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Determination of intensity and spread of light to the surrounding in conventional phototherapy and comparison with novel converging photo unit — an observational study

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Abstract

Background Blue light phototherapy used extensively in the management of hyperbilirubinemia has many side effects like dry eyes, blurring, headache, and altered circadian rhythm. Healthcare providers working around the phototherapy are unduly exposed to these side effects. Altered circadian rhythm results in disruption in the sleep-wake cycle affecting healthcare providers particularly working during the night shift. The constant glare of the blue light interrupts in clinical observation of the baby on phototherapy. With the intent of providing effective phototherapy with minimal exposure of blue light to healthcare providers, a light source called the photo unit was designed and developed.

The objective of this study was to estimate the intensity and spread of blue light to the surrounding in conventional phototherapy and to compare the same with newly developed converging photo unit.

Results The therapeutic range of irradiance was noted up to 22 inch in diameter with conventional phototherapy compared to only 7 inch with our photo unit. The light spread with a conventional phototherapy unit was seen beyond 50 inch in all directions whereas was confined to 19-inch diameter with photo unit.

Conclusion Photo unit developed by the authors has minimal divergence of light to the surrounding, thereby mitigating the side effects of blue light exposure to the people working in the vicinity. Multiple of these photo units can be used to make a phototherapy device.

Keywords Hyperbilirubinemia, Blue light, Photo unit

Background

Neonatal jaundice is a common cause of mortality and morbidity in newborn babies and accounts for up to 60% cases in term and 80% in preterm babies in the 1st week of life. An increase in serum unconjugated bilirubin levels is predominantly due to breakdown of excess RBCs. Unconjugated bilirubin is converted to conjugated form by the liver and is excreted in bile. Higher level of unconjugated bilirubin crosses blood-brain barrier and is neurotoxin [1]. Damage to central nervous system caused by bilirubin is permanent. Hence, hyperbilirubinemia is considered as one of the preventable causes of brain damage in newborn period. Phototherapy, exchange transfusion, and pharmacological

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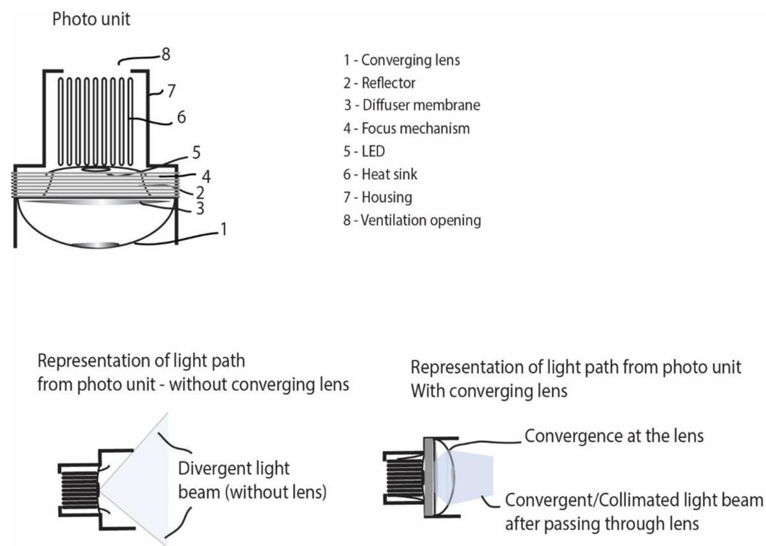

Fig. 1 Illustration of photo unit

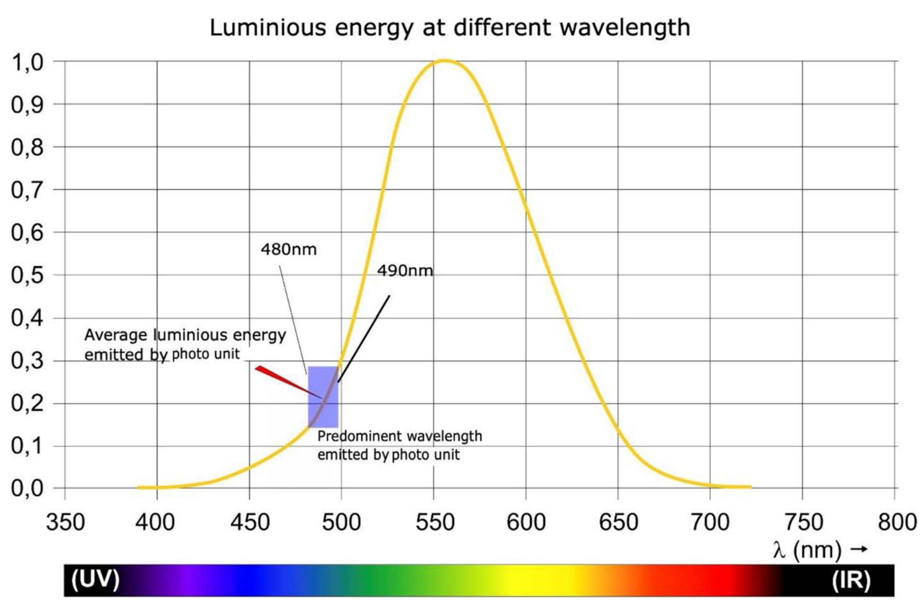

Fig. 2 Luminous energy at different wavelengths

agents are the different modes of treatment for hyperbilirubinemia [2].

Blue light phototherapy has been used extensively for the management of hyperbilirubinemia as it is highly effective in decreasing bilirubin levels and preventing the need for exchange transfusion. However, studies have shown many side effects of blue light. Continuous exposure to blue light was noticed to have various side effects like dry eyes, blurring, headache [3], and altered circadian rhythm. Healthcare workers caring for the baby on phototherapy are constantly exposed to blue light and thereby its side effects. Altered circadian rhythm results in disruption in the sleep-wake cycle affecting healthcare providers particularly working during the night shift [4–7].

Apart from this, the studies have shown that these lights can affect the mood, thereby causing learning disability and affecting academic and intellectual performance [8, 9], and observed that blue light is associated with a significantly high prevalence of skin cancers.

Presently available phototherapy units are designed to provide intensive phototherapy with high irradiance over the target subject placed at the centre. This design invariably leads to unwarranted exposure of the healthcare personnel to the toxic effects of blue light. Several closed systems such as the Biliblanket have addressed this issue but were found to be less efficacious than conventional phototherapy [10]. Added to this, the inability for clinical observation during treatment is another serious limitation.

Lower efficacy of closed systems was attributed to the low irradiance and/or small surface area illuminated by the mat of the fibre-optic phototherapy units [11].

The challenge in providing effective phototherapy for jaundiced neonates can be summarised as the need for intensive phototherapy without exposing the healthcare personnel to blue light hazard and simultaneously retain the ability to make uninterrupted clinical observation. As a solution to meet all these challenges, a light source called converging photo unit was designed and developed.

The objective of this study was to estimate the intensity of the blue light and its spread to surrounding in newly developed converging photo unit and to compare the same with the conventional phototherapy.

Methods

Principle

If the distance between the light source and lens is equal to the focal length, the emergent light tends to be parallel and restricted to a small area This phenomenon is called collimation. If the distance between the light source and the lens is shorter than the focal length, the emergent light will be convergent to a small area. This arrangement conserves the light energy by restricting the spread over a small area (required area) and not disperse it to the surroundings. Bringing this system closer to the treatment region results in reduced dispersion and increased intensity of light to the target area.

Development of the photo unit

Photo unit

It consists of 3-W COB (chip on board) LED (460–490 nm) light with appropriate electronics housed in a short cylinder. A heat sink was provided for heat dissipation. A plano-convex optical lens of focal length 50 mm was fitted at the other end of the cylinder to achieve maximum convergence of the light. The distance between the light source and the lens was roughly equivalent to the focal length of the lens resulting in collimation/convergence of light beams. A mechanism for adjusting this distance by manual repositioning of the lens is optional. which is not constructed in the present unit. This collimated/converged light source is called the photo unit hereafter (Fig. 1).

Using this photo unit, the dispersion of light to the surroundings was determined and compared against the conventional phototherapy.

Set-up

A room of size 10ft × 10ft was chosen for the study. An arrangement of two tables to provide a surface of 50″ × 50″ was placed at the centre. The white fabric was spread over the table. The testing lights were suspended at the centre. All sources of ambient light were limited by switching off the artificial light and covering the windows. The study surface was marked with the lines indicating the direction and distance in inches.

Data collection

Determination of light spread from conventional phototherapy unit

Fanem LED phototherapy (Billiton 2006 SL.NO.ITAL-890172) was used for the experiment. The phototherapy light was suspended at a height of 18 inch from a flat white surface. The intensity of the light in terms of Lux was measured from centre to periphery in eight directions (north, south, east, west, north-east, north-west, south-east, south-west). The intensity was measured at a distance of 1 inch from the previous measurement. The maximum distance covered from the centre was 50 inch.

Estimation of light spread from collimation/convergence photo unit

The unit was suspended from the white flat surface at a distance of 9 inch. This is the height from which the proposed phototherapy system is designed to work. The rest of the measurement is similar to the conventional phototherapy unit.

Light intensity was measured in Lux with both conventional phototherapy unit and photo unit placed at various heights from the measuring surface.

The first set of measurements was done with conventional phototherapy suspended at 18 inch and a photo unit at 9 inch from the surface. The subsequent set of measurements was done with a conventional phototherapy unit suspended at 18 and a photo unit at 18 inch and another one with both these units suspended at 9 inch height from the surface.

Calculation of irradiance from lux

Studies have shown 683 lx at 555 nm gives 1 W/m^2 = 100 μW/sq.mt [12]. The same intensity of 683 lux in the blue light (490nm) will provide 20.8% of that luminous energy (20 μW/cm^2) Fig. 2. In other words, approximately 330 lux of blue light will provide irradiance of 10 μW/cm^2. This will be sufficient for regular phototherapy. The light intensity has to be increased by 3 times to provide

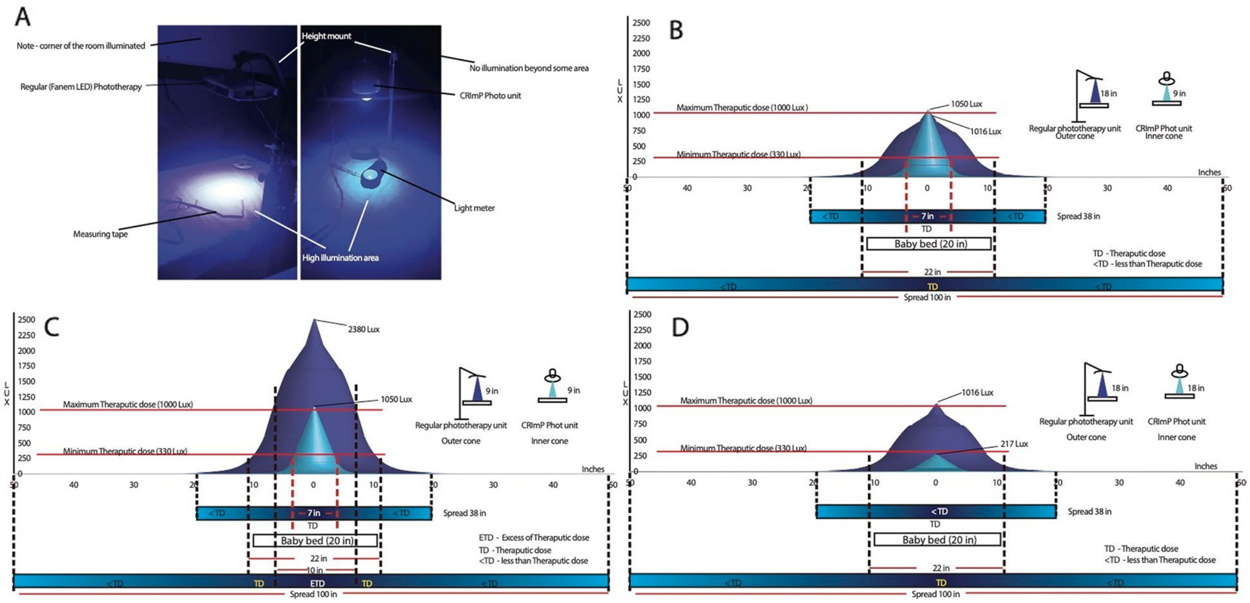

Fig. 3 **A** Graphical representation of the spread of light intensity of both conventional phototherapy and photo unit. **B** Both at their designed heights, i.e. 18 inch and 9 inch, respectively. **C** Both at the height of 9 inch. **D** Both at the height of 18 inch

intensive phototherapy with an irradiance of 30 $\mu W/cm^2$. This can be provided by 990 lux of blue light. Our photo units emitted light predominantly at 480–490 nm range.

Ethics and consent

This study did not involve any human subjects, and hence, no consent was needed.

Results

Light intensity was measured by both conventional phototherapy and photo unit at their designated heights, for clinical use. Conventional phototherapy is at 18 inch and photo unit at 9 inch. Both had a peak value at the centre which was just above 1000 lx. The photo unit clocked an intensity of 1050 lx, and the conventional phototherapy clocked 1016 lx. The therapeutic range of irradiance was noted to be spread up to 22 inch in diameter with conventional phototherapy compared to only 7 inch with our photo unit. Light spread beyond this area was in the subtherapeutic range.

The light spread with a conventional phototherapy unit was seen beyond 50 inch in all directions. We measured only up to 50 inch from the centre. The overall spread with our photo unit was confined to 19-inch diameter, and no light was detectable beyond that. At a distance of 9 inch, the conventional phototherapy unit and photo unit source had a maximum intensity of 2380 and 1050 lux with light extending up to 50 and 19 inch of radius respectively.

When both units were suspended at the height of 18 inch, the maximum intensity of 1016 and 217 lux was noticed at the centre in conventional phototherapy and photo unit source respectively. The divergence of light was observed up to 50 inch of distance in conventional phototherapy, whereas it was up to 19 inch in the photo unit source.

Although the spread of light was the same at both 18- and 9-inch height in our collimated light source (photo unit), the intensity of light differed at a varied distance. The required light irradiance at the desired wavelength was achieved by the photo unit source at 9 inch of height Fig. 3.

Discussion

Neonatal blue light phototherapy (NBLP) has been widely and successfully used in the management of hyperbilirubinemia to reduce the serum bilirubin levels, thereby preventing kernicterus. Phototherapy is one of the commonly used noninvasive mode of treatment. When the phototherapy light irradiates the skin, the bilirubin molecules form nontoxic, excretable isomers of bilirubin which are excreted from the kidney [13, 14].

The efficacy of phototherapy in converting bilirubin to soluble form is determined by the wavelength of the light, irradiance (luminous energy), and surface area of the neonate illuminated. Irradiance is a direct function of the amount of light which is determined by the distance between the baby and the light source, which is directly proportional to each other. The volume of bilirubin that can be handled per unit depends on the body surface area exposed to the light [9].

The most effective light source to degrade bilirubin is at a wavelength range between 420 and 520 nanometres (nm). The light of lower wavelength, i.e. between 420 and 470 (blue), is typically used in treatment which is shown to be effective. Several studies have shown the light at a higher wavelength between 480 and 520 (green) nm is equally effective [15]. It is at this wavelength that light penetrates the skin and is maximally absorbed by the bilirubin.

Regular phototherapy units are placed at a distance of 18 inch and have a wavelength of 460–490 nm.

Bilirubin follows the first-order elimination kinetics [13] and has a dose-response relationship with phototherapy. As the irradiance increases, the rate of elimination of bilirubin increases until a saturation point is reached. Thereafter, the response also decreases. Studies have shown in the range of 400–490 nm, the saturation point was 770 $\mu W/cm^2$ [16].

Ideally, the irradiance is measured using an irradiance metre. Each light source typically has specific spectral range of photons with peak: emission peak. Similarly, each irradiance metre exhibits its own characteristic: spectral sensitivity distribution and peak [17]. The measurement of irradiance and its interpretation for maintaining the phototherapy units is a common practice. Since the availability of irradiance metre is precarious, the irradiance has been calculated from the integration of spectral range and lux in terms of $\mu W/cm^2/nm$.

Implication

In the process of administering the therapeutic intensity of phototherapy light to the baby, there is a widespread of the light to surrounding areas. The caregivers of the baby in the neonatal units (doctors, nursing personnel) are constantly exposed to this blue light during their routine work. Using the above photo unit, a new close range immersive phototherapy (CRImP) device was developed (*patent pending at Indian Patent Office, application no. 202141013556*) which will be studied in the clinical scenario.

In conclusion, the photo unit developed by the authors has minimal divergence of light to the surrounding, thereby mitigating the side effects of blue light exposure to the people working in the vicinity. Further iteration followed by clinical studies is in the pipeline to assess its efficacy, and rate of bilirubin declines.

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Nil.

Authors' contributions
SK has contributed and collected the data and did the literature search and preparation of the manuscript. SMD has contributed in conceiving the research question, protocol development, and analysis of data. He has also guided the work throughout and helped in preparing the manuscript. DT has helped in study design, analysing the data, and preparing the manuscript. The authors read and approved the final manuscript.

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Availability of data and materials
Available with the corresponding author on request.

Declarations

Ethics approval and consent to participate
As this is an in vitro study and no human subjects were involved, ethical committee approval is not applicable to this study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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