Abstract

**Objective**: to propose a method to evaluate and maintain the efficiency of equipment commonly used in Brazil in order to obtain uniform results in phototherapy treatments in different services.

**Material and methods**: the radiometer/photometer used to measure spectral irradiance is locally manufactured and fulfills basic requirements. Measure standardization seeks to be applicable and reproducible to phototherapy devices employed in Brazil. The material necessary for measurements can be easily assembled by the neonatology staff, except for the radiometer. We searched Medline for papers relevant to this review published throughout the last 10 years.

**Results**: irradiance in phototherapy issues should be referred to as “medium spectral irradiance”. We describe how to obtain medium spectral irradiance using fluorescent and halogen phototherapies.

**Comments**: the components of a radiometer/photometer are described. This knowledge is fundamental to understanding sensibility variations and to justifying differences in irradiance when ranges of radiometer recording are a little different. The standardization of this device will certainly simplify the comparison between results in different services.

We also analyzed characteristics of different equipment used in phototherapy that might interfere with their irradiance.


Introduction

Although the in vitro effect of light on bilirubin has been known for a long time, only in 1958, Cremer, Perryman, and Richards were able to demonstrate the in vivo effect of blue light on the reduction of serum bilirubin levels. This was only possible after careful observations made by the nursing staff of the Rockford General Hospital in England.¹ This new property of light was empirically used by nonindustrialized countries until 1968, when Lucey, Ferreiro, and Hewitt decided to study it scientifically, concluding that the photochemical degradation of bilirubin did not result in toxic products to the human body.² The actual effect of light on bilirubin, which basically produced its photoisomerization, was only clarified by Brodersen et al. in 1980.³

The efficiency of phototherapy depends on the waveband (color) and irradiance intensity (energy) of the radiation source and on the surface area exposed.⁴ The Committee on Phototherapy in the Newborn Infant, coordinated by the National Academy of Sciences (U.S.) - National Research Council⁵ - stated in 1974 that the spectrum for maximum light absorption by bilirubin, with possible in vivo implication on its photochemical action, ranges between 425 and 475 nm (blue light).
Today, we know that wavebands outside this spectrum may be used efficiently.\(^6\) However, until the present day, the Committee on Phototherapy in the Newborn Infant still recommends the same spectrum for improved performance. Fluorescent and halogen (quartz) lamps are currently used in commercially available phototherapy equipment.

By taking irradiance into consideration, manufacturers provide spectral absorption curves for the selection of different lamps; therefore, it is possible to choose a lamp spectrum for efficient conversion of bilirubin.\(^8\) Efficiency is determined by irradiance measurement, performed through relatively inexpensive and streamlined phototherapy equipment known as radiometers/photometers,\(^10\) whose limitations should not be neglected. Irradiance is the amount of energy, measured per unit of area, which strikes a given surface.

There is no agreement as to the values that define phototherapy equipment efficiency in terms of irradiance: values may be as low as 4 to 6 µW/cm\(^2\)/nm\(^12,13\) or as high as ≅60 to 80 µW/cm\(^2\)/nm.\(^14,15\) A proposal for the standardization of equipment calibration, necessary for the easier comparison of results obtained from different authors, has never been presented until now. The present study is an attempt toward this standardization.

**Materials and Methods**

It is necessary to periodically assess phototherapy equipment units by means of a radiometer/photometer. The only commercially available radiometer/photometer manufactured in Brazil is the Fanem\textsuperscript{\textregistered}-Mod 620, which delivers light at a waveband fixed between 380 and 530 nm (10% points), with a peak output at 450 nm.\(^16\) The equipment is simple, robust, and operates with a 9-volt battery. The readings are expressed in µW/cm\(^2\)/nm, which stands for the mean irradiance in relation to the readout range.

- **Conventional phototherapy equipment** - this type of equipment uses banks of fluorescent 20-Watt lamps (4 to 10 units). To measure irradiance, the equipment must be switched on two hours before use until the operating temperature is reached.\(^17\) The bank of lamps is transversally positioned in relation to an incubator. A space of only 1 cm should be allowed between the plate that shuts the light-emitting set and the dome. In such a position, the distance between the bank of lamps and the surface of the incubator light pad is approximately 40 cm. This distance is not ideal, however it is restricted by the incubator dome height.

Irradiance is measured on the light pad surface as follows: a paper with 34X60 cm is fixed onto the light pad surface. An area of 42X34 cm corresponding to the phototherapy equipment projection is demarcated on the central portion of the paper. The demarcated area is divided into nine isometric rectangles, and the central part of each rectangle is cut out according to the shape of the radiometer sensor used for measurement (Figure 1). The arithmetic mean of these nine points represents the mean irradiance to which newborns are submitted during therapy.

Whenever irradiance values fall below a preset value (80% of the value obtained from new lamps), lamps have to be replaced and recalibrated. Output voltage and ambient temperature must be verified\(^16\), since they may cause variations in irradiance values.

- **Double phototherapy equipment** - this model was developed in conjunction with the Center for Biomedical Engineering of the Universidade de Campinas (UNICAMP). It consists of two sets of seven lamps each, identical to those in conventional phototherapy, positioned face to face, with a transparent acrylic crib fit in between the two sets. Each set has an acrylic plate or glass over the lamp banks as in conventional

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**Figure 1** - Template for irradiance measurement of fluorescent light equipment
Standardizing the calibration of phototherapy... - Facchini FP

Phototherapy. The lamps are cooled by one or two fans, which improve operating temperature but fail to keep the temperature around 25°C (ideal temperature for maximum performance). Therefore, it is necessary to wait two hours until temperature is stabilized. The upper set of lamps is positioned 30 cm over the crib bottom while the lower set is positioned at 10 cm. The irradiance measurement of the upper and lower sets is performed using the same paper strip with the nine demarcated points, previously described in conventional phototherapy. In double phototherapy, the paper is fixed onto the acrylic crib surface; as measurement points are hollowed, the irradiance of the upper and lower lamp sets can be assessed by moving the radiometer sensor upward or downward. The mean of the nine upper and lower points should not fall below preset values (80% of the initial values). In double phototherapy, a blue side curtain is used for the reflection of radiation that is normally wasted sideways, thus increasing equipment irradiance by 10 to 15%. These curtains must also be used during the monitoring of the sets.

- Phototherapy equipment with halogen light source- this equipment uses halogen lamps for energy output. After the radiant power is filtered, it is projected in the form of a light beam over the infant (spotlights) or carried through a fiber-optic bundle to a skin-connected diffuser (fiber-optic blankets).

- Bilispot® - Fanem Mod 006BP. The first spotlight equipment manufactured in Brazil. Other similar equipment manufactured in Brazil were displayed at the last Hospitalar, fair of medical equipment held in São Paulo in June, 2000.

The Bilispot® - Fanem Mod 006BP has the shape of a metallic tube attached to a rod, which allows changing the light beam incidence angle, moving it near or far from the patient. The light source consists of a 75-Watt dichroic halogen lamp, which is cooled by forced air circulation used to disperse part of the produced heat. A system filters out undesirable radiation such as that within the infrared waveband. There is a set of two Fresnel lenses at the end of the metallic tube, whose purpose is to direct the radiant waves into a narrow bundle. This bundle produces a circle of light with 15 cm in diameter and clearly visible edges when perpendicularly projected on a flat surface at a distance of precisely 50 cm.

The mean irradiance (M) of the equipment is obtained as follows: the projected circle is drawn on a paper and subdivided into three concentric areas obtained through two additional circumferences with a radius of 2.5 and 5 cm, thus splitting the circle into 3 areas (A, B and C) that measure respectively 19.6, 58.9 and 98.2 cm² (Figure 2). In each of these areas, 4 diametrically opposed points are marked for irradiance measurement, which, according to the manufacturer, is considerably reduced from the center to the borders. The arithmetic means of these 4 points, once weighted with respective areas and added, will indicate the mean irradiance of the phototherapy light.

$$\text{M}_{\text{total}} = \frac{19.6}{176.7} \cdot \text{M}_{\text{A}} + \frac{58.9}{176.7} \cdot \text{M}_{\text{B}} + \frac{98.2}{176.7} \cdot \text{M}_{\text{C}}$$

$$\text{M}_{\text{A}} = \text{mean irradiance at the 4 points in area A}$$
$$\text{M}_{\text{B}} = \text{mean irradiance at the 4 points in area B}$$
$$\text{M}_{\text{C}} = \text{mean irradiance at the 4 points in area C}$$
$$176.7 = \text{total area in cm}^2 \text{ of the circle of light projected by the equipment.}$$

The measurement of mean irradiance must be conducted 400 hours after replacing the lamps and every 200 hours after that. We recommend that lamps be replaced when the value is lower than or equals 80% of the initially obtained value.

- Biliblanket Plus®-Ohmeda. In this equipment, the production of radiating power is also obtained through halogen lamps; however, the shaft of light beams is carried through a fiber-optic bundle instead of being projected over the patient’s skin. The tip of the optical fibers goes through a process that changes their reflective
shell. This tip diffuses light energy instead of carrying it. Optical fibers are firstly woven and then turned into a fiber-optic blanket with relatively homogeneous distribution of radiating power. The patient is then positioned on this blanket.

The fiber-optic blanket is wrapped in a special type of paper provided by the manufacturer for irradiance quantification purposes. The illuminated portion, measuring 10 X 15 cm is divided into 6 isometric rectangles and irradiance is measured at the central part of each rectangle (Figure 3). Mean irradiance is the arithmetic mean obtained at the six mentioned points. This measurement must be repeated after 400 hours of use and every 200 hours after that. The replacement of lamps must be performed when mean irradiance falls below 80% of the initial value (new lamp).

![Figure 3 - Template for irradiance measurement of BiliBlanket® - Plus equipment](image)

**Comments**

In phototherapy, fixed waveband radiometers are the most widely used type. This type of radiometer basically consists of a sensor head that filters out undesirable radiating power. Some equipment units have diffusers for partially correcting the effect of off-angle light (Lambert’s cosine law).\(^\text{19}\) The radiating power that passes through the sensor head is turned into electric current by a detector and is carried to the radiometer, where it is quantified as “total irradiance”, expressed in microwatts o milliwatts/cm\(^2\). Some equipment units calculate the mean irradiance in relation to the readout range, providing “spectral irradiance” in µW/cm\(^2\)/nm.\(^8\)

It is important that there be increased equivalence between the irradiation waveband we intend to measure and that captured by the radiometer. As, until the present moment, the ideal waveband for bilirubin photooxidation ranges between 425 and 475 nm, all radiometers should be able to measure the radiating power given off within this spectrum. Unfortunately, this does not occur in practice. Radiometers with broader readout ranges capture radiating power that is unable to convert bilirubin, and radiometers with narrower readout ranges fail to register the radiating power that could be used for bilirubin photoisomerization. Now, the reason why radiometers with slightly different readout ranges indicate different irradiance measurements in a single piece of equipment is clarified. The Neonatology Committee should urge manufacturers to observe this requirement. Perhaps, following the example of the French Society of Perinatal Medicine National Committee on Phototherapy, the Brazilian Society of Pediatrics Neonatology Committee could adopt a Brazilian reference radiometer and edit a table for the conversion of the irradiance obtained through different radiometers and this equipment. In addition, if the efficiency of energy output close to the green waveband (500 to 570 nm) is confirmed\(^6\), radiometers should perhaps be commercialized with double waveband in order to allow the measurement of blue and green light sources.

Despite all these limitations, phototherapy radiometers are extremely useful for the maintenance of phototherapy equipment. The great advantage of radiometers is the measurement of reductions in radiating power efficiency. We consider the replacement of phototherapy lamps essential when such reduction gets close to 20% of the initial value so that efficiency can be maintained close to its maximum, and also because, this way, the replacement of lamps does not incur extra expenses. The imported special blue lamps, which are the most expensive on the market, cost approximately R$16.00 (approximately 8 dollars) each. Considering that a set with 7 lamps lasts at least 1,500 hours, the cost per lamp during one hour will be R$0.072 (approximately 0.036 dollars), and for a 96-hour therapy it will be R$6.91 (approximately 3.45 dollars). The only radiometer manufactured in Brazil is the Fanem-Mod 620. Its spectral curve is within the 380 to 530 nm waveband (10% points) with a peak output at 450-nm\(^\text{16}\). Although the spectral range of this equipment is slightly broader than that recommended by the Committee on Phototherapy in the Newborn Infant, we believe it meets current requirements.\(^\text{10}\)

In fluorescent phototherapy, four types of lamps are used: standard blue lamps such as Sylvania
F20WT12/AZ, which may quickly lose irradiance and need to be frequently replaced; daylight fluorescent lamps; green lamps; and special blue lamps (Philips F20WT12/52), which usually keep 80% of their initial irradiance from 2,000 to 5,000 hours. Our aim is to maintain irradiance the closest possible to their maximum values so that phototherapy can be efficient and quick. This is possible if we periodically check the equipment, replacing lamps as indicated. A timer can be attached to each equipment unit to keep track of lamp hours of use. Some authors recommend that irradiance be measured very frequently, and some others indicate their replacement every 12 hours. We find no reason for such procedure since lamps have a long useful life. The measurement of mean irradiance is performed every 1,000 hours after lamp replacement, and every 500 hours after that. When irradiance drops to a minimum value, the whole set of lamps should be replaced.

All irradiance measurements must be carried out in a dark room, without ambient light. Bumping into lamps or frequently switching them on and off must be avoided as these events shorten the average life of bulbs. Fluorescent lamps optimally work at a temperature around 25°C; however, most equipment units operate at much higher temperatures. This reduces the useful life and irradiance of lamps.

The light bulb glass filters out most part of undesirable radiation within the ultraviolet and infrared waveband in fluorescent lamps. The remaining radiation is almost totally absorbed by the acrylic or glass plate of the equipment, shutting the bank of lamps. This plate is intended for the protection of newborns against occasional falls or breaks of lamps from the set.

The measurement of mean irradiance is comprehensively presented in few publications. De Carvalho measured irradiance only at the central projection of the light source, at a distance of 45 cm from the patient. In a later study, using a piece of equipment containing 7 fluorescent lamps (Biliberço) under the acrylic crib and reflecting surfaces in the upper and side parts, assessed the mean irradiance by measuring 22 points under direct irradiation, and 2 side and 1 upper points under reflected irradiation. Tan determined the mean through the values read at the head, trunk, and knees. Holtrop determined irradiance at the head, thorax, and abdomen. Sarici used four points in a line that passed through the center of the irradiated area. Most publications do not present detailed information on how the irradiance of lamp sets was measured.

As in fluorescent therapy, spectral irradiance over the patient is not homogenous, it is fundamental to use the mean to monitor equipment performance. It is essential to have uniform spectral irradiance in different types of equipment if we plan to measure their performance.

We should ensure that at least one fourth of the newborn’s body surface receives energy from the lamp set.

Incubator-bound preterm babies are a challenge to phototherapy since it is not possible to shorten the distance of the light source due to the interposition of the incubator dome.

In double phototherapy, irradiance is measured in a similar way; however, the distance between the lamp set and the bottom of the acrylic crib may be reduced to a minimum so as to allow proper handling of newborns. The distance for the upper set is 30 cm, and for the lower set 10 cm.

In this type of equipment, we observed that the use of side curtains increased irradiance by 10 to 15%. Since our intention was to maximize baby’s skin exposure, diapers were removed and newborns, with eye pads on, were directly placed in the acrylic crib. We did not use fluid beds, silicone or any other material as they considerably reduce the irradiance of the lower set (a 25% reduction in the case of fluid beds) and apparently do not change patients’ behavior, who do not seem to experience discomfort when placed directly on the acrylic surface of the crib.

When we used this equipment in rooms with controlled temperature (approximately 25°C), we did not observe hypothermia or hyperthermia in treated newborns.

The care with lamps should be the same applied in conventional phototherapy.

The Bilispot manufacturer recommends that the equipment be used at a distance no less than 50 cm, probably due to the incomplete filtration of infrared radiation which could harm the patient if used at a closer distance. Therefore, equipment monitoring should be performed at this distance as well.

The area reached by radiation at this distance is quite restricted (176.7 cm²). If we increase the distance or tip the equipment, the irradiated area is enlarged; however, irradiance drops due to the greater distance from the light source.

The Bilispot uses superposition of two Fresnel lenses at its frontal end in order to direct light waves. It is important to check the correct position of these lenses; otherwise, we have a great dispersion of light waves. When properly positioned at 50 cm from a flat surface, the circle of light is exactly 15 cm in diameter, and has precise edges. The energy irradiated by this
The dissipation system of halogen lamps is insufficient, and as a consequence, their reflecting surface becomes gradually opaque with use, and efficiency is quickly reduced (Figure 4). This way, we recommend that the equipment be initially tested after 400 hours of use, and every 200 hours after that. The attachment of an hour meter is quite useful as it allows controlling equipment, and preventing irradiance tests without reasonable hours of use. No halogen lamp equipment should be jolted when powered up, and should be left off-operation for at least 5 minutes after shutdown. If these procedures are not properly followed, the light bulb filament may be permanently impaired.47

The Biliblanket®-Plus, has a more powerful light source than the Bilispot®. Its relative spectral response after filtration is quite different from special blue fluorescent lights (Figure 5). The Biliblanket peak output ranges between 500 and 540 nm, in the green waveband. Therefore, the Fanem® Mod.620 is not the best available radiometer for assessment; the manufacturer’s manual, however, does not warn against this. The Biliblanket, when assessed by the Fanem® Mod.620, has a mean irradiance slightly higher than the Bilispot®, even if its maximum power is used.

![Figure 4](image1.png)

**Figure 4** - Comparison of the reflecting surface between a new halogen lamp and a halogen lamp after 900 hours of use in the Bilispot® equipment (observe the opaque aspect of the lamp on the right side, caused by use)
According to the manufacturer, the useful life of the Biliblanket® light bulb is approximately 800 hours, when its maximum power is used. This is the only piece of equipment in our unit that comes with an hour meter. The equipment is firstly monitored after 400 hours of use and every 200 hours after that, since maximum power is always used.

The irradiance recommended by manufacturers is not justified. They suggest dividing the radiating region into four squares, measuring irradiance at the central part of each square. The irradiance at the central point of the blanket is also measured. Mean irradiance is regarded as the arithmetic mean of the sum of the four points plus two times the measurement of the central part. The studies we analyzed do not present any specification as to the used assessment technique.

We expect that our proposal for the standardization of phototherapy equipment will draw some attention to the necessity of having some criteria for the comparison between different phototherapy devices used in neonatology units. In addition, our objective was to share the experience we acquired throughout 40 years of work in the field of phototherapy.

References