. Journal of Perinatolology. Vol. 21, S93-S97.

[4] Wentworth S. D. 2005. Neonatal Phototherapy– Today's Lights, Lamps and Devices. Infant, Vol. 1, No. 1, pp. 14-19.

[5] Bhutani, V. K. 2011. Phototherapy to Prevent Severe Neonatal Hyperbilirubinemia in the Newborn Infant 35 or More Weeks of Gestation. Pediatrics, Vol. 128, No. 4, pp. 1046-1052.

[6] Carvalho, M., Carvalho, D., Trzmielina, S., Lopes, J. M. A., & Hansen, T. W. R. 1999. Intensified Phototherapy using Daylight Fluorescent Lamps. Acta Paediatrica, Vol. 88, No. 7, pp. 768-771.

[7] Maisels M. J. 1996. Why Use Homeopathic Doses of Phototherapy?.Pediatrics, Vol. 98, No. 2, pp. 283-287.

[8] Vreman H. J., Wong R. J., Stevenson D. K., Route R. K., Reader S. D., Fejer M. M. and Seidman D. S. 1998. Light-emitting Diodes: A Novel Light Source for Phototherapy. Pediatric Research, Vol. 44, No. 5, pp. 804-809.

[9] Subcommittee of Hyperbilirubinemia 2004. Management of Hyperbilirubinemia in the Newborn Infant 35 or More Weeks of Gestation, Pediatrics. Vol. 114, No. 1, pp. 297-316

[10] Mahajan G., Kaushal R. K., Sankhyan N., Sharma R. L. and Nakra, M. 2005. Transcutaneous Bilirubinometer in Assessment of Neonatal Jaundice in Northern India. Indian Pediatr, Vol. 42, No. 1, pp. 41-45.

[11] Department of Health. 1992 The Application of Phototherapy. Health Equipment Information (HEI) No. 202 September 1992.

[12] Chang Y. S., Hwang J. H., Kwon H. N., Choi C. W., Ko S. Y., Park W. S. and Lee M. 2005. In Vitro and In Vivo Efficacy of New Blue Light Emitting Diode Phototherapy Compared to Conventional Halogen Quartz Phototherapy for Neonatal Jaundice. Journal of Korean Medical Science, Vol. 20, No. 1, pp. 61-64.

[13] Hendrik J. Vreman, R.J.W., David K. Stevenson, *et al*. 2004. In vitro Efficacy Measurement of LED-Based Phototherapy Devices Compared to Traditional Light Sources In a Model System. EASL International Bilirubin Workshop, pp. 51-56.

[14] Salih F. M. 2001. Can Sunlight Replace Phototherapy Units in the Treatment of Neonatal Jaundice? An In Vitro Study. Photodermatology, Photoimmunology & Photomedicine, Vol. 17, No. 6, pp. 272-277.