THE EFFICACY OF DIFFERENT TYPE OF PHOTOTHERAPY LIGHT DEVICES FOR NEONATAL JAUNDICE TREATMENT

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ABSTRACT

It has been reported that 60% of term neonates and 80% of the pre-terms develop jaundice in the first week of life and the proportion of jaundice in Malaysia is on the rise. As phototherapy light is the primary source of treatment for jaundice, it is crucial for hospital to have the best phototherapy light devices which can help to treat jaundice effectively. This would help to shorten neonate patient hospital stay, reduce staff workload as well as increasing treatment capacity of the hospital. Hospitals in Malaysia are using several type of phototherapy devices in their wards. The most commonly found are Light Emitting Diode (LED) and conventional fluorescent light devices. This observational study compares the efficacy of three different types of phototherapy light devices; LED, 6-tubes fluorescent light & 4-tubes fluorescent light in jaundice treatment. Total of 15 term infant subject patients were included and assigned into three groups where 5 patients were treated for each device group. Inclusion criteria for the subject includes term patient, admission weigh of more than 2.5kg and reached total serum bilirubin (TSB) level which need phototherapy treatment. The primary outcome measured was the rate of TSB reduction in jaundice patients within 24 hours period while the secondary outcome measured was the total treatment time needed for every jaundice patient prior to discharge. For primary outcome, results showed the rate of mean TSB reduction for LED is significantly higher than both of the conventional fluorescent light devices ($P<0.05$). Meanwhile, the rate of mean TSB reduction for both 6-tubes and 4-tubes fluorescent light devices were similar ($P>0.05$). For secondary outcome, although LED recorded the shortest mean treatment time prior to discharge, there is no significant difference in the mean treatment time between each group of phototherapy light devices ($P>0.05$). This study concludes that LED phototherapy light device is more efficacient that both type of conventional phototherapy devices; 4-tubes and 6 tubes fluorescent light devices in reducing TSB level of jaundice patient.

ABSTRAK

Dilaporkan sebanyak 60% neonat matang dan 80% neonat pra-matang menghidap penyakit jaundis pada minggu kelahiran yang pertama dan kadar ini semakin meningkat di Malaysia. Lampu fototerapi merupakan sumber utama rawatan jaundis, jadi amat penting bagi hospital untuk mempunyai peranti fototerapi terbaik dalam membantu merawat jaundis dengan berkesan. Hal ini akan membantu memendekkan tempoh rawatan pesakit neonat di hospital, mengurangkan beban kerja staf di samping meningkatkan kapasiti rawatan di hospital. Hospital-hospital di Malaysia menggunakan beberapa jenis peranti fototerapi di dalam wad mereka. Jenis yang selalu digunakan ialah Diod Pemancar Cahaya (LED) dan peranti cahaya pendarfluor konvensional. Kajian melalui pemerhatian ini membandingkan keberkesanan tiga jenis peranti fototerapi yang berbeza; LED, lampu pendarfluor 6-tiub & lampu pendarfluor 4-tiub dalam merawat jaundis. Sebanyak 15 pesakit neonat matang diambil menjadi subjek dan dibahagikan ke dalam tiga kumpulan di mana 5 pesakit dirawat untuk setiap kumpulan peranti. Kriteria pemilihan untuk subjek merangkumi pesakit matang, berat masuk melebihi 2.5kg dan mempunyai kadar jumlah serum bilirubin (TSB) yang memerlukan rawatan fototerapi. Objektif utama kajian yang diukur adalah kadar pengurangan TSB pada pesakit jaundis dalam tempoh 24 jam manakala objektif kedua yang diukur adalah jumlah masa rawatan yang diperlukan untuk setiap pesakit jaundis sebelum discaj. Bagi objektif utama, keputusan menunjukkan purata kadar pengurangan TSB untuk LED lebih tinggi secara signifikan berbanding kedua-dua peranti cahaya pendarfluor konvensional ($P<0.05$). Sementara itu, purata kadar pengurangan TSB bagi kedua-dua peranti lampu pendarfluor 6-tiub dan 4-tiub adalah sama ($P>0.05$). Bagi objektif kedua, walaupun LED mencatat purata tempoh rawatan paling singkat sebelum discaj, namun tiada perbezaan yang signifikan bagi purata tempoh rawatan antara setiap kumpulan peranti cahaya fototerapi ($P>0.05$). Kajian ini menyimpulkan bahawa peranti LED lebih berkesan daripada kedua-

dua jenis peranti fototerapi konvensional; peranti cahaya pendarfluor 4-tiub dan 6 tiub dalam mengurangkan kadar TSB pesakit jaundis.

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LIST OF SYMBOLS AND ABBREVIATIONS

LED	:	Light-emitting diode
TSB	:	Total serum bilirubin
G6PD	:	Glucose-6-phosphate dehydrogenase
ET	:	Exchange transfusion
AAP	:	American Academy of Paediatrics
NICU	:	Neonatal Intensive Care Unit

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CHAPTER 1: INTRODUCTION

1.1 Overview

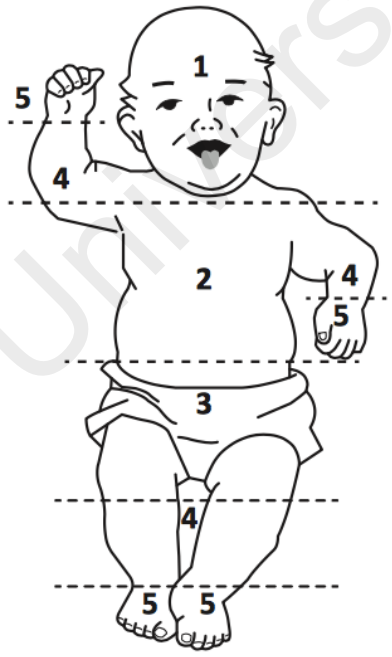
Referring to Cigna Health Care Coverage Position through their report title Home Phototherapy for Hyperbilirubinemia said that Hyperbilirubinemia, or neonatal jaundice, is a condition in which there is a higher-than-normal level of bilirubin in the blood. (Cigna Health Care, 2005) Bilirubin is a yellowish, water-soluble pigment found in the blood when it replaces old red blood cells. Liver would help to excrete the conjugated bilirubin through urine and stool. However, unconjugated bilirubin is not water soluble and may remain in the blood. Hyperbilirubinemia is a common condition of newborns characterized by yellow eyes and skin as shown in figure 1.1 below. The condition is the result of an imbalance between the production and excretion of bilirubin (Olusanya, Osibanjo, & Slusher, 2015)

.

Figure 1.1: A jaundice baby showing yellow skin and eyes (Sangopan, 2016)

Neonatal jaundice remains a colossal issue worldwide, especially in developing countries where resources are always limited. It affects 84% of term newborn babies. (Bhutani, et al., 2013) The majority of these neonates has benign course; however, in 2%-5% of cases, serum unconjugated bilirubin can go up to dangerous levels, leading to chronic bilirubin encephalopathy; a permanent brain damage. (Sgro M, 2006)

Initial screening for detection of jaundice is usually done by visual assessment Kramer's Rule. This is assessed by observing the severity and to what extent the yellow discolouration appear on the neonate's skin. Medical practitioner would usually blanch the neonate's skin with slight finger pressure and the underlying colour of the skin would be noted. Jaundice would be apparent at the bilirubin levels of 5 to 7 mg/dL or 86 to 120 µmol/L and advances from head to toe as the unconjugated bilirubin level rises in the body. (Kramer, 1969) Figure 1.2 shows the correlation between the progression of skin discolouration of body parts and the serum bilirubin levels.



Area of the Body	Level	Range of Serum Bilirubin	
		µmol/L	mg/dL
Head and neck	1	68 - 133	4 - 8
Upper trunk (above umbilicus)	2	85 - 204	5 - 12
Lower trunk and thighs (below umbilicus)	3	136 - 272	8 - 16
Arms and lower legs	4	187 - 306	11 - 18
Palms and soles	5	≥306	≥18

Figure 1.2: Relationship of skin discolouration of each body area and the range of serum bilirubin based on Kramer's Rule (Kramer, 1969)

When the yellow colour of the skin is obvious, every neonate would undergo Total Serum Bilirubin (TSB) measurement in the clinical laboratory based on the neonate's blood sample. The blood sample is usually taken from the neonate's tissue in heel using heel stick collection method. Spectrophotometry would be run to identify and quantify the bilirubin amount in a specific amount of serum. It measures the amount of ultraviolet light absorbed by bilirubin pigment in the neonate's blood sample, producing results in milligrams per desiliter (mg/dL). (Maisels, 2000) This TSB measurement is a gold standard in determining the level of neonatal jaundice.

Based on the TSB level of neonates, their treatment strategy would be further determined based on their gestational age and risk factors including sepsis, isoimmune haemolytic disease, neonatal encephalopathy, and G6PD deficiency. For example, common cases hyperbilirubinemia with neonate gestational age of more than or equal to 35 weeks, the indication for treatment is summarised in the table 1.1 below:

Table 1.1: Threshold patient TSB level for phototherapy treatment and exchange transfusion (American Academy of Pediatrics Subcommittee on Hyperbilirubinemia, 2004)

Age	LOW RISK ≥38 weeks and well		MEDIUM RISK ≥38 weeks with risk factors or 35 - 37 weeks + 6 days and well		HIGH RISK 35 - 37 weeks + 6 days with risk factors	
Hours of life	Conventional Phototherapy - TSB in mg/dL (μmol/L)	ET - TSB in mg/dL (μmol/L)	Conventional Phototherapy - TSB in mg/dL (μmol/L)	ET - TSB in mg/dL (μmol/L)	Conventional Phototherapy - TSB in mg/dL (μmol/L)	ET - TSB in mg/dL (μmol/L)
<24*						
24	9 (154)	19 (325)	7 (120)	17 (291)	5 (86)	15 (257)
48	12 (205)	22 (376)	10 (171)	19 (325)	8 (137)	17 (291)
72	15 (257)	24 (410)	12 (205)	21 (359)	10 (171)	18.5 (316)
96	17 (291)	25 (428)	14 (239)	22.5 (385)	11 (188)	19 (325)
>96	18 (308)	25 (428)	15 (257)	22.5 (385)	12 (205)	19 (325)

Phototherapy is an effective treatment for hyperbilirubinemia and is easily available and devoid of major complications compared to exchange transfusion (ET) which has got a complication rate of 4%-5%. (American Academy of Pediatrics Subcommittee on Hyperbilirubinemia, 2004)

Figure 1.3 A neonate jaundice patient is being treated with phototherapy light (Churchill, 2017)

The success of phototherapy depends on the photochemical transformation of bilirubin in areas exposed to light. (McDonagh, 1984) This reaction alters the molecular structure of bilirubin and allows photoproducts to be eliminated by the kidneys and liver without being metabolically transformed. Therefore, the basic mechanism of action of phototherapy is the use of photoenergy to transform bilirubin into more hydrosoluble products. (Dennery, Seidman, & Stevenson, 2001) Bilirubin absorbs light in the region from 400 to 500nm. The light emitted in this spectrum enters the epidermis and reaches subcutaneous tissue. Thus, only bilirubin found close to the skin surface (2 mm) is directly affected by light. (Agati & Fusi, 1990)

The efficacy of phototherapy also depends on the spectrum of light emitted (optimal within blue to green spectrum of 460-490 NM), irradiance, and footprint (body surface area covered). (Ennever, 1990) The dose of phototherapy largely determines how quickly it works; the dose, in turn, is determined by the wavelength of the light, the intensity of the light (irradiance), the distance between the light and the infant, and the body surface area exposed to the light. Commercially available phototherapy systems include those that deliver light via fluorescent bulbs, halogen quartz lamps, light-emitting diodes, and fibre optic mattresses.

1.2 Problem Statement

It has been reported that 60% of term neonates and 80% of the pre-terms develop jaundice in the first week of life and the proportion of jaundice in Malaysia is on the rise. (Chou, et al., 2003) As phototherapy light is the primary source of treatment for jaundice, it is crucial for hospital to have the best phototherapy light device which can help to treat jaundice effectively. This would help to shorten neonate patient hospital stay, reduce staff workload as well as increasing treatment capacity of the hospital. (Yilmaz, Ozkiraz, Akcan, & Canpolat, 2015)

Hospitals in Malaysia are using several type of phototherapy devices in their wards. These include Light Emitting Diode (LED), fluorescent tube, halogen bulb and fibreoptic cable. As the jaundice cases is high, hospitals especially the more visited government hospitals need to have the best option for their phototherapy light devices.

This paper would help to identify the best type of phototherapy device for the effective treatment of neonatal jaundice.

1.3 Aim of study

The aim of this research is to compare the efficacy of different type of phototherapy light devices in neonatal jaundice treatment. This would help to identify the best type of phototherapy light devices to treat jaundice patients.

1.4 Objective of Study

The objectives of this study are:

1) To compare the rate of TSB reduction in jaundice patients within 24 hours period between 4-tubes fluorescent device, 6-tubes fluorescent device and LED device
2) To compare the total treatment time needed for every jaundice patient before discharge between 4-tubes fluorescent device, 6-tubes fluorescent device and LED device

1.5 Scope of Study

This study involved 3 different phototherapy light devices including one LED and two fluorescent type (4-tubes and 6-tubes). Each of these devices were used to treat 5 term infant patient with jaundice and needed phototherapy treatment (15 patients in total). 15 patients were selected which satisfy the following inclusion criteria;

a) Term patient (have gestational age equal to, or more than 38 weeks);

b) Admission weight of more than 2.5kg;

c) Patient reached TSB level needed for phototherapy treatment based on the guidelines by American Academy of Paediatrics.

The study and data collection were conducted in Neonatal Intensive Care Unit (NICU) Department of Hospital Sungai Buloh.

CHAPTER 2: LITERATURE REVIEW

2.1 Hyperbilirubinemia & Treatment

Jaundice or hyperbilirubinemia condition occurs when unconjugated bilirubin pigment deposited in the skin and mucus membrane. Bilirubin is a yellow pigment produced during normal breakdown of red blood cell. It is a waste product that would be filtered out from blood in liver and undergo excretion in bile which will eventually eliminated via stool.

However in newborn, the bilirubin production rate is actually more than twice the production in adult; at a rate of approximately 6 – 8 mg per kg per day. This is due to high red blood cell turnover as well as relative polycythaemia. (Gartner & Herschel, 2001) As the liver of the neonate is not fully matured yet, it could not filter out the high bilirubin produced thus causing excessive amount of unconjugated bilirubin. The yellowish colour of the skin usually can be seen two to four days after birth. This situation is illustrated in the figure 2.1 below.

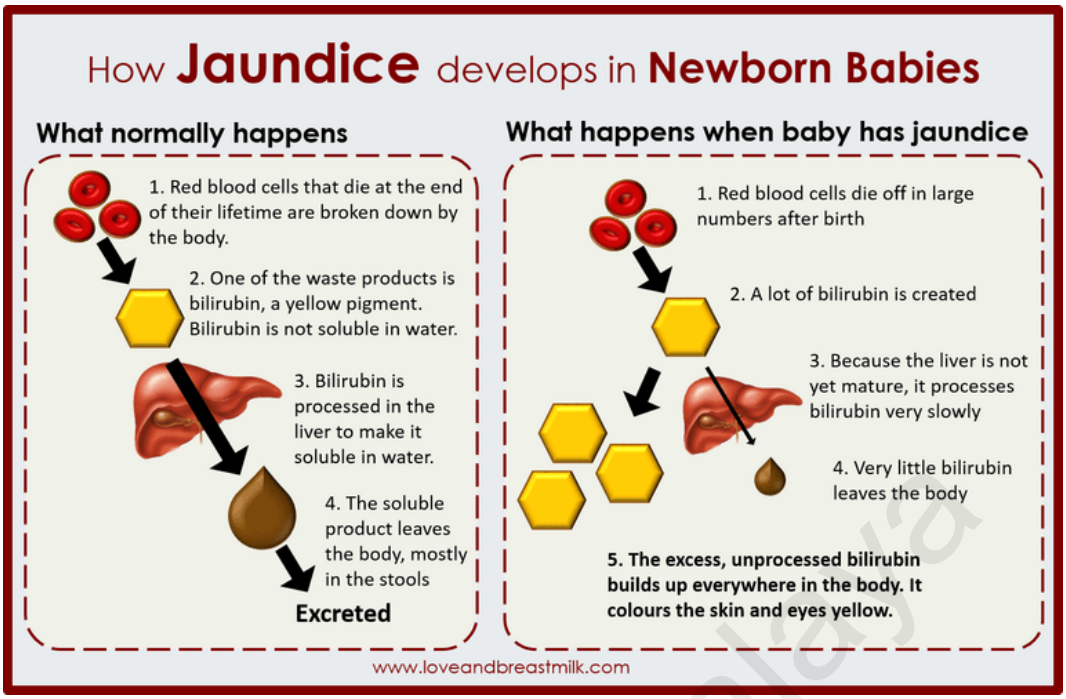


Figure 2.1: Condition in neonate body which causing jaundice to develop (Love and Breast Milk, 2017)

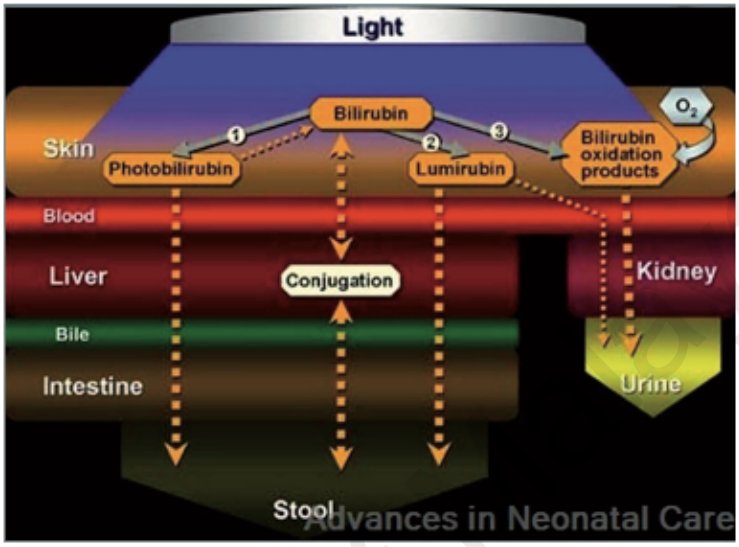
In many cases, jaundice cases are mostly benign and does not pose serious health risk to the neonate. It would usually subside within one to three weeks as the liver mature and neonate feed more which help to excrete excess bilirubin from the body. However, uncontrolled high level of bilirubin could lead to kernicterus, bilirubin encephalopathy and neurologic dysfunction.

There are 2 common treatment for jaundice; mostly common phototherapy treatment and blood exchange transfusion.

2.2 Phototherapy as Jaundice Treatment

Phototherapy is currently the gold standard in treating neonatal jaundice. It involves the usage of visible light to lower the bilirubin level. This light reduces the level of serum bilirubin in the blood by breaking down the bilirubin present in the skin

interstitial spaces and superficial capillaries, into water-soluble isomer which could be excreted without conjugation in the liver. This mechanism is illustrated in figure 2.2 below:



The mechanism of phototherapy. When bilirubin molecules absorb light, 2 main photochemical reactions occur: Native 4Z, 15Z-bilirubin converts to 4Z, 15E bilirubin (also known as photobilirubin) and to lumirubin. Unlike 4Z, 15Z bilirubin, photobilirubin can be excreted via the liver without conjugation, but its clearance is very slow and its conversion is reversible. In the bowel (away from the light), photobilirubin is converted back to native bilirubin. Lumirubin is not reversible. So, although much less lumirubin than photobilirubin is formed, lumirubin is cleared from the serum much more rapidly, and it is likely that lumirubin formation is primarily responsible for the decline in serum bilirubin that results from phototherapy. Small amounts of native bilirubin are also oxidized to monopyrroles and dipyrroles that can be excreted in the urine. This is a slow process and only a minor contributor to the elimination of bilirubin during phototherapy. Diagram courtesy of Mary Puchalski.

Figure 2.2: Mechanism of phototherapy in breaking down bilirubin

(Stokowski, 2011)

In this process, the bilirubin absorb the infusion of discrete photons from the illumination of light onto the skin. Rapid photochemical reaction would then occurred within the bilirubin molecules including photooxidation, structural isomerization and configurational isomerization, in order to create excretable and non-toxic isomers. These newly formed isomers has more polarity and different shape than the original isomer thus allowing its excretion from bile into the liver without the need to undergo conjugation or need for special excretion transport. (Ebbesen, Madsen, Stovring, & Hundborg, 2007) The excess bilirubin level excretion would also be helped by urinary and gastrointestinal elimination.

2.3 Factors Affecting The Efficacy of Phototherapy Treatment

The efficacy of the bilirubin reduction is mainly affected by the dose of phototherapy. This dose is influenced by this several key factors as below (Maisels, 2000):

- Wavelength range and peak of the light source (Spectral qualities)
- Irradiance of the light (Intensity)
- Distance between light source and neonate skin
- Surface area illuminated by the light source (Footprint)

2.3.1 Wavelength range and peak of the light source (Spectral qualities)

Vreman et al. explained the most effective light source to breakdown bilirubin would emit light in a narrow wavelength range between 400 to 520 nanometers (nm) with a peak at 460±10 nm. (Vreman, Wong, & Stevenson, 2004) Light penetrates skin at great capacity and bilirubin would undergo maximal light absorption at these wavelengths. The

most effective colour based on the wavelength would be blue colour, along with green and turquoise light (blue-green spectrum) (Maisels, 2000)

2.3.2 Irradiance of the light (Intensity)

Irradiance, or the intensity of the light is determined by the number of photons emitted per square centimetre of exposed body surface. The spectral irradiance is proportional to the efficacy of bilirubin breakdown where the higher the irradiance, the faster the time taken to reduce the serum bilirubin level. (Tan, 1982) The irradiance of any light source is quantified in $\mu W/cm^2/nm$. This can be measured using a spectral radiometer which responds to light's effective wavelength. For a high TSB level patient, an intensive phototherapy treatment would be preferred which require irradiance of more than $30\mu W/cm^2/nm$

2.3.3 Distance between light source and neonate skin

Like any normal light properties, the intensity of light is inversely proportional to the distance between the light source and the target. The intensity of the light source received by the neonate body surface increases as the light become closer. Thus the phototherapy light would break down more efficiently as the light moves closer to the neonate skin surface. However, manufacturer would usually specify the optimal distance between the light source and body surface in order to get maximum result with least possible risks or side effects. Normally it would be between 30-40cm distance.

2.3.4 Surface area illuminated by the light

As the surface area illuminated by the light increases, the rate of serum bilirubin reduction increases. This is because higher number of bilirubin molecules within the larger illuminated area would react to the light making the phototherapy more efficient. Quite a number of phototherapy light sources used does not cover sufficient area of neonate skin to the light radiation. This phototherapy light usually have concentrated irradiance towards their footprint centre, but declines drastically towards the outer edge of the illumination area as show in the figure 2.3 below. (Hart & Cameron, 2005) This may cause only a proportion of the neonate body receives effective dose to allow efficient bilirubin breakdown. To solve this issue, the neonate patient need to be well positioned inside the efficient footprint of the phototherapy light or with the use of multiple phototherapy light source for coverage of minimum 80% of the skin surface. (Buhatin, 2009)

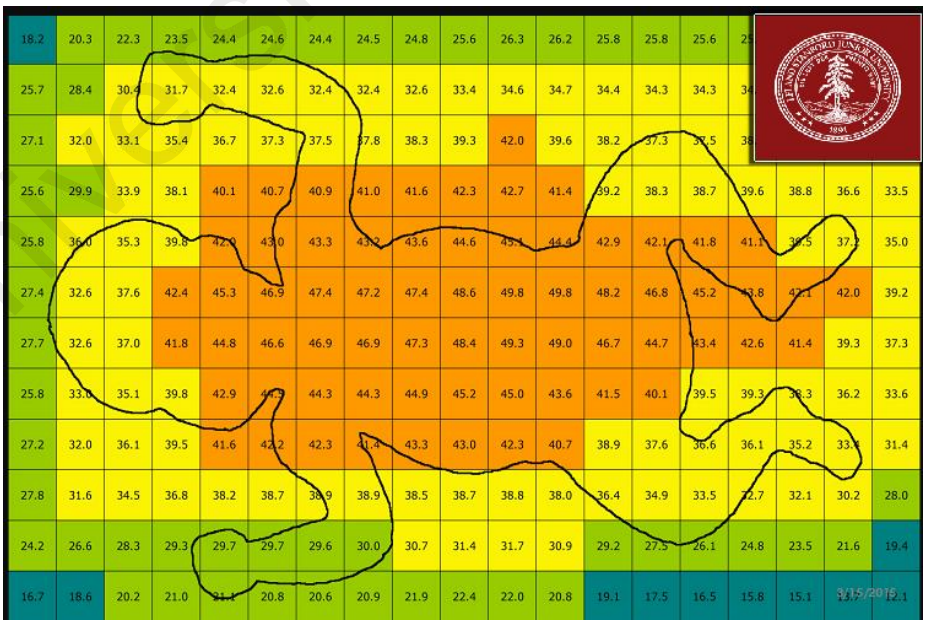


Figure 2.3: Light irradiance concentrated in the middle of the footprint and declines towards the edge (Vreman, Wong, Murdock, & Stevenson, 2008)

2.4 Type of Phototherapy Light Devices

There are currently many type of phototherapy light devices which are available and are being used by medical centres worldwide. The conventional phototherapy systems would include fluorescent and halogen tube while the more recent phototherapy light devices include Light Emtting Diode (LED) type as well as fibre optic blanket. Each one of them has its own benefits and drawbacks. Every type of devices able to achieve different level of dose or irradiance thus affecting their efficacy in managing jaundice.

2.4.1 Fluorescent Tube

This type of light device is the most common conventional light source device used for phototherapy (Figure 2.4). This is partly because of its advantage of being inexpensive. Its intensity and irradiance would decay over time and usually would need replacement after 1,000 to 2,000 hours. However, American Academy of Paediatrics (AAP) found that fluorescent tubes might differ significantly between each other. Different fluorescent tubes could produce different irradiance even when they are in the same wavelength between 425nm to 475nm. (American Academy of Pediatrics Subcommittee on Hyperbilirubinemia, 2004) Cool-white, daylight, blue and special blue (the most effective) are different kind of bulbs used in this fluorescent tube type. Different brands also feature different number of tubes and colours in their fluorescent phototherapy system.

Figure 2.4: Fluorescent type phototherapy light with 5 light tubes (Healicom, 2020)

2.4.2 Halogen Spot Light

This light source involve the use of one or more quartz halogen bulb (Figure 2.5). Medical practitioner would like it due to its compactness and caregiver-friendly. Although it could produce sufficient irradiance to manage phototherapy, its irradiance would only be focused in the centre of its small single circle of bulb light. Another of its drawback is the quartz bulb which would generate significant amount of heat. Caution need to be exercised to not risk the neonate during the phototherapy treatment.

Figure 2.5: Halogen light phototherapy device with one halogen bulb (Dharmendra, 2018)

2.4.3 Light-Emitting Diodes (LED)

LED light device uses gallium nitrate or indium as its semiconductor element. It is one of the recent innovation in the phototherapy system (Figure 2.6). It emits high irradiance within the blue/blue-green spectrum while generating little heat. (Maisels M. , 2005) However the irradiance emitted usually differ between each brand. It is important to note that some of it does actually emit lower irradiance than the conventional phototherapy. This type of phototherapy device generates minimal heat allowing it to be placed closer to neonate thus higher irradiance could reach the neonate body surface. As is the common LED, it is more cost efficient and long lasting and as compared to other type of light sources.

Figure 2.6: Phototherapy light device using blue LED lights (Halo Medicals, 2020)

2.4.4 Fibre Optic Blanket

Fibre optic blanket consists of tungsten halogen/ LED bulb which delivers light via fibre optic cable inside a plastic pad as illustrated in figure 2.7 below. This pad is placed underneath the neonate to break down bilirubin at the back of the body. It is usually used to complement with overhead phototherapy device to maximise the body surface area illuminated. The pad does not generate heat as it only contain fibre optic cable which transmitted light from the main bulb.

Figure 2.7: Fibre optic phototherapy device delivering phototherapy treatment onto mannequin baby (India Mart, 2007)

2.5 Previous Studies on Efficacy of Different Type of Phototherapy Light Devices

Many studies have been conducted over the years to evaluate the efficacy of each type of phototherapy light devices in treating jaundice. Many of this recent studies have been focusing on comparing the most recent innovation in LED light with the conventional phototherapy which includes fluorescent and halogen light type. These studies however produce mixed result with some studies found one type is better than the other while other results showed there were no difference in efficacy between each type of phototherapy light devices.

Adhikari et al. found that there was no significant difference in the efficacy of different phototherapy light devices to treat hyperbilirubinemia. (Adhikari, Mathai, Moorthy, Chawla, & Dhingra, 2017) They conducted a study comparing between blue-white light (4 blue tubes and 2 white tubes), compact fluorescent light and LED phototherapy light devices. After measuring the mean TSB level at 24 hours post phototherapy treatment and needs for exchange transfusion, the results showed no significant difference between each light type in managing jaundice.

Table 2: Summary statistics and analysis of serum bilirubin values among three groups

Measured parameter	B and W	CFL	LED	*F*	*P*
Bilirubin at start of therapy (mg/dl): Transcutaneous, mean (SD)	19.9 (3.3)	20.3 (3.3)	18.8 (2.5)	1.349	0.271
Bilirubin at start of therapy (mg/dl): Laboratory value, mean (SD)	19.2 (4)	20.7 (3)	18.1 (2.4)	2.492	0.095
Bilirubin at 24 h of therapy (mg/dl): Transcutaneous, mean (SD)	15.9 (26)	16.5 (2.2)	15.3 (1.6)	0.061	0.941
Mean duration of phototherapy in h (SD)	40.6 (9.6)	40.7 (11.2)	40.1 (8.3)	0.016	0.984
Bilirubin at the end of phototherapy (mg/dl): Transcutaneous, mean (SD)	13.1 (1.2)	13.2 (1.1)	12.6 (1.7)	0.876	0.424
Bilirubin at the end of phototherapy (mg/dl): Laboratory value, mean (SD)	12.9 (1.5)	11.6 (2.9)	12.1 (1.8)	1.572	0.220
Number of exchange transfusions	0	0	0		

SD: Standard deviation, CFL: Compact fluorescent lamp group, LED: Light-emitting diode group, B and W: Blue and white light group

Figure 2.8: Results showed no significant difference between the efficacy of every type of phototherapy light device

(Adhikari, Mathai, Moorthy, Chawla, & Dhingra, 2017)

However, a study by Bhat JI et al. found that LED phototherapy is more efficacious than conventional phototherapy device. The rate of fall in TSB is higher and the duration of treatment time is lower for the LED treatment. (Bhat, et al., 2016) The research involved a 3 year prospective observational study conducted to determine efficacy of two type of phototherapy devices; single surface light-emitting diode (LED) and conventional phototherapy device in treating jaundice. Conducted in a teaching hospital, 406 term newborn babies received the treatment; 230 patients receiving LED treatment & 176 patients receiving conventional phototherapy device treatment. The

duration of phototherapy treatment and the rate of reduction in total serum bilirubin (TSB) were recorded.

Table 2: Final outcomes of the two groups

Parameter	LED (230)	Conventional (176)	*P*
Serum bilirubin at discharge, median (IQR)	12 (2.5)	12 (0.2)	0.671
Rate of fall at 6 h, median (IQR)	3.8 (1.90)	3.9 (1.38)	0.00
Rate of fall at 12 h, median (IQR)	2.45 (1.32)	2.0 (0.95)	0.003
Rate of fall at 18 h, median (IQR)	1.77 (0.91)	1.8 (1.2)	0.039
DVET (%)	15 (6.5)	20 (11.4)	0.085

DVET – Double volume exchange transfusion; LED – Light-emitting diode; IQR – Interquartile range

Figure 2.9: Rate of fall of TSB is significantly higher in LED group than conventional light device (Bhat, et al., 2016)

The result also showed a significant statistical significance as it involved a high number of participants. However, due to limited resources, the spectral irradiance of the phototherapy devices used were not able to be checked due to non-availability of radiometer. This could be a source of serious error as the efficacy of the devices used, especially the older devices, were severely compromised. Unchecked irradiance or inappropriately checked irradiance could prove sometimes fatal. (Kumar, et al., 2010)

Another research supporting the LED superiority was conducted by Martins et al which demonstrate that the efficacy of Super LED phototherapy for treating hyperbilirubinemia in premature infants was significantly better than halogen phototherapy. This study involves the effect of phototherapy lights on preterm newborn

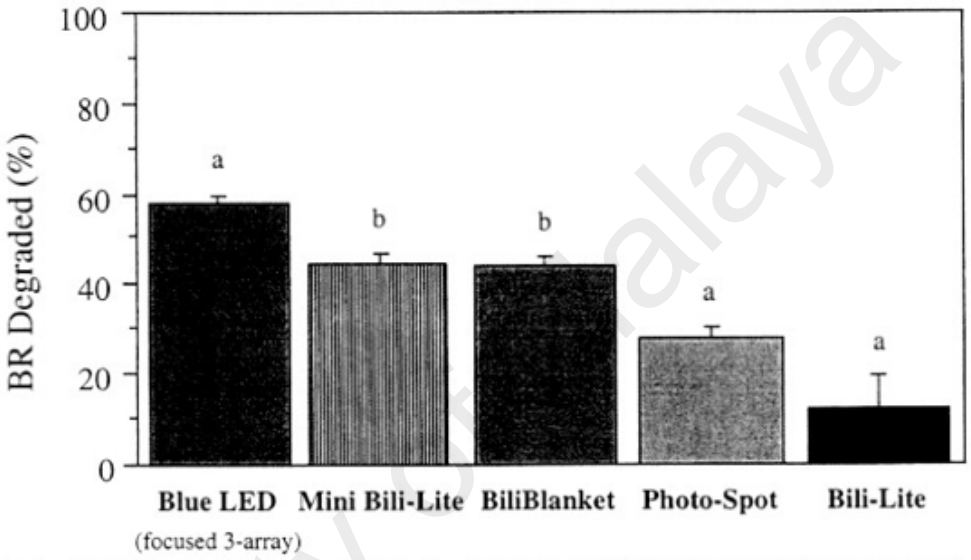
which complement the previous research involving term newborn babies. (Martins, Carvalho, Moreira, & Lopes, 2007)

The research used a phototherapy system developed by Brazilian medical industry which employs a bank of LEDs with a distinct physical and chemical composition (indium gallium nitrate) and emitting high intensity blue light at wavelengths ranging from 420 to 500 nm, with a maximum peak at 450 nm. The addition of indium to the semiconductor element gives significantly greater power to these LEDs rather than using gallium nitrate alone. This is a good innovative element possible to be added to the commercially available LED phototherapy lights in the market.

Daniel S Seidman conducted a study involving 104 healthy term jaundice infant to evaluate the efficacy of narrow spectral band blue-green LED (peak wavelength at 505nm) and blue LED (peak wavelength at 459nm) against conventional halogen phototherapy light. The outcome of the study is measured using duration of phototherapy and TSB reduction rate. Although the blue LED was found to be more effective than the blue-green LED, there was no statistically significant difference in the efficacy using blue, blue-green or conventional halogen bulb phototherapy. (Seidman, et al., 2003) The blue LED was found to be more effective than the blue-green LED which is consistent with their previous study. (Vreman, Wong, & Stevenson, 1998)

As the purpose of their study was to evaluate the efficacy of using phototherapy device with a very narrow wavelength band, the LED devices were placed at a distance which produced only at the intensity irradiance within the measured limits of the conventional phototherapy device (5–8 μW/cm2/nm.) Thus the significance of the results obtained is limited to efficacy at low light intensity only.

Romagnoli et al gives another overview in the comparison study. His research confirm that that fiberoptic phototherapy had the same effectiveness of conventional phototherapy. The best results have been obtained using combined phototherapy, which allowed to reach lower serum bilirubin levels, a shorter duration of treatment and a significant reduction of exchange transfusions. (Romagnoli, et al., 2006)



Distance (cm)	10	30	contact	22	50
Irrad. (μW/cm²/nm)	>200	71	68	9.6	17
Bilirubin deg. (%)	58 ± 1	45 ± 2	44 ± 3	28 ± 2	13 ± 6

Figure 2.10: Comparison of in vitro efficacy of different type of phototherapy light devices. (Vreman, Wong, & Stevenson, 1998)

Ignacia Silva et al. in his paper titled "Single vs. double phototherapy in the treatment of full-term newborns with nonhemolytic hyperbilirubinemia" compares the efficacy between the single and double phototherapy on jaundice treatment. Double phototherapy did not prove to be more effective than single phototherapy in the treatment of nonhemolytic hyperbilirubinemia in term newborns. Nevertheless, the results do suggest that double phototherapy may be more effective in term neonates with higher bilirubin levels at admission. (Silva, et al., 2009)

The findings of the research would help the hospitals in increasing the efficiency of their jaundice treatment. Hospitals might decide to add additional panel of phototherapy light on single patient to help increasing the bilirubin breakdown rate. Nonetheless it must be noted that in the study, the double panels used is placed at exactly 90 degrees to each other. However many hospitals use double panels placed at the top and bottom of baby. (Zainab & Adlina, 2004) Thus the result of this study might not really reflect the real situation of the hospitals which uses the top and bottom double panel.

2.6 Summary of Literature Reviews

Table 2.1: Summary of literature reviews from related studies

	Authors	Title	Project details	Pros	Cons	Subjects	Remarks
1	(Bhat, et al., 2016)	Efficacy of different types of phototherapy devices: A 3-year prospective study from Northern India	A 3 year prospective observational study conducted to determine efficacy of two type of phototherapy devices; single surface light-emitting diode (LED) and conventional phototherapy device in treating jaundice. Conducted in a teaching hospital, 406 newborn babies received the treatment; 230 patients receiving LED treatment & 176 patients receiving conventional phototherapy device treatment. The duration of phototherapy treatment and the rate of reduction in total serum bilirubin (TSB) were recorded.	The study involved many participants;406 babies which increases the statistical significance of the research.	The spectral irradiance of the phototherapy devices used were not able to be checked due to nonavailability of radiometer (limited resources). This could be a source of serious error as the efficacy of the devices used, especially the older devices, were severely compromised. The number of neonates receiving treatment for LED is higher than the conventional devices as the number of LED devices used is higher. Thus making the data collected for the conventional	406 near term and term neonates (LED:230 & Conventional :176)	LED phototherapy was found more efficacious than conventional phototherapy device. The rate of fall in TSB is higher and the duration of treatment time is lower for the LED treatment.

					treatment much lesser than the LED.		
2	(Seidman, Stevenson, & Vreman, 2003)	A Prospective Randomized Controlled Study of Phototherapy Using Blue and Blue-Green Light-Emitting Devices, and Conventional Halogen-Quartz Phototherapy	The study involved 104 healthy term jaundice infant to evaluate the efficacy of narrow spectral band blue-green LED (peak wavelength at 505nm) and blue LED (peak wavelength at 459nm) against conventional halogen phototherapy light. The outcome of the study is measured using duration of phototherapy and TSB reduction rate.	This research compares the two narrow band found to be the most effective band for phototherapy treatment in accordance to the authors' recent in vitro efficacy studies. The blue LED was found to be more effective than the blue-green LED which is consistent with their previous study.	As the purpose of the study was to evaluate the efficacy of using phototherapy device with a very narrow wavelength band, the LED devices were placed at a distance which produced only at the intensity irradiance within the measured limits of the conventional phototherapy device (5–8 μW/cm2/nm.) Thus the result is limited to efficacy at low light intensity.	104 healthy jaundice infant; 25 for blue LED, 22 for blue-green LED & 57 for conventional (as control)	Although the blue LED was found to be more effective than the blue-green LED, there was no statistically significant difference in the efficacy using blue, blue-green or conventional halogen bulb phototherapy.
3	(Silva, et al., 2009)	Single vs. double phototherapy in the treatment of full-term newborns with nonhemolytic hyperbilirubinemia	The study was to compare the effectiveness of single (1 panel) with the double (2 panels) phototherapy in lowering hyperbilirubinemia (jaundice) in term newborns. 77 patients participated in the study. The decrease in bilirubin level at 24 hours of treatment as well as the	The findings of the research would help the hospitals in increasing the efficiency of their jaundice treatment. Hospitals might decide to add additional panel of	In the study, the double panels used is placed at exactly 90 degrees to each other. However many hospitals use double panels placed at the top and bottom of baby. Thus the result	77 term newborns; 37 for single panel, 40 for double panel	Double phototherapy did not prove to be more effective than single phototherapy in the treatment of nonhemolytic hyperbilirubinemia in term newborns.

			readmission rate of the patients were recorded for comparison.	phototherapy light on single patient to help increasing the bilirubin breakdown rate.	of this study might not really reflect the real situation of the hospitals which uses the top and bottom double panel		Nevertheless, the results do suggest that double phototherapy may be more effective in term neonates with higher bilirubin levels at admission.
4	(Martins, Carvalho, Moreira, & Lopes, 2007)	Efficacy of new micro processed phototherapy system with five high intensity light emitting diodes (Super LED)	The paper compare the efficacy of a micro-processed phototherapy device consists of five high intensity LED (super LED) with the controlled conventional twin halogen spotlight phototherapy device. The phototherapy treatment duration and the rate of TSB reduction were recorded for both group.	The research uses a phototherapy system developed by Brazilian medical industry which employs a bank of LEDs with a distinct physical and chemical composition (indium gallium nitrate) The addition of indium to the semiconductor element gives significantly greater power to these LEDs rather than using gallium nitrate alone.	The modified super LED phototherapy system could be better compared with the current LED phototherapy to give better indication of the improved technology. Many research already showed the better efficacy of LED than the conventional halogen phototherapy	88 preterm newborn infants; 44 for super LED, 44 for halogen light	This super LED phototherapy system showed significantly higher efficacy as compared to the halogen phototherapy system
5	(Arnolda, et al., 2018)	A comparison of the effectiveness of three	This observational study compared the efficacy of three LED machines, one double-	This study compares between two different single-sided	The irradiance of each light is not specifically controlled. As there is	310 infants (>33 weeks) had been	Use of double-sided phototherapy

		LED phototherapy machines, single- and double-sided, for treating neonatal jaundice in a low resource setting	sided and two single-sided in routine use in Da Nang Hospital, Vietnam. The study collected data of average hourly change in TSB over the first six hours of treatment, duration of treatment; average hourly change in TSB over treatment, and length of stay in the neonatal unit.	LED devices as well as comparing to a double sided LED device	two setting (high and low irradiance) on the single sided LED devices, authors could not control which setting the clinician used on each baby due to the observational nature of the study	allocated to the three machines: 113 to the PTV3000, 104 to the Lullaby, and 93 to the Firefly	can substantially increase the speed of TSB reduction, and substantially decrease the duration of treatment and length of stay in the NICU
6	(Hart & Cameron, 2005)	The importance of irradiance and area in neonatal phototherapy	The research measures the irradiance over the surface area of neonates for commercially available phototherapy light devices	The study involved seven brand and type of light devices including the white light source, metal halide lamp, fluorescent light and LED light. This allow direct comparison between each light's performance	This study was conducted more than 10 years ago in which LED is not widely used as commercially available phototherapy light source	7 different brands of commercially available phototherapy light devices	The study clearly shows the high irradiance produced by the LED light devices as compared to metal halide and fluorescent light
7	(Brandão, Draque, Sañudo, Filho, & Almeida, 2015)	LED versus daylight phototherapy at low irradiance in newborns >= 35 weeks of gestation: randomized controlled trial	The research compare the decline in TSB after 24 hours of phototherapy between LED and fluorescent light from below neonates (mattress) in breastfed neonates.	The research compares the light effect between two type of device specifically using the device from below the neonates. This give new insights as	The amount of bulb for each type of light device is different which would greatly affect its irradiance. The comparison was done with different irradiance.	150 term neonates; 74 neonates treated with LED, 76 neonates treated with	The results show that LED with heterogenous irradiance have the same effectiveness as the daylight fluorescent phototherapy with

				compared to the common treatment from above the neonates.		fluorescent light	homogenous irradiance
8	(Vandborg, Hansen, Greisen, & Ebbesen, 2012)	Dose-Response Relationship of Phototherapy for Hyperbilirubinemia	The aim of this study is to determine the saturation (peak) point – an irradiation level above where there is no further decrease in TsB – for phototherapy device. The irradiance is varied to compare the Tsb reduction level for each irradiance.	This research shows relationship between the distance of light source to neonate and the irradiance level. This also mean the efficiency of the phototherapy light is affected by the manufacturer irradiance as well as its distance to neonates.	The device used is only of one type of phototherapy light which is used with varying distance to neonates. More devices are needed to make the results more convincing	150 term neonates (>33 weeks)	There is linear relationship between the irradiance and the reduction in TsB reading after 24 hours. Irradiance is one of the main factor for the efficiency of a phototherapy light device.
9	(Bhutani, Newborn, & Pediatrics, 2011)	Phototherapy to Prevent Severe Neonatal Hyperbilirubinemia in the Newborn Infant 35 or More Weeks of Gestation	The investigation assessed phototherapy devices currently available in the market including fluorescent, halogen, fibre optic and LED light source in the laboratory. Relevant literature was also reviewed to standardize the use of phototherapy according to American Academy of Pediatrics (AAPG) Guideline in newborn infant aged more than 35 gestation weeks.	The research is inclusive where it involved comparison between all the available type of phototherapy light devices used in hospitals. It also suggest recommendations according to widely used AAPG.	The data collected was collected from the manufacturer and no common testing was conducted for fair comparison	7 brand of phototherapy light devices were compared	The characterisic of effective phototherapy light device: (1) emanation of light in the blue-to-green range that covers the in vivo plasma bilirubin assimilation range (like 460-490 nm); (2) irradiance of no less than 30 mu

							W.cm(- 2).nm(- 1) (affirmed with a proper irradiance meter aligned over the suitable wavelength extend); (3) illumination of maximal body surface; and (4) showing of a decline in all out bilirubin fixations amid the initial 4 to 6 hours of introduction.
10	(Sebbe, Villaverde, Moreira, Barbosa, & Veissid, 2009)	Characterization of a novel LEDs device prototype for neonatal jaundice and its comparison with fluorescent lamps sources: Phototherapy treatment of hyperbilirubinemia in Wistar rats	The authors design a novel LED device prototype for neonatal jaundice and comparing it with the conventional fluorescent light source. This test was done on Wistar rats instead of human	This paper introduced a new design of LED phototherapy light which would have more significant effect on hyperbilirubinemia and comparing it with the current fluorescent light	This new design is only compared with the conventional light source but not the LED light source readily available in the market. Plus it was only tested on rats and not on human yet.	30 Wistar rats; 15 rats each for each light source	The rate of bilirubin reduction using the novel LED device is 1 time greater than the conventional fluorescent light source.
11	(Althomali, et al., 2018)	Neonatal jaundice causes and management	The paper review the various type of neonatal jaundice and their management. This review	The review studied many paper and journals covering	The paper review is limited to only 3 publications which are	No subject involved as it	This paper explains the basic of jaundice and the

			was conducted using comprehensive search on MEDLINE, Pubmed and EMBASE from January 2001 to March 2017	more than 15 years and includes the recent findings	MEDLINE, Pubmed and EMBASE	is a review paper	protocol associated with jaundice management
12	(Jnah, Newberry, & Eisenbeisz , 2018)	Comparison of Transcutaneous and Serum Bilirubin Measurements in Neonates 30 to 34 Weeks' Gestation Before, During, and After Phototherapy	The paper compare the correlation and consistency between transcutaneous (TcB) and serum bilirubin (TsB) measurements in a multiracial premature infant population before, during, and after phototherapy.	This paper shows positive correlation between TcB and TsB throughout the pre, during and post phototherapy.	Although there are correlation between TcB and TsB, the TcB reading is consistently lower than TsB which is more accurate	45 pre-term neonates aged 30-34 weeks' gestation	The TcB measurement which is more cost effective provide a reliable estimation of TsB reading due to their strong correlation
13	(Ng, Carlisle, Ly, & Morris, 2017)	Heating of Newborn Infants due to Blue Light-Emitting Diode Fibreoptic Phototherapy Pads	The paper studied the temperature and the effect of using the LED fibreoptic phototherapy light device on the jaundice babies during 90 minutes phototherapy session.	The study identify the side effect of using the LED fibreoptic light device which would have direct contact with the neonates skin. Its usage might cause increase in temperature for the baby.	The study involved small sample of subjects which include 10 well term babies	10 term babies which are more than 34 weeks	There are slight increase in temperature of the babies using the fibreoptic LED light device. This type of light device needed closer monitoring than the other type of device which does not have direct skin contact

14	(Jia-ning, et al., 2017)	Photobiological safety of light source of neonatal jaundice therapeutic device	The paper compare the optical radiation, thermal radiation and photobiological safety of different type of phototherapy light devices including traditional blue fluorescent light and the more common blue LED light	The paper compares the efficiency and the safety between the traditional fluorescent blue light and different brand of LED blue light devices	The research was using the old fluorescent which has low irradiance thus does not really reflect the recent fluorescent model which have much higher irradiance than the old set	Two type of devices compared; traditional fluorescent device and LED light device	The blue light of LED is the ideal light source due to its optimum wavelength, irradiance and safety. The attenuation of aging fluorescent light could cause radiation damage to neonates
15	(Chang, et al., 2005)	In vitro and in vivo efficacy of new blue light emitting diode phototherapy compared to conventional halogen quartz phototherapy for neonatal jaundice	In this research, authors comparing the efficacy of new blue LED phototherapy light source with the commercially used halogen quartz phototherapy light. They are compared by measuring both in vivo and in vitro bilirubin degradation.	This research using both the in vitro and in vivo method. The in vitro results would enhance the in vivo results to allow better comparison	This research involved the animal trials and have not been tested yet on human	20 Gunn rats; 10 rats each for each device	The research shows that high intensity blue LED device is more effective than conventional phototherapy for both in vitro and in vivo bilirubin photodegradation
16	(Saboute, Mazouri, Khalesi, Nejad, & Razaghian , 2017)	The Effect of Intensive Phototherapy on Management of Hyperbilirubinemia in Neonates with the Gestational Age of 34 Weeks and More	The retrospective cohort study was conducted in NICU of Akbar-abadi Hospital, Iran from 2014-2016. This research involved 219 neonates. The TsB level were recorded to evaluate the effect of intensive phototherapy	This paper also identify the most frequent cause for hyperbilirumenia is due to nonhemolytic jaundice. The data collected was also from the real cases.	The authors did not follow up the subjects 24 hours post therapy to monitor any bilirubin rebound after terminating the intensive phototherapy and side effects of the procedure.	219 term neonates	Intensive phototherapy could efficiently lower the total bilirubin level in the neonates with gestational age of 34 weeks and more with

							hyperbilirubinemia of different causes. Besides, the efficacy of intensive phototherapy was more significant in the subjects with higher levels of total bilirubin.
17	(Sachdeva, Murki, Oleti, & Kandraju, 2015)	Intermittent versus continuous phototherapy for the treatment of neonatal non-hemolytic moderate hyperbilirubinemia in infants more than 34 weeks of gestational age: a randomized controlled trial	In the randomized control trial, healthy late preterm and term neonates with hyperbilirubinemia are divided into two groups; IPT & CPT; intermittent phototherapy (12 hours on, 12 hours off cycle) and continuous phototherapy. The rate of bilirubin reduction for both groups are measured.	This is a new treatment design which could be useful in increasing the efficacy of jaundice treatment in hospital	The proposed intermittent treatment might not be so viable as it would greatly increase the treatment time of neonatal jaundice in the hospital.	75 neonates more than 34 weeks gestational age; IPT = 36 neonates CPT = 39 neonates	The paper concluded that In both term and late preterm infants with non-hemolytic moderate hyperbilirubinemia, intermittent phototherapy is as efficacious as continuous phototherapy.
18	(Bertini, et al., 2008)	Transepidermal water loss and cerebral hemodynamics in preterm infants: conventional	This paper evaluate the effect of LED light and conventional phototherapy light on the transepidermal water loss and cerebral hemodynamics in preterm neonates. These are measured using a Tewameter	This paper comparing the side effect of using both the newer LED phototherapy light and the conventional phototherapy light.	The results gained were only up to 12 hours post phototherapy. More time is needed to assess the real side	31 preterm infants; conventional = 14 infants; LED = 17 infants	The paper summarise that LED light source is more preferable than the conventional phototherapy for

		versus LED phototherapy	TM 210 and cerebral Doppler ultrasound on 31 pre-term infants.	This allows better evaluation and choices for the best treatment light.	effect of the phototherapy		therapy of hyperbilirubinemia in preterm infants due to its lesser side effects.
19	(Kahveci, et al., 2013)	Phototherapy causes a transient DNA damage in jaundiced newborns	The research tried to answer the following questions: 1) Does phototherapy (PT) cause genotoxicity in full-term newborn babies undergoing PT as a result of neonatal jaundice?, 2) if genotoxic effect occurs, is there any relationship between the duration of PT and genotoxicity?, and 3) is genotoxic effect temporary or not?	The research covers the data not only during the period of phototherapy, but also up to 3.5 years after the treatment to evaluate the side effect of phototherapy to neonatal DNA.	The results gained after the 3 years period might also be affected by other factors thus making the results less reliable	22 full term jaundice neonates	This study shows the negative side effect of phototherapy treatment on sister chromatid exchange (DNA) is a temporary effect. The effect are obvious during phototherapy but no significant effect seen during childhood.
20	(Takcı, Yiğit, Bayram, Korkmaz, & Yurdakök, 2013)	Comparison of intensive light-emitting diode and intensive compact fluorescent phototherapy in non-hemolytic jaundice	The paper compare the efficacy of both the intensive LED and fluorescent light (CFT) in jaundice treatment. Rate of bilirubin decrement is measured for the whole duration of phototherapy treatment.	The rates of bilirubin decrement were comparable between the LED and fluorescent groups. However, the fluorescent groups recorded slightly elevated mean body temperature as side effects.	The duration of phototherapy treatment is quite short which is less than 23 hours. Follow up treatment data would provide more information.	43 infants over 35 week gestational age; LED = 23 infants CFT = 20 infants	The results shows the treatment of intensive phototherapy using both LED and CFT are comparable. They would cause rapid decrease in bilirubin level in the first few hours. However the CFT

							would cause slight increase in body temperature.
21	(Donnebor g, Vandborg, Hansen, Rodrigo-Domingo, & Ebbesen, 2018)	Double versus single intensive phototherapy with LEDs in treatment of neonatal hyperbilirubinemia	The study focus on comparing the ability of double versus single light phototherapy during intensive phototherapy using high level of LED light irradiance. TsB readings were collected after 24 hours.	This research focuses on using intensive phototherapy which have high efficiency but comparing it between single and double phototherapy. Thus the limitation of surface area illuminated and the light irradiance could be identified.	The research was carried out for a period of 24 hours. The follow up reading beyond the time might give better information	83 infants more than 33 week gestational age; single = 42 infants double = 41 infants	The efficiency of the intensive phototherapy light would still be improved when the illumated surface area of neonates increases.
22	(Borden, et al., 2018)	Variation in the Phototherapy Practices and Irradiance of Devices in a Major Metropolitan Area	This study assessed local American phototherapy practices by measuring the phototherapy light's irradiance in neonatal intensive care unit and nurseries. 39 phototherapy light devices of 7 area hospitals were involved.	This study discovers the real situation occurring in many local hospitals. This gives a better indication of the hospital's compliance to the given guideline for jaundice management.	Some hospitals might still use the old devices which are still useful to save costs. Thus the aging factor of the devices have not been factored in.	79 phototherapy light devices from 7 hospitals in USA	The local protocols and practices discovered from 7 local hospitals still vary despite the guideline for phototherapy jaundice management has been established. Intensive phototherapy was suboptimal for 62% of devices. Straightforward

							changes, such as decreasing the distance between an infant and the light source and establishing a consistent irradiance-based protocol, could substantially improve the quality of the intervention.
23	(Mreihil, Nakstad, Stensvold, Benth, & Hansen, 2018)	Uniform national guidelines do not prevent wide variations in the clinical application of phototherapy for neonatal jaundice	The paper compares the usage of phototherapy light devices for jaundice management in NICU in Norway. This research conducted from 2013-2014 where the device irradiance was measured from random units at 20 cm and 50 cm from the light source.	This study involved the survey and interaction with the medical practitioner who handle the neonatal jaundice thus getting a better source of information.	The set up for the device before being measured is done by different people from different hospitals. This might cause high variations which could affect the actual results.	39 phototherapy light devices from 21 NICU in Norway	Rules for the distance from the device to the infant varied from 10 to 40 cm and in practice they varied from 15 to 48 cm, with irradiance ranging from 11.1-56.1 W/m(2). There were significant variations between NICUs with regard to the overall treatment duration and duration in most birthweight categories.

24	(Jiao, Jin, Meng, & Wen, 2018)	An analysis on treatment effect of blue light phototherapy combined with Bifico in treating neonatal hemolytic jaundice	The study evaluated the clinical effect of treating haemolytic jaundice by combining the blue light LED phototherapy with Bifico. 120 subjects studied and divided into two groups of the same number (control and treatment). The rate of bilirubin reduction as well as the treatment time was recorded.	This is a unique study which proposes additional treatment by using Bifico on top of the conventional blue light phototherapy treatment. This allows for more effective treatment of jaundice in neonates.	The study have not yet been supported by other study as such. It might need more clinical study including the side effect of this kind of treatment before it could be realised.	120 neonates; 60 neonates treated with Bifico; 60 neonates as control	The study showed significant improvement in rate of TsB reduction and treatment time with the usage of Bifico on top of the conventional blue light phototerapy. It has high potential for clinical application later.
25	(Slusher, et al., 2018)	Filtered sunlight versus intensive electric powered phototherapy in moderate-to-severe neonatal hyperbilirubinaemia: a randomised controlled non-inferiority trial	This is a prospective randomised controlled trial in Nigeria. 174 neonates were randomly assigned with filtered sunlight (FSPT) or intensive electric LED (IEPT) treatment. FSPT involved treatment using filtered sunlight in transparent polycarbonate room with special tinting film. IEPT involved the use of normal intensive LED phototherapy light. The efficacy were assessed using the TSB decline rate and the treatment period.	This is a good alternative for the hospital which might have limitation in budget to purchase the required intensive phototherapy light. However it might need extra space to accommodate the space required.	The FSPT is heavily dependent on availability of clear sunlight to be effective. It might not be so feasible in countries where there is lack of sunlight.	174 term neonates; 87 FSPT and 87 IEPT	The implementation of FSPT is considered safe and the results showed the FSPT is no less efficacious than the IEPT for treatment of term and near term neonates.

26	(Gutta, et al., 2019)	Light Emitting Diode (LED) Phototherapy versus Conventional Phototherapy in Neonatal Hyperbilirubinemia : A Single Blinded Randomized Control Trial from Coastal India	This project conducted from 2013-2015 compare the efficacy of LED versus conventional (4 blue + 2 white lights) phototherapy. It measure rate of TSB decrease as primary outcome and urinary lumirubin levels as the secondary outcome.	This study also identify the effect of different phototherapy devices on the urinary lumirubin levels which is hardly to be found from other research projects.	Conventional phototherapy mentioned is actually only referring to a type of old fluorescent light rather than many other type and irradiance of conventional phototherapy.	166 neonates (>35 weeks); 83 LED & 83 conventional	LED gives a better and significant rate of decrease in TSB and in the increase in urinary lumirubin level than conventional light.
27	(Mills & Tudehope, 2001)	Fibreoptic phototherapy for neonatal jaundice	This study evaluated the fibre optic light source as a new mode of phototherapy which reportedly could lower the bilirubin level of neonate while maintaining minimal disruption to infant care. This was done using the standard Cochrane Collaboration search strategy. Total of 24 selected studies were chosen involving different population and clinical situations.	This research evaluates many different kind of studies involving fibre optic phototherapy treatment which help to evaluate the efficacy of the newly introduced light source.	The study is limited to the outcome of other researches and does not produce any novel outcome which could be compared to other studies.	31 studies were compared in which only 24 met their inclusion criteria for evaluation	Fibreoptic was found to be more effective than no treatment. However it is less effective as compared to conventional phototherapy.
28	(Adhikari, Mathai, Moorthy, Chawla, &	Efficacy of different types of phototherapy units on neonatal hyperbilirubinemia	Study was done to compare the efficacy between 3 type of phototherapy light; blue/white light, compact fluorescent lamp and LED light device. 30	On top of comparing 3 different type of devices, this study also explains the side effect of each type of	Only 1 device used for each type which limited the effective randomization on its efficacy. It could also	90 neonates; 30 for each type of light devices	No difference in efficacy recorded between each type of light devices. There was no

	Dhingra, 2017)		neonates were assigned to each group type. TSB levels at 24 hours post phototherapy were recorded as well as any need for exchange transfusion.	phototherapy light devices on the neonate.	do better if rate of bilirubin reduction also been measured.		significant difference in the mean TSB level at 24 hours post phototherapy treatment.
29	(Yenamandra, Kumar, Garg, Kumar, & Singh, 2018)	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 neonatal hyperbilirubinemia	The project evaluated 4 different system of phototherapy devices – single surface conventional + fibre optic blanket (group 1), double surface LED light (group 2), single surface LED + fibre optic blanket (group 3) & double surface conventional light (group 4). It primarily measure the bilirubin measurement at different time intervals. Adverse effects were also noted.	The study is unique where it compares the efficacy of four different combination of phototherapy light devices ranging from the conventional devices up to the most recent fibre optic blanket.	This paper did not record and discuss regarding the irradiance for each of the phototherapy light devices used during the study. This is one of the main factor which could affect the efficacy for each devices.	Total 236 neonates. Group 1 (n=60) Group 2 (n=59) Group 3 (n=62) Group 4 (n=55)	Rate of decrease in bilirubin is greatest in double surface LED, followed by double surface conventional light, fibre optic blanket + LED & lastly fibre optic blanket + conventional light
30	(Taheri, Sajjadian, Asadi, & Salamati, 2016)	Declining pattern of bilirubin in the first and second six hours of intensive versus double	This study conducted between January 2012 to January 2013 investigated the most effective hours of declining TSB between double phototherapy and	The unique parameter was measured in this study which is the most effective hours in declining the	It does not really compare different type of phototherapy light devices. Instead it compared the efficacy of same type of light	100 neonates; 50 for intensive phototherapy & 50 patient	Intensive phototherapy is shown to reduce more serum bilirubin level than double

		phototherapy in neonatal jaundice	intensive phototherapy for hyperbilirubinemia treatment.	serum bilirubin. This helps to understand more on the most effective time of phototherapy treatment.	with different arrangements and places located around the patient body.	for double phototherapy.	phototherapy in the first 6 hours of phototherapy but produce similar efficacy in the second 6 hours.

CHAPTER 3: METHODOLOGY

3.1 Settings & Patient Selection

The study was conducted in one of the main neonatal hospital in Malaysia, Hospital Sungai Buloh. This hospital was chosen primarily because of its status as one of the hospital with highest admission of neonatal patient thus highlighting the urgency to have the most effective phototherapy system. Patient subjects were randomly selected from newborns admitted for phototherapy in the NICU from January to February 2020. 15 patients were chosen which satisfy the following inclusion criteria;

a) Term patient (have gestational age equal to, or more than 38 weeks);

b) Admission weight of more than 2.5kg;

c) Patient reached TSB level needed for phototherapy treatment based on the guidelines by American Academy of Paediatrics. (American Academy of Pediatrics Subcommittee on Hyperbilirubinemia, 2004)

3.2 Type of Phototherapy Light Devices

Three different phototherapy light devices were readily available inside the NICU and used for this study; one using LED and another two using fluorescent tubes with 4 tubes and 6 tubes each.

3.2.1 LED Phototherapy Light Device – Medwarm KMF-01

Figure 3.1: Medwarm KMF-01 LED phototherapy light device

The LED light used was an intensive Medwarm brand LED phototherapy device manufactured by Istanbul Medikal Ltd Company, Turkey. It has 34 pieces of LED bulb on its light panel. It was claimed to have a 5 level adjustable irradiance mode ranging from 20 up to 100 $\mu W/cm^2/nm$ where the most commonly used is the 3rd level (~60 $\mu W/cm^2/nm$). This is also the level fixed to be used throughout this study.

This light device has a great of lifetime of up to 40,000 hours. It is the most compact light device among the three type of phototherapy light devices used in this study.

3.2.2 6-Tubes Fluorescent Phototherapy Light Device – Neotech Nice 4000 CFL

Figure 3.2: Neotech Nice 4000 CFL 6-tubes fluorescent light device

The Neotech Nice 4000 CFL fluorescent phototherapy light was manufactured by Nice Neotech Medical Systems, India. All 6 tubes were using 18W blue coloured fluorescent tubes. The range of its light wavelength is between 450 to 460 nm. The lifetime of its fluorescent tube could last up to 1500 hours. This device is a bit bulkier than the 4-tubes fluorescent light devices as it can place more fluorescent tubes.

3.2.3 4-Tubes Fluorescent Phototherapy Light Device – Medela

Figure 3.3: Medela 4-tubes fluorescent phototherapy light device

The other type of fluorescent phototherapy light device has 4 tubes was The Medela brand fluorescent phototherapy light device. It was manufactured by Medela AG Medical Technology, Switzerland. All 4 tubes also have 18W blue coloured fluorescent tubes and could last up to 1500 hours too.

A detailed side by side comparison between all 3 type of phototherapy light devices – LED, 6-tubes fluorescent light and 4-tubes fluorescent light was shown in the table 3.1 below.

Table 3.1: Comparison of features between different type of phototherapy light devices

Features	Medwarm LED Light	Neotech 6-tubes Fluorescent Light	Medela 4-tubes Fluorescent Light
Type of Light	LED	Fluorescent Light	Fluorescent Light
Number of Light/Bulb	34 pieces blue LED bulb	6 tubes blue fluorescent light	4 tubes blue fluorescent light
Wavelength (nm)	450 – 470	450 - 460	450 - 465
Lamp lifetime (hours)	Up to 40,000	Up to 1500	Up to 1500

The irradiance for each devices has been measured using irradiance meter Biliblanket Light Meter II by GE Healthcare, USA. This was done by placing the meter on top of table trolley which has a 30cm distance from the light source as illustrated in figure 3.4 below. The meter was turned on and the reading on display showing the irradiance for each devices were recorded.

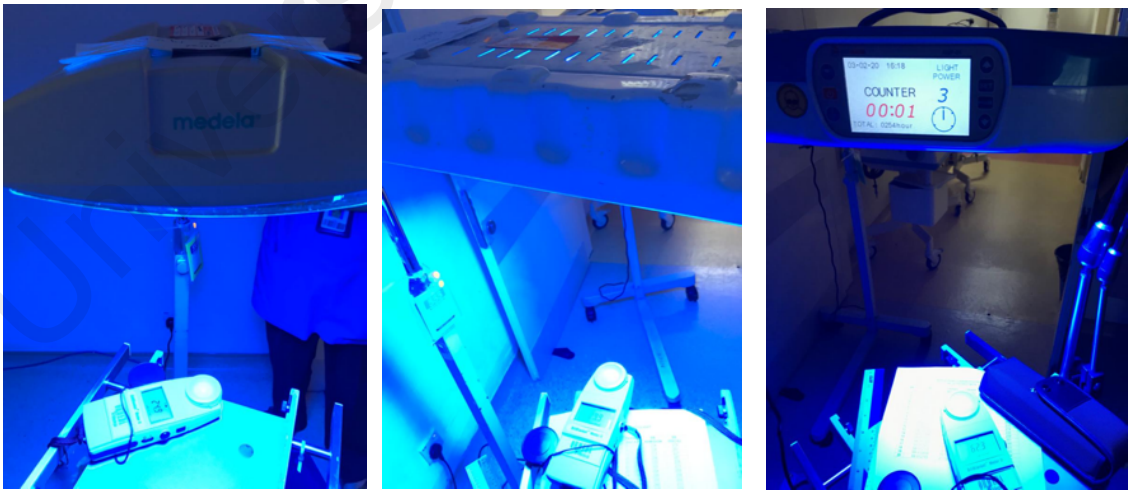


Figure 3.4: Measurement of irradiance for each type of phototherapy light devices

3.3 Data Collection

Each phototherapy light device used were tagged with a note to record the ID for every eligible newborn (which satisfy the inclusion criteria) to indicate which patient received treatment from the respective devices. In this study, only 5 eligible patients per device were selected for data retrieval. The admitted patients' demographic were retrieved from the hospital database including their sex, gestational age, phototherapy admission weight and admission age.

During the admission for phototherapy treatment, each patient was placed inside the infant bassinet. Their cloth were removed leaving only diapers to allow higher surface area of skin exposed to the phototherapy light treatment. An eye patch was then put on to cover each patient's eyes from prolonged exposure to the bright light. This is illustrated in figure 3.5.

Figure 3.5: Neonate patient with the cloth removed and eye patch is put on

In order to get the reading for initial TSB value, patient's blood were collected using the heel stick collection method. During this process, neonate's heel were first cleaned using alcohol wipe before a small sterile lancet used to puncture the spot. A few drops of neonate's blood were then collected from their heel using a small tube as illustrated in figure 3.6. Once the blood collected is enough, cotton balls were placed and pressed briefly on the puncture spot. It was then wrapped with bandage to stop the minor bleeding. The blood sample was then sent to laboratory where the blood was analysed using BR-501 Dual Wavelength Total Bilirubin Meter from Apel, Japan. The value of the TSB was recorded as initial TSB or TSB value at 0 hour.

Figure 3.6: Blood collection during heel stick blood sampling

After the heel stick blood sampling finished, phototherapy device was placed on top of the patient bassinet at a distance of approximately 30 cm between the light source and the patient body surface. Some of the neonate would need to use overhead infant warmer during the treatment, thus the light device would be placed beside the bassinet

with the light source head tilted towards the patient as shown in figure 3.7. This is to prevent the phototherapy light device from blocking the heat as well as protecting the plastic case of the device. The distance would still be maintained at 30 cm between the light source and patient body surface.

The phototherapy light device would then be turned on and the time was recorded as 0 hour during the start of the treatment. The phototherapy was administered continuously except only during minor procedures such as fluid administration, feeding and blood sampling. After 6 hours, heel prick blood sampling would be repeated again and the sample was sent to laboratory to get the TSB level at 6th hour after treatment. TSB level were recorded at 6 hours intervals for each patient up to the 24th hour for this study. Treatments still continued until the TSB level dropped below 200 μmol/ L in which the patients were allowed to be discharged. The hospital practiced the patient to be discharged every 12 hours when TSB level dropped below the aforementioned value. Total treatment time taken for each patient were also recorded for secondary outcome.

Figure 3.7: Phototherapy light device used together with overhead infant warmer during patient treatment

3.4 Statistical Analysis

All the data collected were analysed using the software calculator provided in the Good Calculators website. (Good Calculators, 2020) The mean and standard deviation calculated and presented in tables. One-way ANOVA test were done to compare the mean between each group. This ANOVA test, also known as analysis of variance, was used as it compare the means of patient TSB reduction of three different type of phototherapy light device groups in a single test. It assess the amount of variation within group, proportionate to the amount of variation between groups. When there is a significant difference between means of each group, T-test was used to compare significance between two mean values of different group. The ANOVA test is used first as it allowed

comparison of more than 2 different variable with lesser possible error rather than using T-test solely. A statistically significant data would have the value of $p<0.05$.

3.5 Outcome Measures

The main outcome assessed was the TSB reduction rate in 24 hours during the phototherapy treatment for each devices. Secondary outcome measured was the total treatment time for each patient before being discharged.

CHAPTER 4: RESULT & DISCUSSION

Neonatal jaundice or hyperbilirubinemia has been becoming common in many newborn nowadays. Its management requires accurate diagnosis as well as efficient treatment to prevent further complications or any bad effect towards the neonates. (Arnolda, et al., 2018) Phototherapy is the main treatment for jaundice. This makes the efficacy and performance of phototherapy light sources would determine the success of jaundice treatment. There are various type of phototherapy light sources available in the market but the most common type found in Malaysia hospitals are LED and fluorescent.

The focus of this paper is to study the efficacy of different type of phototherapy light devices commonly found – LED & fluorescent. In this study, the rate of TSB reduction in jaundice patient were analysed and their total treatment time prior to discharge were recorded for each group of phototherapy light sources. The TSB reduction rate or its speed is important for high risk intervention to avoid any need for ET while the treatment time could help to reduce medical practitioners' workload and increase the treatment capacity of the hospital.

4.1 Patient Demographics

Between January to February 2020, a total of 15 neonate patients were chosen to be in the study. These patients passed the enrolment criteria highlighted earlier in the methodology above. All 15 patients which underwent treatment from the 3 group of light source treatments – LED light, 6-tubes fluorescent light & 4-tubes fluorescent light – were chosen (5 patients for each group) and their demographics were recorded. The record are shown in the table 4.1 below.

Table 4.1: Patient demographics of 15 patients grouped in 3 type of treatment light

Type of Treatment Light	Patient	Sex (Female (F)/ Male (M))	Gestational Age (Weeks)	Admission Weight (Kg)	Admission Age (Days)	Initial TSB Reading (μmol/ L)
Medwarm LED Phototherapy Light	Patient 1	M	39	2.8	8	318
	Patient 2	M	38	3.0	4	288
	Patient 3	F	39	2.9	6	295
	Patient 4	M	38	3.7	9	376
	Patient 5	F	40	3.2	12	287
Neotech Fluorescent Phototherapy Light (6 Tubes)	Patient 6	F	38	3.1	7	335
	Patient 7	M	38	2.7	8	326
	Patient 8	M	40	2.9	10	275
	Patient 9	F	38	3.5	5	266
	Patient 10	F	39	3.0	7	269
Medela Fluorescent Phototherapy Light (4 Tubes)	Patient 11	F	39	2.9	9	284
	Patient 12	M	40	3.3	6	266
	Patient 13	F	39	3.5	5	302
	Patient 14	M	38	2.6	8	273
	Patient 15	F	39	3.1	8	313
P-value			0.746	0.932	0.913	0.440

Based on the one-way ANOVA, there is no significant difference between neonate patients in each type of phototherapy device group with respect to the gestational age as well as admission weight and age ($P>0.05$). There is also no significant difference in the initial TSB reading between patients from each group as $P>0.05$. Similar demographic and initial TSB reading allows fair comparison in phototherapy device efficacy by determining the rate of TSB reduction as well as the total treatment time needed before patients were allowed to discharge.

The reading for irradiance for each phototherapy light devices were recorded in Table 4.5 below. LED phototherapy light recorded the highest intensity with 62.3 $\mu W/cm^2/nm$ followed by 6-tubes phototherapy light (29.9 $\mu W/cm^2/nm$) and 4-tubes phototherapy light (24.9 $\mu W/cm^2/nm$).

4.2 Results from Each Group of Phototherapy Light Devices

In this study, the efficacy of each phototherapy light is measured via its rate of TSB reduction for jaundice patient within 24 hours and total treatment time prior to patient discharge. The TSB reading were recorded every 6 hours as shown in the table 4.2, 4.4 and 4.6 below. These readings are also illustrated in graph form in figure 4.1, figure 4.2 and figure 4.3. From the reading, their rate for TSB reduction were calculated. The time of discharge for each patient were also recorded to determine the total treatment time required by each of them before being allowed to discharge.

4.2.1 LED Phototherapy Light Device Group

Table 4.2: TSB reading, TSB rate and total treatment time for LED Phototherapy Light Group (Medwarm)

Patient	Total Serum Bilirubin Reading (µmol/ L)					Rate of TSB Reduction (%)	Total Treatment Time Before Discharge (Hours)
	0 hour	6th hour	12th hour	18th hour	24th hour		
Patient 1	318	290	275	252	238	25.16	48
Patient 2	288	272	254	239	227	21.18	36
Patient 3	295	266	238	206	183	37.97	24
Patient 4	376	360	315	287	258	31.38	48
Patient 5	287	295	260	240	225	21.60	36
MEAN						27.46 ± 7.16	38.4 ± 10.04

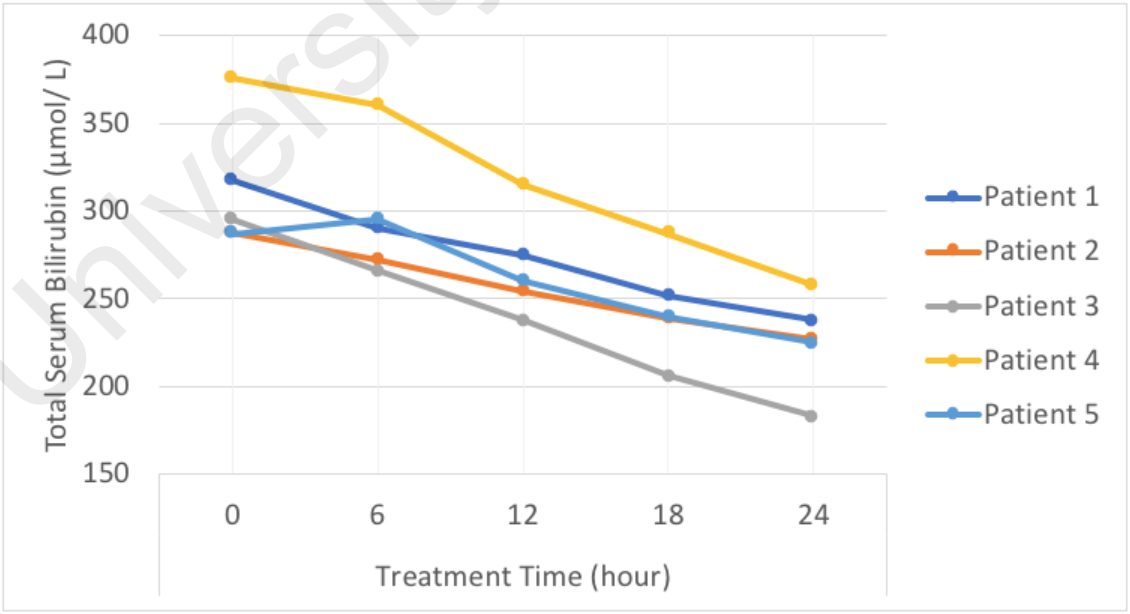


Figure 4.1: Graph of total serum bilirubin against the treatment time for each patient in LED light device group

Based on table 4.2, patient 3 recorded the highest rate of TSB reduction within 24 hours for the LED group. Although the initial rate of patient 3 almost similar with patient 2 and 5, its rate perform the best at every 6 hours interval until the 24th hour of treatment time. This patient is the only patient allowed to be discharged within 24 hours across the group and all 3 group of device treatment.

Patient 4 started with the highest TSB reading at 376 μmol/ L and record a high TSB reduction rate at 31.38%. Although it has a high TSB reduction rate, the total treatment time for this patient takes 48 hours before being allowed to discharge. It has the same treatment time with Patient 1 which has the rate at 25.16%. Meanwhile, Patient 2 and Patient 5 both started with the lowest TSB reading at 288 μmol/ L and 287 μmol/ L respectively, but both record only ~21% TSB reduction rate which is among the lowest in the LED group. However, they still managed to record 12 hours lower treatment time than both Patient 1 and Patient 4. This might happened because both Patient 1 and Patient 4 started at much higher TSB level and the TSB reduction rate might be decreasing over treatment time.

In average, the LED device group produced the mean rate of TSB reduction at 27.46% during the 24 hours treatment. For the total treatment time prior to discharge, it recorded a mean time of 38.4 hours per patient.

Another point of view is made where the rate of TSB reduction for each patient at each interval was calculated and recorded in table 4.3 below.

Table 4.3: Rate of TSB reduction at each interval for each patient of LED light device within 24 hours

Patient	Rate of TSB Reduction at Each Treatment Time Interval (%)			
	6th hour	12th hour	18th hour	24th hour
Patient 1	8.81	5.17	8.36	5.56
Patient 2	5.56	6.62	5.91	5.02
Patient 3	9.83	10.53	13.45	11.17
Patient 4	4.26	12.50	8.89	10.10
Patient 5	-2.79	11.86	7.69	6.25
Mean	5.13 ± 4.98	9.34 ± 3.26	8.86 ± 2.80	7.62 ± 2.81

This interval data shows that the LED light device reduce the TSB of the patient the best between 12th to 18th hour. The rate started slow at 6th hours interval before increasing and then decreased at the end of the 24 hours period. It has a peak mean TSB reduction rate at 9.34% during the 12th hour reading.

It is worth to note there is a negative reading for patient 5 during the 6th hour. This is because the patient's initial TSB reading has increased from initial TSB reading of 287 μmol/L to 295 μmol/ L at the 6th hour interval. This shows that the TSB reading could still increase although it is under phototherapy treatment.

4.2.2 6-Tubes Fluorescent Light Device Group

Table 4.4: TSB reading, TSB rate and total treatment time for 6-Tubes Fluorescent Phototherapy Light Group (Neotech)

Patient	Total Serum Bilirubin Reading (µmol/ L)					Rate of TSB Reduction (%)	Total Treatment Time Before Discharge (Hours)
	0 hour	6th hour	12th hour	18th hour	24th hour		
Patient 6	335	312	293	280	267	20.30	60
Patient 7	326	320	296	290	277	15.03	72
Patient 8	275	263	248	231	215	21.82	36
Patient 9	266	255	249	242	232	12.78	48
Patient 10	269	248	237	228	220	18.22	48
MEAN						17.63 ± 3.71	52.8 ± 13.68

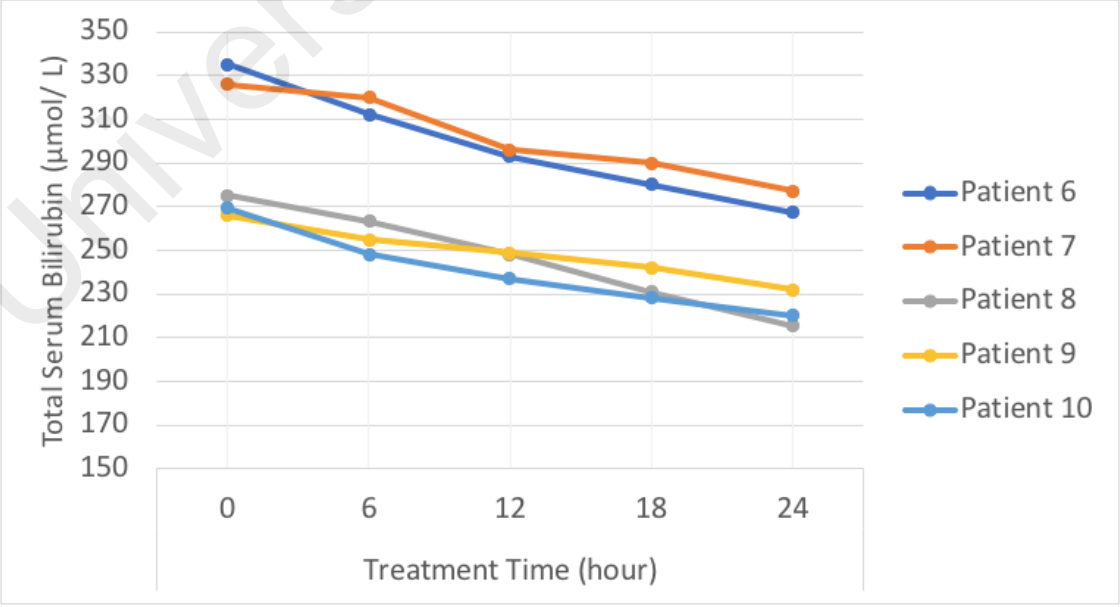


Figure 4.2: Graph of total serum bilirubin against the treatment time for each patient in 6-tubes fluorescent light device group

From the table 4.4, the rate of 24 hours TSB reduction in each patient ranging from 12.78% up to 21.82% for the 6-tubes fluorescent light group. Total treatment time for each patient also had a longer period than the LED group, ranging from 36 hours up to 72 hours. With mean of 17.63% TSB reduction rate for its patient and 52.8 hours mean treatment time prior to discharge, LED is more superior than 6-tubes fluorescent device.

Patient 8 recorded the highest rate for TSB reduction within 24 hours but still did not achieve the required level to be discharged which is below 200 μmol/ L. Meanwhile, Patient 9 has the lowest rate of TSB reduction within 24 hours at 12.78% although the initial TSB reading was the lowest among the rest of the group. On the other hand, patient with the second lowest TSB reduction rate at 15.03%; Patient 7, started with one of the highest initial TSB reading. This evidence did show that the high initial TSB reading does not really correlate with high TSB reduction rate.

Another table is recorded in table 4.5 to show the rate of TSB reduction at each interval within the 24 hours treatment time.

Table 4.5: Rate of TSB reduction at each interval for each patient of 6-tubes fluorescent light device within 24 hours

Patient	Rate of TSB Reduction at Each Treatment Time Interval (%)			
	6th hour	12th hour	18th hour	24th hour
Patient 6	6.87	6.09	4.44	4.64
Patient 7	1.84	7.50	2.03	4.48
Patient 8	4.36	5.70	6.85	6.93
Patient 9	4.14	2.35	2.81	4.13
Patient 10	7.81	4.44	3.80	3.51
Mean	5.00 ± 2.37	5.22 ± 1.94	3.99 ± 1.85	4.74 ± 1.30

Based on the data shown in table 4.3, the mean rate of TSB reduction started almost the same rate as the LED device. However, it only peaks up to 5.22% during the 12th hours interval before decreases at 18th hour and increases a little again by the 24th hours interval. This pattern shows a bit irregularity as compared to the LED device.

4.2.3 4-Tubes Fluorescent Light Device Group

Table 4.6: TSB reading, TSB rate and total treatment time for 4 Tubes Fluorescent Phototherapy Light Group (Medela)

Patient	Total Serum Bilirubin Reading (µmol/ L)					Rate of TSB Reduction (%)	Total Treatment Time Before Discharge (Hours)
	0 hour	6th hour	12th hour	18th hour	24th hour		
Patient 11	284	298	230	220	218	23.24	36
Patient 12	266	261	254	236	224	15.79	36
Patient 13	302	302	296	283	270	10.60	72
Patient 14	273	257	237	225	216	20.88	36
Patient 15	313	304	298	286	279	10.86	84
MEAN						16.27 ± 5.73	52.8 ± 23.39

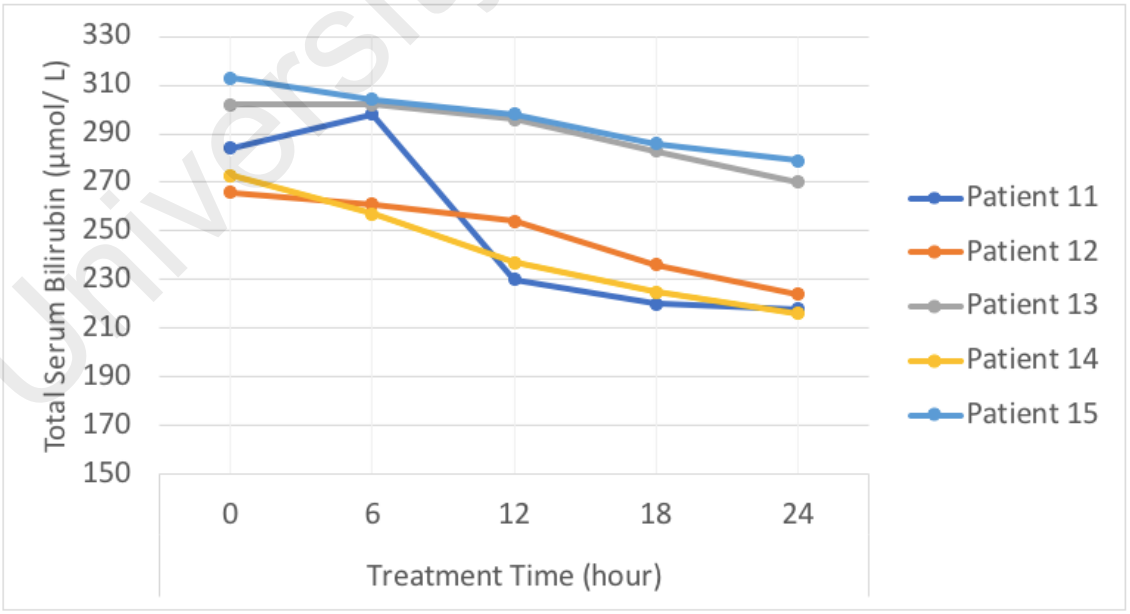


Figure 4.3: Graph of total serum bilirubin against the treatment time for each patient in 4-tubes fluorescent light device group

The data from table 4.6 shows that the mean TSB reduction rate for 4-tubes fluorescent light device is 16.27%, lower than both LED and 6-tubes fluorescent light. Although one of the patient in this group has the longest total treatment time up to 84 hours, this 4-tubes fluorescent device recorded similar mean of pre-discharge total treatment time with 6-tubes fluorescent device. Both recorded mean of 52.8 hours treatment time.

Patient 11 has the highest rate of TSB reduction among the patient in the group and finished treatment after 36 hours. The other two patient with highest TSB reduction in the group, Patient 12 and Patient 14, also recorded total treatment time of 36 hours. On the other hand, the patient with the lowest TSB reduction rate at ~10%, Patient 13 and Patient 15 recorded a longer treatment time at 72 hours and 84 hours respectively. This shows the correlation between slower rate would contribute to longer treatment time for each patient before being allowed to discharge.

As is the case for Patient 5 in LED group, the data from figure 4.3 also shows Patient 11 had an increase in TSB level at the 6^{th} hour reading before steeply decreasing during the 12^{th} hour. This could be normal as the TSB level might still increase during the phototherapy treatment. However, the sharp decrease from 6^{th} to 12^{th} hour might suggest the phototherapy light did not effectively reach the patient prior to the 6^{th} hour due to improper placement eg longer distance from light source to patient, or some interruptions occur during the early period.

The TSB rate at each time interval is calculated and tabulated in table 4.7 below to get another view of the efficacy of this 4-tubes fluorescent device.

Table 4.7: Rate of TSB reduction at each interval for each patient of 4-tubes fluorescent light device within 24 hours

Patient	Rate of TSB Reduction at Each Treatment Time Interval (%)			
	6th hour	12th hour	18th hour	24th hour
Patient 11	-4.93	22.82	4.35	0.91
Patient 12	1.88	2.68	7.09	5.08
Patient 13	0.00	1.99	4.39	4.59
Patient 14	5.86	7.78	5.06	4.00
Patient 15	2.88	1.97	4.03	2.45
Mean	1.14 ± 3.40	7.45 ± 8.93	4.98 ± 1.24	3.41 ± 1.71

From the data shown in table 4.7, the mean rate of TSB reduction for each patient started at low percentage around ~1%. It reaches the peak at the 12th hour before the rate decreases again until the 24th hour period. This pattern is almost similar with the LED group where the rate started low, reaches peak at 12th hour interval before decreases until the 24th hour treatment time.

As discussed above, the rate of Patient 11 is negative at 6th hour due to increase in TSB level whereas in Patient 13, the rate is 0% because the TSB level remain unchanged.

4.3 Direct comparison between LED device, 6-tubes fluorescent device & 4-tubes fluorescent device

Based on the data from the previous tables, a graph of mean TSB against the treatment time is shown in figure 4.4 below to better visualise the effect of each phototherapy light devices within the 24 hours period.

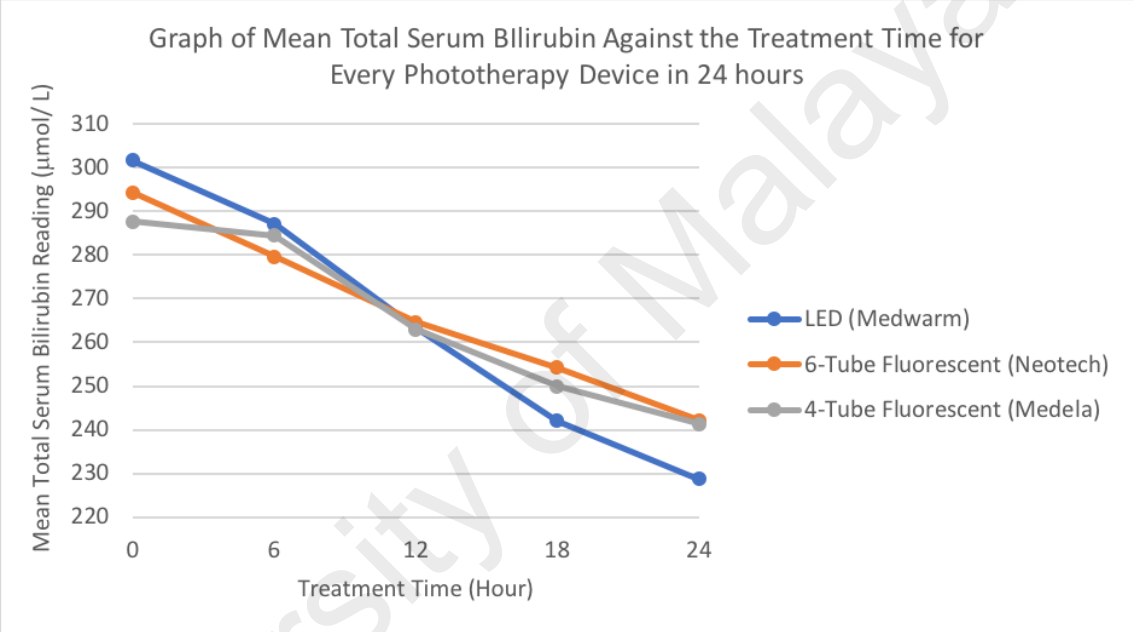


Figure 4.4: Graph of mean TSB reading against the treatment time for each type of phototherapy light devices

Based on the graph in figure 4.4, LED light devices recorded the most rapid and best performing light with the greatest steep/gradient. It started with the highest initial mean TSB but managed to reduce it until the value went below the mean TSB of the other two light devices in the 24 hours timeframe. In comparison, the graph looks almost similar for both the 6-tubes and 4-tubes fluorescent light. Although the 6-tubes fluorescent light has more rapid effect on TSB value within 6 hours than the 4-tubes light, they end up with almost the same mean TSB value at the end of the 24 hours period.

Table 4.8 compiles the mean data from each group of phototherapy lights devices for direct comparison and evaluation. In order to understand the significance of these data, one-way ANOVA analysis were done. These data are tabulated and statistically analysed together in the table to allow clearer comparison.

Table 4.8: Parameter comparison and statistical analysis between every type of phototherapy light devices

Measured Paramater	LED (Medwarm)	6-Tube Fluorescent (Neotech)	4-Tube Fluorescent (Medela)	P-value
Irradiance ($\mu W/cm^2/nm$)	62.3	29.9	24.9	-
Rate of Mean TSB Reduction (%) within 24 hours	27.46 ± 7.16	17.63 ± 3.71	16.27 ± 5.73	0.0181
Mean Total Treatment Time (Hour)	38.4 ± 10.0	52.8 ± 13.7	52.8 ± 23.4	0.3236

4.3.1 Primary Outcome: Rate of TSB reduction for each patient within 24 hours

Referring to the table 4.8 above, LED phototherapy light recorded the highest rate of mean TSB reduction within 24 hours at 27.46% . The TSB reduction rate is much higher than the rate recorded by 6-tubes and 4-tubes fluorescent phototherapy light which are close together at 17.63% and 16.27% respectively.

Based on the statistical analysis one-way ANOVA done, the rate of mean TSB reduction for LED is significantly higher than both of the conventional fluorescent light devices ($P<0.05$). Meanwhile, the rate of mean TSB reduction for both 6-tubes and 4-

tubes fluorescent light devices were similar as T-test analysis showed p-value is 0.3345 ($p>0.05$)

The result proved LED phototherapy light is the most efficacious among the three devices as it produced the highest rate of TSB reduction in jaundice patient within 24 hours. Its rate was significantly higher than both 6-tubes and 4-tubes fluorescent light devices.

The superiority of LED shown in this study is affected by its high irradiance. Its irradiance value is twice as high as both of the fluorescent light devices. As the spectral irradiance is proportional to the efficacy of bilirubin breakdown, the higher irradiance of LED allow faster time to break down and reduce the serum bilirubin level. (Tan, 1982) The higher irradiance allows the bilirubin in the blood to absorb more discrete photons which eventually produce more photochemical reaction. This reaction produced more soluble bilirubin which are then excreted through liver as well as urinary and stool elimination.

This finding was supported by Bhat JI et al. which found that LED phototherapy is more efficacious than conventional phototherapy device. (Bhat, et al., 2016) The result is also in agreement with a study conducted by Gutta et al. in 2019. (Gutta, et al., 2019) Their study on 166 neonate patient found that LED gives a better and significant rate of decrease in TSB than conventional fluorescent phototherapy light (4 blue + 2 white lights).

This cause factor is further strengthened by Chang et al. that proved high intensity blue LED device is more effective than conventional phototherapy for both in vitro and in vivo bilirubin photodegradation. (Chang, et al., 2005) Meanwhile, both 4-tubes and 6-tubes produced similar rate of TSB reduction because they have almost similar irradiance value.

From another perspective, the superiority of LED as compared to conventional fluorescent light is in contradiction with research paper by Adhikari et al. They claimed there was no significant difference in the efficacy of different phototherapy light devices including fluorescent, LED & blue-white light. (Adhikari, Mathai, Moorthy, Chawla, & Dhingra, 2017) However, this study is found to use LED light sources which has similar or lower value of irradiance than the other two light sources. Hence the result was similar among the three light sources in their study.

On top of that, the mean rate TSB reduction at each 6 hour interval for each phototherapy light device were shown in table 4.9 and figure 4.5 below. This was done to understand the effective time at which the phototherapy performs the best.

Table 4.9: Mean rate of TSB reduction at each interval within 24 hours for each patient from every phototherapy light device group

Device	Mean Rate of TSB Reduction at Each Treatment Time Interval (%)			
	6th hour	12th hour	18th hour	24th hour
LED Light	5.13 ± 4.98	9.34 ± 3.26	8.86 ± 2.80	7.62 ± 2.81
6-Tubes Fluorescent Light	5.00 ± 2.37	5.22 ± 1.94	3.99 ± 1.85	4.74 ± 1.30
4-Tubes Fluorescent Light	1.14 ± 3.40	7.45 ± 8.93	4.98 ± 1.24	3.41 ± 1.71

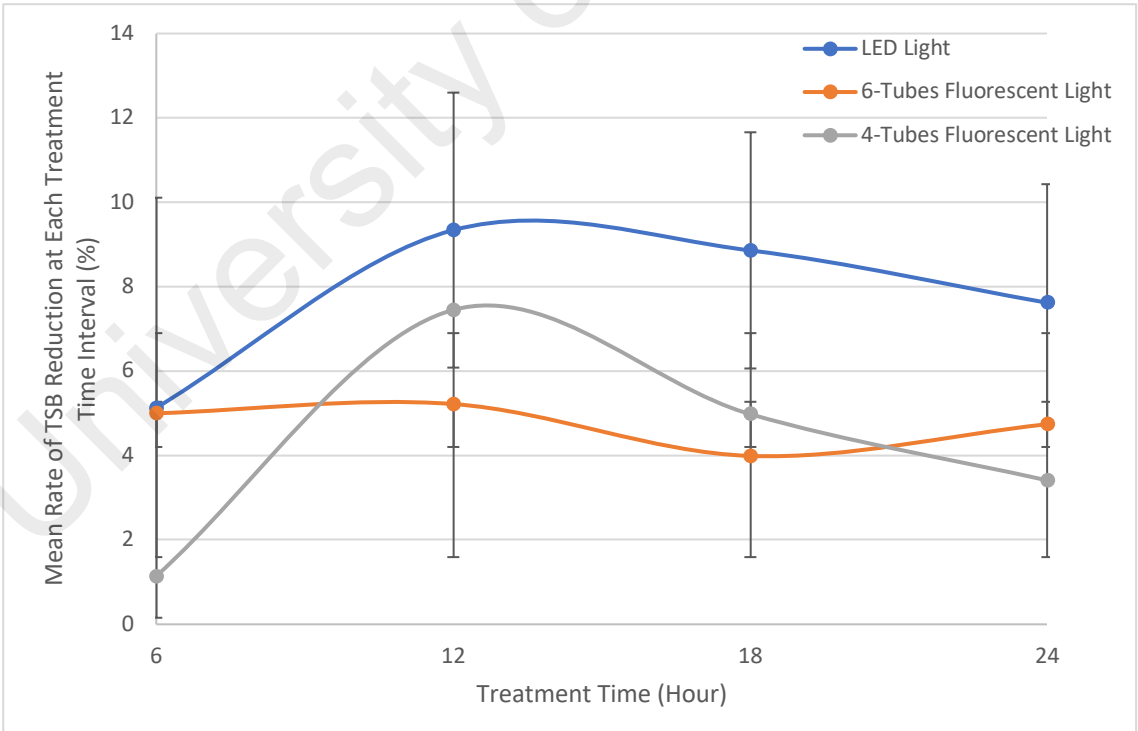


Figure 4.5: Graph of mean rate of TSB reduction at each time interval within 24 hours for each phototherapy light device group

The mean rate of patient TSB reduction in LED for each interval exceeds all the rate at any interval from the fluorescent light device groups. The pattern shown in graph figure 4.5 demonstrates some similarities between all the light device groups. The rate started at lower rate during the 6th hour interval before reaches peak at the 12th hour interval. After that, the rate decreases again until the 24th hour for both LED and 4-tubes fluorescent device. For 6-tubes fluorescent device, the rate decreases at the 18th hour interval before increases again at the 24th hour interval. The rate increment however did not reach the peak during the 12th hour interval.

This data shows generally the phototherapy light device is most efficient in between the 6th to 12th hour of the phototherapy treatment. This might help the medical practitioner to strategize the treatment plan for neonates especially if there are too many patient needing treatment at the same time while the device availability is scarce. Each jaundice patient could receive at least 12 hours treatment alternately between each other which would help to prevent the jaundice from worsen.

4.3.2 Secondary Outcome: Total patient treatment time prior to discharge

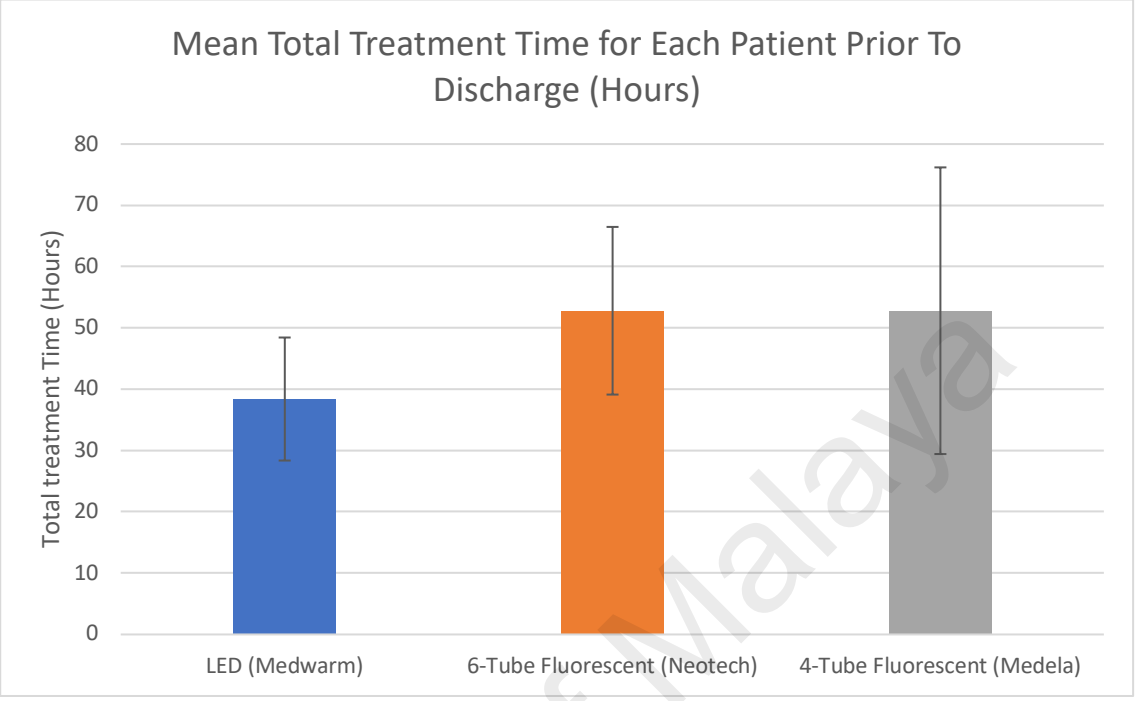


Figure 4.6: Mean total treatment time for each patient prior to discharge for each phototherapy light device group

Based on figure 4.6, LED phototherapy light device recorded the shortest treatment time required prior to discharge with only 38.4 hours. Both 6-tubes and 4-tubes fluorescent phototherapy light has the same mean of total treatment time at 52.8 hours.

Although LED recorded the shortest mean treatment time prior to discharge, there is no significant difference in the mean treatment time between each group of phototherapy light devices ($P>0.05$). This shows that all three type of phototherapy light devices has similar treatment time for each jaundice patient prior to discharge.

All three type of phototherapy light devices produced similar effect in term of the treatment time required before discharge. Although the LED mean treatment time is lower

than both fluorescent light which has the same value, the difference is not significant. This might be contributed by the fact that the discharge process of each neonate patient was only done every 12 hours instead of when the patient already reach discharge level at below 200 μmol/ L. Thus, the spread of mean treatment time between each group will be closer and would not show significant difference. This reason is supported by Bhat et al. which shows significant difference in mean treatment time between the LED and conventional phototherapy light using survival curve analysis. (Bhat, et al., 2016)

4.4 Limitations

There are few limitations which need to be highlighted for improvement in future studies. The number of sample used in this study is only 5 neonate patients for each type of phototherapy light devices due to certain constriction. Higher number of samples could be used to increase the significance of the research. The number of phototherapy used is also limited to only one device each. This does not represent the real situation as there is no effective randomization to reflect it.

Besides, the devices used in our study are limited to units which are readily available in the hospital. The LED device was found to be bought more recent than the fluorescent devices. The Medwarm LED light device were purchased last year whereas both fluorescent light devices were already bought few years before. This might have effect in term of the effectiveness of the product in which newer product would usually perform better than older product. Notwithstanding, it is worth to note that the tubes of the fluorescent devices were changed every 6 months to ensure optimal irradiance.

Another shortcoming identified is the inability to monitor the strict compliance to the phototherapy treatment guide. Some medical practitioner could be placing the phototherapy light without measuring the exact distance of 30cm between the light source and the neonate patient's skin surface. The irregular distance could cause irradiance to vary between each patient under treatment and hence affecting treatment efficacy. There is also intensity level in the Medwarm LED phototherapy light device which might be altered by some individual and eventually affecting the irradiance given.

CHAPTER 5: CONCLUSION

The study found that LED phototherapy light device is more efficient than both type of conventional phototherapy devices; 4-tubes and 6 tubes fluorescent light devices. LED light has significantly higher rate of TSB reduction than the other two devices. Both fluorescent light has similar efficacy as they has similar rate of TSB reduction as well as same treatment time prior to discharge. Although the secondary outcome, treatment time is similar between all type of light source devices, the mean treatment time value of LED device is lower than both 4-tubes and 6-tubes fluorescent light devices which have the exact same treatment time value.

Future studies could consider comparing between more type of light devices available in the market. This includes fibre optic blanket and halogen light. This would give a more holistic overview of the efficacy for every type of phototherapy light devices.

As more of LED type devices being used nowadays, a comparison study could be done to compare the efficiency of different brand of LED type light devices. Every manufacturers would claim their product is the best but a proper study could allow the medical practitioner to decide which brand could be the best in reducing jaundice patient TSB level.

On top of that, the effect of using double phototherapy using any combination of the light devices could also be analysed. This is because some users would claim usage of two phototherapy on a single patient could significantly reduce TSB level as compared to using one device only. This future study would help to optimise treatment approach and maximise the use of the light devices to provide better jaundice management.

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