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Improving Effectiveness of Phototherapy in an Academic Center: A Quality Improvement Project

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Abstract
Neonatal hyperbilirubinemia is a common cause of delayed discharge and readmissions in our institution. As previously published, the irradiance our phototherapy (PT) units provided was below the irradiance recommended by the AAP for intensive phototherapy ($>30\,\mu W/cm^2/nm$). We measured irradiance delivered by our PT units (Drager 4000) using a standardized footprint grid. By varying number of blue and white fluorescent PT lights, height of PT unit above the neonate and type of bed used (open bassinet versus isolette), we determined the optimal PT arrangement needed to deliver intensive PT ($30\,\mu W/cm^2/nm$). We then developed a standardized, multidisciplinary protocol specifying light arrangement and distance required needed to achieve the desired irradiance level. We were able to show improved irradiance following above changes. Onsite measurement of irradiance provided by local phototherapy units and development of a multidisciplinary, standardized protocol are necessary to assure delivery of recommended levels PT for neonates with hyperbilirubinemia.

Keywords
phototherapy, mean footprint irradiance, American Academy of Pediatrics, newborn intensive care unit

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Introduction

The majority of late preterm and term neonates (60%-80%) have clinical jaundice after birth.[1,2] In many studies, jaundice is the most common hospital readmission for neonates.[3,4] Phototherapy, the standard treatment for significant unconjugated neonatal hyperbilirubinemia,successfully treats 99% of severe neonatal hyperbilirubinemia in term neonates[5] and has been shown to decrease the need for exchange transfusion and improve neurological outcomes.[1,6] Before discharge from the hospital, 5-40/1000 term and late preterm neonates are treated with phototherapy (PT).[7]

The efficacy of PT is dependent on the emission spectrum and irradiance delivered by the PT units used. The light source, the distance between the patient and the light source, and as well as the neonate's skin exposure all impact the total irradiance received. Irradiance provided by a light source declines over time with use with significant variability in irradiance decay by light source type.[8] Irradiance is measured using an irradiance meter and is recorded as microwatts per centimeter squared per nanometer ($\mu W/cm^2/nm$) over a wavelength of 400-520 nm.[1,7,9,10] It is inversely proportional to the square of the distance between the light source and jaundiced skin surface.[11] The highest irradiance is measured below the center of the light source and decreases towards the periphery.[12,13] The American Academy of Pediatrics (AAP) defines intensive phototherapy as an irradiance of $30\,\mu W/cm^2/nm$ measured at the center of the PT and recommends a minimal irradiance level of $8\text{-}10\,\mu W/cm^2/nm$.[1] One option to achieve intensive phototherapy per AAP is to bring fluorescent tubes as close as possible (which may be as close as 10 cm) unless using halogen lamps

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which can burn the infant if brought closer than the manufactures' recommendation.[1] The AAP recommends using intensive PT for term and late-preterm infants as per the Bhutani nomogram which is based on age and risk category[1] and state that the PT should be delivered to "as much of the infant as possible."

Despite the importance of delivering adequate irradiance, sub-therapeutic PT is common.[14-17] Pejaver and Vishwanath,[14] studied PT units in 24 neonatal units in India and found only 31% of 58 PT units provided an acceptable irradiance level. In a study from Brazil, Ferreira et al,[15] found 33.3% of 36 PT units provided acceptable irradiance. Owa et al,[16] studied irradiance of 63 PT units from 12 nurseries in Nigeria and found 75% of the PT units had an irradiance below 5 μW/cm^2/nm and only 6% provided an irradiance in the effective range. Even in high-income countries such as the Netherlands only 48% of PT units delivered the minimal recommended irradiance level of 10 μW/cm^2/nm.[17]

Borden et al,[18] studied the level of irradiance provided by PT at 7 metropolitan hospitals, including our own center, in Minneapolis, Minnesota. While 100% of PT units provided the minimum of 8-10 μW/cm^2/nm, only 38% provided intensive phototherapy (≥30 μW/cm^2/nm). Our practice at that time was to provide PT in an isolette in all term and late pre-term neonates. The mean footprint irradiance (MFR) for devices at our own center was only 19.6 ± 3.3 μW/cm^2/nm with a maximum central PT irradiance of 24.6 ± 4.7 μW/cm^2/nm.[18] None of PT units at our center delivered intensive PT with our typical arrangement.

We presented these results to an interdisciplinary team including physicians, nursing, biomedical engineering, and unit leadership. This team responded rapidly to the initial results. To optimize the irradiance delivered in each of our 3 hospital units, we made a series of interventions.

The aim of this quality improvement study was to improve the efficacy of phototherapy by readjusting and standardizing our PT protocols to deliver appropriate effective irradiance.

Methods

The irradiance of fluorescent PT units (Draeger Photo-Therapy 4000 unit (Draeger Medical Systems, Inc. Telford, PA 18969, USA) for delivering PT was measured during 3 time periods (Baseline, Intervention #1, and Intervention #2) at an academic center to improve delivery of PT in 3 units: Newborn Intensive Care Unit (NICU), Birth Center, and Pediatric Inpatient Unit. The Draeger PT unit houses 4 blue and 2 white folded fluorescent lights (Figure 1) which can be used in different combinations. Spectral emission for PT device is 400-550 nm with peak irradiance emission at 650 nm.

Figure 1. Draeger photo-therapy 4000.

Irradiance was measured using the Ohmeda Medical Bili Blanket Meter II (GE Healthcare, Maple Grove, MN, USA). This meter measures a spectral range of 400-520 nm with a center wavelength of 450 nm and a bandwidth of 60 nm. The measuring range of its spectral irradiance is 0.1-299.9 μW/cm^2/nm. According to the manufacturer's instructions (GE Healthcare, 2012), the device can be used to measure irradiance from LED, fluorescent, halogen, and fiber optic PT devices.

Irradiance was measured using a 34 (W) × 45 cm (L) ×, 10 cm (H) (~depth of term neonates trunk) wooden board divided into a grid of 90, 3.8 cm^2, squares which was placed on the mattress surface (Figure 2). In this study we measured irradiances at distances ranging from 15 to 32 cm above 5 points (box 16, 39, 41, 43, and 68) on the grid that represented neonatal anatomy (ie, central PT point on the infant, head, foot, arms) in both an open bassinet and in an isolette.[18] As previously described, the PT unit was centered directly over the grid at the prescribed distance above the irradiance meter laid on the grid.[18] The mean irradiance of all 5 footprint measurements (MFR) as well as the maximum irradiance at the center of the grid were calculated at each distance. After establishing our baseline irradiance for our typically used phototherapy configuration (isolette, 4 blue lights, 30 cm) in the previously published study[18] we initiated Intervention #1. This included replacement of the white fluorescent tubes with blue fluorescent tubes which may be turned on or off and initiating a new nursing protocol for all infants >35 weeks gestation. This protocol recommended placing infants in a bassinet with a white sheet, a PT light to patient distance of 15 cm, and 6 blue lamps illuminated. In Intervention #2, we maintained infants in a bassinet, but increased the PT light to patient distance to 30 cm and decreased to 4 blue lamps illuminated. PT

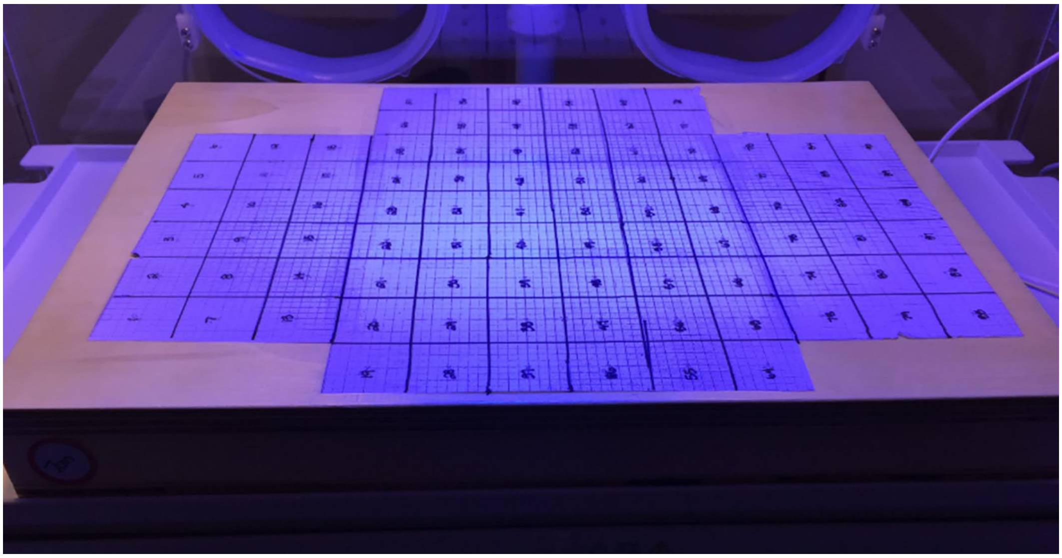

Figure 2. PT sample measure depicting grid used for measuring irradiance footprint.

irradiance was measured after each intervention was implemented.

Ethical Approval and Informed Consent

Permission from Institutional review board was not required as the study did not involve human subjects. Ethical approval was not required for this quality improvement project.

Results

Irradiance measured varied by phototherapy configuration. The MFR during interventions #1 and #2 in a bassinet of 15 PT units using two (4 vs 6) fluorescent light combinations at a height of 15 to 32 cm above the grid decreased as the distance to the light source increased and number of illuminated bulbs decreased (Figure 3). The MFR of Intervention #1 configuration, using either 4 or 6 blue fluorescent tubes at 15 cm above the grid ($84.8 \pm 8.6\,\mu W/cm^2/nm$ and $104.6 \pm 8.5\,\mu W/cm^2/nm$) respectively, was above the irradiance recommended by the AAP for intensive phototherapy.

Based on the above finding, our standard PT protocol for low-medium risk neonates was revised to use a PT unit with 4 illuminated blue lights placed 30 cm above the neonate in an open bassinet (Intervention #2). Using this arrangement, the MFR was $32.5 \pm 5\,\mu W/cm^2/nm$. The majority of units (73%) had a MFR of $\geq 30\,\mu W/cm^2/nm$ and 93% had a central PT irradiance of $\geq 30\,\mu W/cm^2/nm$. For higher risk neonate's 6 lights can be illuminated at this distance of 30 cm with 100% of devices providing a mean central PT irradiance of $\geq 30\,\mu W/cm^2/nm$ and a MFR of $44 \pm 5.3\,\mu W/cm^2/nm$.

As reported in the previous study, the mean central and total footprint irradiance levels decreased when measured through an isolette.[18] In this current study, measured reduction in irradiance in an isolette versus a bassinette was highly variable and ranged from 5% to 50% reduction of irradiance at matched distances. At a distance of 32 cm in an isolette, 6 blue lights provided a MFR of $36.4 \pm 6.4\,\mu W/cm^2/nm$ while 4 blue lights provided an irradiance of $23 \pm 4.5\,\mu W/cm^2/nm$. Using 6 blue lights at this distance, 90% of devices had a MFR of $\geq 30\,\mu W/cm^2/nm$ versus 50% if only 4 blue lights were illuminated. For infants in an isolette, we now use 6 blue lights. For further details see previously published study.[18]

Discussion

As previously stated, the aim of this quality improvement study was to improve the efficacy of phototherapy by adjusting and standardizing our PT protocols to deliver appropriate effective irradiance. We were able to successfully accomplish our aims using a multi-disciplinary team and have incorporated these changes into daily practice in our institution. It is important for all healthcare professionals caring for neonates to appreciate the factors that influence the efficacy of phototherapy. Involving the entire team including biomedical

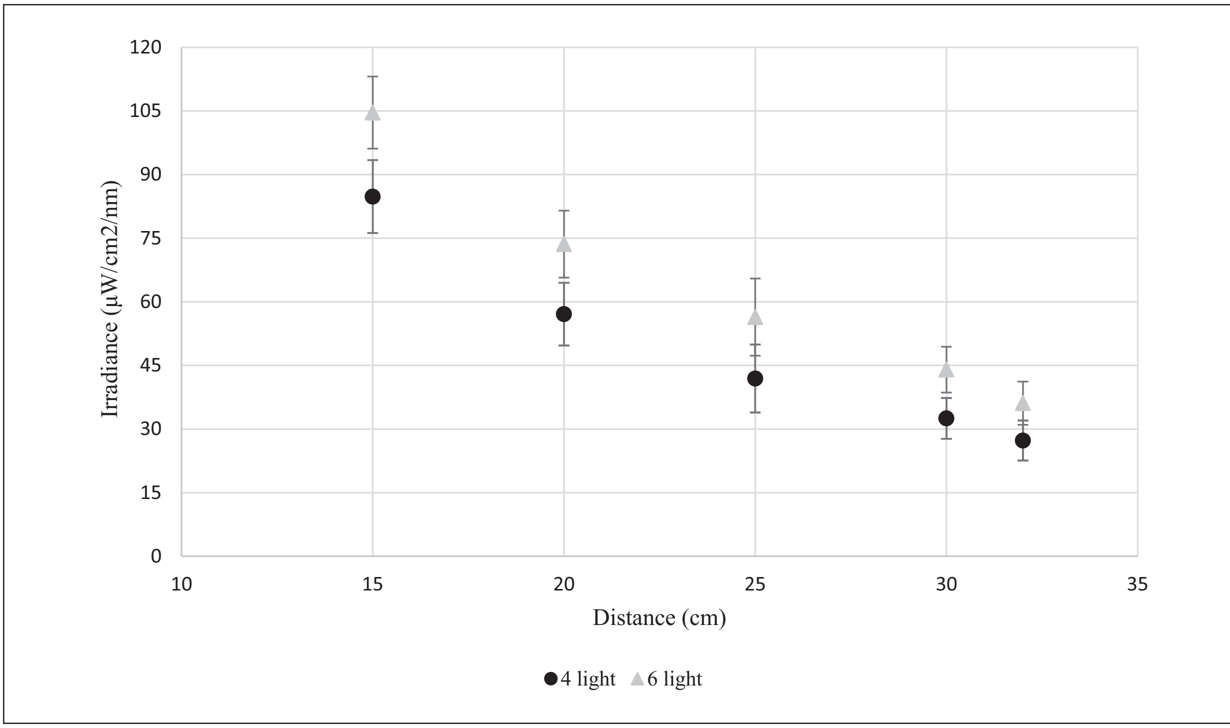

Figure 3. Mean ± SD footprint irradiance by distance for 4 versus 6 illuminated blue lights in open bassinet during Intervention #1 and Intervention #2.

engineering, nursing and nursing leadership as well as physicians resulted in rapid response to the data and institution of the resultant ongoing QI project. Because these changes were evidence-based and low-cost, they have been strongly supported by leadership as have the ongoing re-evaluations and changes.

As shown in other publications, it is possible to improve irradiance using simple interventions such as those we employed in our institutions.[19-21] However, as noted in our project, periodic re-evaluation and readjustment of protocols is essential for maintaining effective phototherapy given changes in equipment and variations in irradiance provided by PT units over time.[19]

Increasing the irradiance delivered to the neonate produces a faster rate of decline of the serum bilirubin.[22,23] The blue-green light in the wavelength range 450-475 nm is most effective for phototherapy because it overlaps the peak absorption spectrum of bilirubin.[24,25] As noted in this study, irradiance distribution to the illuminated area (footprint) is not uniform, with the irradiance at the center far exceeding that at the periphery.[1] The uneven irradiance distribution makes measuring a mean footprint irradiance helpful, although standard for footprint irradiance are not routinely available. Knowing the irradiance of PT delivered to one's own patients is vital and as we have shown varies substantially by distance, type of light source, blue versus white and whether the neonate is cared for in an isolette or an open bassinet. Measuring irradiance of PT units will help assure effective phototherapy is being delivered.[26-28]

In the age of increasing concerns for PT toxicity measuring irradiance levels will also help ensure that more irradiance than needed for the individual neonate is not used.[1,3,11] Use of heat generating blubs, such as the fluorescent bulbs used at our institution, can be associated with overheating of the infant and dehydration from increased insensible losses, especially in preterm infants. Care must be taken to monitor the infant to avoid these complications when decreasing the distance of the PT device to the patient. As we noted, at the distance suggested by the AAP for fluorescent tubes, the irradiance was much higher than needed for the low-medium risk infant without hemolysis, nearing exchange levels or with signs of ABE. Using an irradiance meter will allow the clinician to dose the PT appropriately for the age, risk category, and clinical condition of the infant.

As our results showed at the initiation of our quality improvement project, none of our PT units were delivering intensive phototherapy.[18] By changing the distance between the light source and the neonate and changing the number of tubes/lights illuminated we can titrate our PT to that needed by an individual infant.

For most neonates requiring a bassinet, we illuminate 4 fluorescent tubes/lights 30 cm. For those neonates requiring an isolette, we illuminate 6 tubes/ fluorescent lights at a distance of 32 cm. We appropriately maximize irradiance for neonates nearing exchange transfusion level or for those with signs of ABE.[27,28]

Limitations to our QI project include the time needed to actually carry out a project such as ours including the time needed to periodically recheck the irradiance and adjust the protocol as needed based on input from other team members. One notable example of this was the need to assure that the neonates stayed warm when they were placed in open bassinets instead of an isolette, as had previously been the practice in our institution while also assuring irradiance received by low-medium risk infants was not potentially excessive. Warming up the hospital room and turning off side phototherapy bulbs to allow moving the main unit closer to the neonate are two solutions to this problem. Another limitation was our need to decrease the number of points at which we measured irradiance significantly in order to make the project sustainable over time. Measuring fewer points makes our MFR less accurate than in the previously published study.[18]

We also recognize that care must be taken when relating irradiance produced by PT units over time. As noted previously, irradiance provided by fluorescent bulbs or any light source declines over time and complicates the direct comparison of irradiance measured at different time points.

Many hospitals have several brands of phototherapy units which could affect the institution and sustainability of a protocol such as ours more difficult and time consuming as the adjustment of each brand to optimize phototherapy would likely be different.

The key lessons for the interdisciplinary team providing care to neonates receiving PT addressed included: (1) Standardization of the PT protocol is necessary. (2) Protocol must assure that each neonate receives the appropriate irradiance or dose of blue/blue-green light accounting for the type of PT unit, distance from the neonate and the type of bed (bassinet versus isolette). (3) Having an irradiance meter on site is beneficial, allowing the clinicians to assess the level of irradiance provided to a patient in real-time and adjust the PT accordingly to deliver desired irradiance based on the individual neonates risk factors and clinical condition. An irradiance meter also helps identify when bulbs need to be replaced, or PT units needing servicing, sooner than expected. The next appropriate step in our QI project would be to determine if the time to discharge after changing our protocols results in earlier discharge of our neonates with jaundice requiring phototherapy.

Conclusion

Effective phototherapy plays an important role in preventing morbidity and the need for exchange transfusion in neonates with severe hyperbilirubinemia.[29-32] We have demonstrated that the irradiance level is a variable that can be easily optimized by an interdisciplinary team, to improve the overall care of the neonate with significant hyperbilirubinemia for whom phototherapy is warranted.

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Author Contributions

Ashajyothi M. Siddappa: drafted initial manuscript, reviewed and revised the manuscript and helped conduct the study.
Frances L. Prekker: analyzed the data, helped conduct the study and edited the manuscript.
Tina M. Slusher: conceptualized and designed the study, helped conduct the study, and critically reviewed the manuscript for intellectual content.
All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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