The Importance of Irradiance and Area in Neonatal Phototherapy

Graham Charles Hart and Rob G Cameron

Bradford Royal Infirmary

Corresponding author:
Graham Hart
Medical Physics Department
Bradford Royal Infirmary
Duckworth Lane
Bradford BD9 6RJ

Tel: 01274 364135
Fax: 01274 364134
Email: graham.hart@bradfordhospitals.nhs.uk

Keywords: phototherapy, jaundice, neonatal
Abstract

Background: Despite a long period of development, there are still significant variations in the spectral output, the levels of irradiance and irradiated area provided by commercial phototherapy systems. These variations depend on the types and output of the lamps used to produce the phototherapy, along with the design of the systems, and principally on whether the phototherapy is provided from overhead or underneath.

Objective: To see whether commercially-available phototherapy systems produce sufficient irradiance over the surface area of the neonate

Methods: Surface plots of the output irradiance have been made on a number of systems, and have been used to calculate the effective irradiance on the surface of a premature or term baby, using mapped outlines.

Results: Show a 10-fold difference in peak central irradiances between the systems tested, with a 4- to 5-fold difference in effective irradiance to the baby surfaces. Although work published over 20 years ago showed that levels of irradiance should reach 2mW.cm⁻² to achieve optimal effectiveness, some of the commercial systems tested do not appear to achieve this level.

Conclusion: Purchasers of neonatal phototherapy systems need to take into account whether the systems will produce sufficient irradiance over the area required to ensure that the phototherapy is maximally effective, as this is likely to reduce the time that the neonate needs to undergo the treatment.
Introduction

A recent report from the American Academy of Pediatrics (AAP) on neonatal hyperbilirubinaemia confirms the efficacy of phototherapy as a treatment.[1] Despite the long period of development since Cremer’s original paper,[2] there are still significant variations in the spectral output, levels of irradiance and irradiated area provided by commercial phototherapy systems. This was noted in the AAP report.

It is clear that the irradiance produced by phototherapy systems is an important factor. Many authors have shown that increasing irradiance produces a faster rate of fall of serum bilirubin.[3][4][5][6][7][8] Tan showed over twenty years ago that irradiances of 2mW.cm\(^{-2}\) (~40µW.cm\(^{-2}\).nm\(^{-1}\)) are needed before a possible plateau response in the rate of bilirubin degradation is reached.[9] Nevertheless, some current commercial phototherapy systems do not produce these irradiances.

Bringing the lights closer could increase the irradiance of overhead phototherapy systems. Since this cannot easily be achieved for neonates in incubators, one solution is to provide phototherapy from underneath, as the neonate thus lies closer to the lights. This has been shown to be more effective than conventional overhead phototherapy.[10] Another solution is to provide phototherapy from both above and below. This also seems to show a greater level of efficacy when compared to overhead phototherapy alone.[11]

The other parameter that affects the phototherapy’s effectiveness is the area of the neonate irradiated by the system. Maisels highlighted the need to consider this issue,[8] and it was also used by Dicken, Vreman and Wentworth in the assessment of the overall performance of phototherapy systems.[12][13][14]

The above ideas appear to confirm the idea that many conventional phototherapy systems do not produce sufficient irradiance to maximise the degradation of bilirubin.

If overhead phototherapy does indeed reach Tan’s plateau value of optimum irradiance, logic suggests that way to increase the effectiveness of phototherapy would be to effectively double the treatment area by irradiating the neonate from below as well as above.

Materials & Methods

The effective irradiance of a number of phototherapy systems was assessed by taking a series of irradiance measurements at 2cm intervals in the illuminated field. Measurements were made using an International Light IL1700 radiometer with an SED033 detector, ‘BR’ bilirubin filter and a ‘W’ cosine diffuser. The radiometer and detector were calibrated against a secondary standard spectroradiometer, using a Philips TL52 phototherapy lamp as the light source.

All measurements for the overhead phototherapy systems were made with a source-to-measurement distance of 45cm at the centre of the field, representing a typical treatment distance for neonates in incubators. For the fixed or underneath systems, measurements were made on the surface of the treatment area for that system, which included a blue-green gel mattress (JLJ Healthcare). Measurements were made until the output had fallen to approximately 10% of the peak value or until the sides of the crib had been reached.

The method used for the irradiance mapping was similar to that used by Vreman and Dicken.[13][12] The data was entered into Excel spreadsheets and then linearly interpolated from the 2cm grid used during the measurement process into a 1cm grid to aid the mapping process. Outlines of both a premature and a term baby, similar to Vreman’s, were then mapped onto other spreadsheets. The only significant difference from Vreman’s approach is the use of an ellipsoidal model to simulate the curved edges of the
body. This model suggested that the effective irradiance within 1 cm of the edge of the head and body should be reduced from 100% to 80%, and to 50% for the arms and legs, which reduces the overall effective irradiance by ~14%. The outline for the premature baby is shown in figure 1.

Each cell within the outlines was then multiplied by the corresponding interpolated irradiance values, centring the outlines of the premature and term babies at the centre of the irradiance fields. Values of the total irradiance were then calculated for the whole irradiated surface to assess the relative effectiveness of the phototherapy systems under test.

However, because neonates are known to move within the incubator or crib, the calculations were repeated with the outlines translated by 4 cm (and where possible 8 cm) in both the x- and y-directions, to assess whether this would make any difference to the received irradiance.

Results

Measurements were made on a number of phototherapy systems:
- Hill-Rom Microlite, overhead unit based on white light sources;
- Draeger Phototherapie 800, overhead unit using a blue metal halide lamp;
- Medestime Duo, which has two independent overhead units, each containing four blue compact fluorescent lamps;
- Natus neoBLUE, overhead unit using a blue LED array (used here on its high output setting);
- Medestime Bilicrystal IV2, a dual phototherapy system based on six blue compact fluorescent lamps in an underneath unit, with a further five compact fluorescent lamps in a fixed overhead unit;
- Medela Bilibed, using a single blue compact fluorescent lamp underneath, with the baby lying on a blue-green gel mattress;
- A Medela Bilibed, modified in-house at Bradford as an experimental unit. This unit contained 800 x Nichia NSB500 blue LEDs as the light source, with the baby lying on a blue-green gel mattress.

Figures 2 & 3 show the surface plots of the different units tested. All surface plots are plotted on the same vertical scale to aid direct comparison of the systems.
Table 1 gives the results of the measurements and calculations of total surface irradiance for both term and premature neonates. The ratio figures were obtained by dividing the mean of the moved total irradiance figures by the central total irradiance.

Discussion

The surface plots in figures 2 & 3 clearly demonstrate the large differences in measured irradiance of the systems tested. This is mirrored in the total irradiance figures given in table 1.

The plots appear to show that the systems with lower levels of irradiance have a more even irradiance field than the higher output systems. Although this is true in absolute terms, the lower irradiance systems also show a similar percentage drop between centre and edge.

Three of the systems tested did not reach Tan’s 2mW.cm² central irradiance figure and also delivered lower total effective irradiances, which implies they will not be as clinically effective as units that produce a greater level of irradiance.

Bringing the overhead units closer to the surface of the neonate would undoubtedly increase the measured irradiance, since the irradiance from an extended source is approximately proportional to 1/distance from the source. This is usually not an option for a neonate being treated in an incubator, and for neonates in cribs the level of heat generated by the lights also has to be taken into account.

The underneath systems show a significantly higher level of irradiance than the overhead systems, principally due to the closeness of the light sources to the baby’s skin surface. In these systems, the light has in fact been attenuated by the use of the gel mattress, which scatters the light and reduces the
irradiance at the surface of the neonate by approximately 30%. Use of a less attenuating surface would lead to a further increase in the irradiance.

The surface plot for the experimental LED array (figure 3D) shows a bimodal irradiance distribution, caused by the layout of the LEDs in two square panels with a small central gap. The resolution of the reduced irradiance between the panels demonstrates the sensitivity of the method to changes in the shape of the light field.

Although there is a clear relationship between the central irradiance value and the overall total irradiance figures for the term and premature baby outlines, they do not correlate perfectly. This is because of differences in the shapes of the light fields, and demonstrates that both the peak irradiance and the area irradiated must be considered when seeking to assess the overall likely clinical effectiveness of the system.

Moving the outline by either 4cm or 8cm over the irradiated field did not appear to lead to a significant change in the level of irradiance. This was not done for either the Medela Bilibel or the modified unit containing the LED array, as the units are designed so the baby remains in a fixed position relative to the lights.

The irradiance measurements here were all made with a fixed bandwidth broad-band radiometer. Maisels reminds us that we have to be careful about ‘measuring’ irradiance and Costarino goes further,[8][15] saying that ‘information obtained from a fixed band width radiometer designed to measure radiant flux in the blue light range may not allow meaningful comparison of phototherapy units in the clinical setting’. This problem occurs because of the widely differing spectra of phototherapy systems. Some authors have decided to use spectroradiometric measurements, such as Wentworth who integrated the spectra from 400 – 550nm.[14]

However, using this kind of technique means that wavelengths outside the usually accepted action spectrum will contribute to the ‘useful’ measured irradiance. The BR filter attached to the detector in our measurements is set to allow wavelengths in a 50nm band centred on 450nm, to match Cremer’s action spectrum. Costarino’s comments assume that wavelengths outside the blue region make a positive contribution to phototherapy. If this is not the case, however, Costarino’s assumption is incorrect and measurement devices such as the one used here do indeed provide a reasonable way of assessing the useful irradiance of phototherapy systems. The majority evidence thus far appears to support Cremer’s action spectrum and so was used.

Reviews such as those produced by the UK’s Medicines & Healthcare Products Regulatory Agency highlight the value of comparing systems using the same measurement techniques and equipment.[16] This paper also demonstrates that direct comparisons can show significant differences between commercially available systems of both the central and total effective irradiance over the surface of the neonate.

Purchasers of neonatal phototherapy systems need to take into account whether the systems will produce sufficient irradiance over the area required to ensure that the phototherapy is maximally effective, as this is likely to reduce the time that the neonate needs to undergo the treatment.
Acknowledgements

Medela for providing two Bilibeds for use in these measurements. The authors are grateful for permission to modify one of the Bilibeds, which was converted to hold the blue LED array. The authors are however responsible for the design and performance of the experimental LED array.

Jackie Lloyd-Jones of JLJ Healthcare for the loan of the Medestime phototherapy equipment.

Hugh Morrison for making many of the measurements that formed the surface irradiance mapping.

Marina Hart, Stephanie Wentworth and Diane Crawford for their many helpful comments during the writing of the final script.

Funding

This project was funded through an NHS R&D programme at Bradford Teaching Hospitals NHS Foundation Trust.

Licence statement

The corresponding author has the right to grant on behalf of all authors and does grant on behalf of all authors, an exclusive licence (or non exclusively for government employees) on a worldwide basis to the BMJ Publishing Group Ltd and its Licensees to permit this article (if accepted) to be published in Archives of Diseases in Childhood editions and any other BMJPGL products to exploit all subsidiary rights, as set out in our licence (http://adc.bmjjournals.com/misc/ifora/licenceform.shtml)

Figure legends

Figure 1
Premature baby outline, showing the weighting factors used in the calculation of total effective irradiance

Figure 2
Surface Plots for A: Microlite; B: Draeger; C: Duo; D: neoBLUE
The plots show a three-dimensional representation of the irradiance produced by the phototherapy systems over the area of the crib. Irradiance on the vertical axis is measured in mW.cm⁻². The horizontal axes represent distance on the crib surface.

Figure 3
Surface Plots for A: IV2 (overhead); B: Bilibed; C: IV2 (under); D: LED
References


13 Vreman HJ, Wong RJ, Murdock JR, Stevenson DK. In-vitro efficacy of an LED-based phototherapy device (neoBLUE™) compared to traditional light sources. Society for Pediatric Research Meeting 2003 (poster).


