COMMENTARIES

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Why Use Homeopathic Doses of Phototherapy?

More light!

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Phototherapy is used worldwide for the treatment of hyperbilirubinemia; it is safe and it works. Although there exists a vast body of literature of human, animal, and laboratory investigation dealing with the mechanisms of action, biological effects, complications, and clinical use of phototherapy (and there are several excellent recent reviews9,10), personal experience suggests that there is considerable misunderstanding about how phototherapy works, how its dose is measured, and how it should be administered. Furthermore, both the way we use phototherapy today and the indications for its use (particularly in full-term infants) have changed.1

In a bygone era, when healthy newborns remained in the hospital for at least 3 days, and hyperbilirubinemia was treated aggressively, large numbers of infants who became modestly jaundiced (serum bilirubin levels of 10 to 13 mg/dL) received phototherapy and remained in the nursery until the bilirubin levels declined. Because many infants in the United States are now discharged before 24 hours, and most by 36 hours, after birth, these bilirubin levels are seldom encountered in the nursery, and phototherapy use has declined dramatically.2

Today, full-term infants who do not need phototherapy are a different lot. By and large, they have left the hospital and are readmitted on the fourth to seventh days for the treatment of serum bilirubin levels of 20 mg/dL or higher. Levels of more than 25 mg/dL are not unusual, and much higher levels have been seen.3 Thus, unlike 80-hour-old infants with serum bilirubin levels of 13 mg/dL who used to receive phototherapy more or less prophylactically (to prevent a further rise in bilirubin), today’s infants require a different approach. When they need phototherapy, they need a therapeutic dose, the objective being to get the bilirubin down as soon as possible. I will not deal with this issue in low birth weight infants, for whom phototherapy is used largely prophylactically to prevent the slowly rising serum bilirubin from reaching dangerous levels.) Nevertheless, although the appropriate information has been available for many years, most full-term newborns receive phototherapy in a dose that is well below the optimum therapeutic range. Although this type of phototherapy may lower the bilirubin slowly, it is often ineffective in the face of moderate degrees of hemolysis (e.g., ABO incompatibility) or significant bruising, and it does not work quickly enough for those infants with bilirubin levels significantly in excess of 20 mg/dL.

EFFICACY OF PHOTOTHERAPY

Phototherapy, like many therapeutic agents, demonstrates a clear dose-response relationship (Fig 1), and clinical studies have shown that there are three major factors that influence the dose and, therefore, the efficacy of phototherapy:

1. The spectrum of light delivered by the phototherapy unit. This is determined by the type of light source and any filters used. Because of the optical properties of bilirubin and skin, the most effective wavelengths are in the blue-green spectrum.

2. The power output of the phototherapy light and flux of light energy incident on the infant, expressed as irradiance (watts per square meter; Table 1). Irradiance depends not only on the power of the light, but also on the distance of the light from the infant. When measured over a specific portion of the spectrum (e.g., the blue spectrum, approximately 425 to 475 nm), it is called the spectral irradiance and is measured in microwatts per square centimeter per nanometer.

3. The surface area of the infant exposed to phototherapy.

See “Appendix” for a more detailed explanation of how the dose of phototherapy is measured.

Fig 1. Relationship between average spectral irradiance and decrease in serum bilirubin concentration. Full-term infants with nonhemolytic hyperbilirubinemia were exposed to special blue lights (Phillips TL 52/20W) of different intensities. Spectral irradiance was measured as the average of readings at the head, trunk, and knees. Drawn from the data of Tan.4

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TABLE. Radiometric Quantities Used

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Dimensions</th>
<th>Usual Units of Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance (radiant power incident on a surface</td>
<td>W/m²</td>
<td>W/cm²</td>
</tr>
<tr>
<td>per unit area of the surface)</td>
<td>W/m²/μm²</td>
<td>μW/cm² per μm²</td>
</tr>
<tr>
<td>Spectral irradiance (radiance in a certain</td>
<td>W/m²/μm²</td>
<td>μW/cm² per μm²</td>
</tr>
<tr>
<td>wavelength band)</td>
<td>W/m²/μm²</td>
<td>μW/cm² per μm²</td>
</tr>
<tr>
<td>Spectral power (average spectral irradiance</td>
<td>W/m²/μm²</td>
<td>μW/cm² per μm²</td>
</tr>
<tr>
<td>across a surface area)</td>
<td>W/m²/μm²</td>
<td>μW/cm² per μm²</td>
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Light Spectrum

“Special blue” fluorescent tubes provide much more irradiance in the blue spectrum than other tubes and are the most effective light source currently available in the United States for phototherapy (Fig 2). They are labeled F20T12/BB or TL52/20W (Philips) and are different from regular blue tubes (labeled F20T12/B). However, because special blue tubes give infants a bluish tinge and may obscure cyanosis, many pediatricians prefer daylight, cool white or tungsten-halogen lamps. Fortunately, full-term infants admitted to the hospital because of hyperbilirubinemia are usually in no distress, and the fact that they look blue while receiving phototherapy is of little concern. If necessary, switching off the lights for a few seconds will provide reassurance. Another potential disadvantage is that nursing staff working near special blue lights sometimes have headaches, dizziness, and nausea. Placing a screen or skirt around the light will shield staff from the effects of the light.

If hyperbilirubinemia in a full-term infant is of sufficient concern to merit admission to the hospital, I suggest that the infant should be treated with the most efficient form of phototherapy available—special blue lights. (Donzelli and coworkers have recently provided preliminary data using an experimental blue-green lamp that might prove even more effective than special blue lights.) There is also a common misconception that ultraviolet light is used for phototherapy. Parents and hospital staff need to be assured that this is not so, and that the intensity of the light is much weaker than ordinary sunlight.

Irradiance

There is a direct relationship between the efficacy of phototherapy and the irradiance used (Fig 1), and irradiance is directly related to the distance between the lights and the infant (Fig 2). It decreases rapidly with increasing distance and cannot be reliably estimated by eye. Maximum irradiance is easily achieved by bringing the fluorescent tubes as close to the infant as possible. To do this, put the infant in a bassinet, not an incubator (the top of the incubator prevents you from bringing the light sufficiently close to the infant). We use a free-standing Olympic Bill-Lite, (Olympic Medical Corp, Seattle, WA). When lowered as far as it will go, the tubes are within 14 cm of the mattress (and closer to the infant). At this distance, special blue tubes provide an average spectral irradiance of more than 50 μW/cm² per nanometer (see Fig 2). We have not observed significant warming of naked full-term infants treated this way with daylight or blue tubes. If slight warming does occur, the lamps can be elevated slightly. Note that halogen phototherapy lamps cannot be positioned closer to the infant than recommended by the manufacturers without incurring the risk of a burn.

Surface Area

Fiberoptic light systems have made it easy and convenient to address the third factor affecting efficacy—the surface area of the infant exposed to phototherapy. The use of a standard phototherapy system described above, while the infant lies on a fiberoptic pad, increases the surface area of the infant exposed to phototherapy. This type of double phototherapy is approximately twice as effective as single phototherapy in low birth weight infants10 and almost 50% better in full-term infants.11 (The difference in the response of low birth weight and full-term infants is likely due to the fact that, at similar irradiance levels, the fiberoptic pad covers more of a small than a large infant; see below.)

Fiberoptic phototherapy pads have their limitations, however, one of which is the inverse relationship between surface area and irradiance. For a given light source, enlarging the pad means that the light must be distributed over a greater area, thus reducing the irradiance (when compared with a smaller pad and the same light source). To achieve high levels of spectral irradiance (>20 μW/cm² per nano-
Spectral Power

Because irradiance and surface area are important, it makes more sense to express the dose of phototherapy in terms of spectral power delivered to the infant. This is the product of the skin surface irradiance and the spectral irradiance across this surface area. Thus, spectral power (expressed as milliwatts per nanometer) is a useful concept, particularly when fiberoptic pads are used, because it takes into account both the irradiance and the exposed surface area (see "Appendix").

ECRI, an organization that tests health devices, recently evaluated three fiberoptic systems: the Fiberoptic Medical Wallaby II phototherapy system (Fiberoptic Medical Products, Inc, Allentown, PA); the Ohmeda Bilblanket phototherapy system (Ohmeda, Inc, Columbus, MD and the Olympic Bill-Lite pad. Fiberoptic Medical offers two pads, a smaller neonatal pad and a larger wraparound pad. As can be seen from Fig 3, left panel, both the Wallaby Neonatal and Ohmeda pads used at the highest light intensity (irradiance) settings produced an average spectral irradiance of about 22 to 23 μW/cm² per nanometer in the 420- to 480-nm band, similar to that produced by overhead lamps placed 25 cm (10 in) above the infant. The wraparound pad of the Wallaby II and the Olympic pads could only produce irradiance levels of approximately 8 to 9 μW/cm² per nanometer. When measurements of average spectral power were compared, however (to correct for differences in the surface area of the light pads), both Wallaby pads were similar to the Ohmeda pad, whereas the Olympic pad was clearly inferior (Fig 3, right panel).

Note that in terms of average spectral power, however, all of the fiberoptic systems are significantly inferior to standard overhead lamps, because the skin surface area illuminated is so much greater when overhead lamps are used. Thus, special blue tubes 15 cm above the mattress (average spectral irradiance, 54 μW/cm² per nanometer) provide about 30 mW/nm to the surface of the infant. Note also that the data presented in Fig 3 were obtained in the laboratory and provide no information about the relative clinical efficacy of these fiberoptic systems. We could improve the therapeutic response by using two or even three of the pads to cover almost the entire lower surface of the infant. Even three Ohmeda pads, however, would be equivalent to a spectral power of about 8.5 mW/nm, significantly less than available from a special blue unit.

A highly effective way of delivering phototherapy is to expose the infant to a fluorescent unit with special blue tubes both below and above or completely surrounding the infant. A 360° phototherapy system, with special blue tubes, has been used in France and produced a 30% decline in bilirubin within 4 hours in nonhemolyzing infants (R. Caldera, MD, and MédiPrima, Tours, France, letter, 1995). A similar system has been developed in the United States but has not been evaluated rigorously.

A recent example of effective phototherapy is provided in the study by Garg et al. These investigators took a standard fluorescent phototherapy unit with four special blue tubes and modified a nursery bassinet so that the bottom of the bassinet rested directly on top of the phototherapy unit. The infant was placed on a waterbed, which both permitted transmission of the light and dissipated any heat generated by the light. The lights below the infant produced an irradiance of 35 μW/cm² per nanometer (calculated spectral power is 19 mW/nm). The overhead unit was a standard phototherapy unit, which delivered only 9 to 10 μW/cm² per nanometer. Nevertheless, the combination of these two units produced an average decline of 43% (7.4 mg/dL) in serum bilirubin levels in the first 24 hours. In infants who received standard phototherapy from the overhead unit alone, the bilirubin level decreased by only 6% (1 mg/dL).

**Comparison of Average Spectral Irradiance**

![Graph showing comparison of average spectral irradiance for different fiberoptic systems.](image1)

**Comparison of Average Spectral Power**

![Graph showing comparison of average spectral power for different fiberoptic systems.](image2)

*Fig 3. Comparison of average spectral irradiance (left panel) and spectral power (right panel) of different fiberoptic systems. Spectral irradiance was measured across the 420- to 480-nm spectral band using an Optec 746A spectroradiometer. Note that these measurements may not correspond to those obtained using a commercial radiometer. Measurements were obtained at three different positions along the center axis of each fiberoptic pad, and an average was obtained at the low- and high-intensity settings. Average spectral irradiance levels were measured from overhead lamps placed 30 in (76 cm) from the spectroradiometer (low-intensity distance) or 10 in (25 cm) from the spectroradiometer (high-intensity distance). FM neonate and FM wrap indicate Fiberoptic Medical Wallaby II neonatal and wraparound pad; Ohmeda, Ohmeda Bilblanket; and Olympic, Olympic Bill-Light pad. Redrawn with permission from Health Devices.*

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Using special blue lights with sufficient irradiance and special blue tubes above and below the infant, Tan and colleagues have shown that a decline in bilirubin levels of 40% to 50% in 24 hours can be achieved. Although Tan’s data suggest that this is the saturation point beyond which an increase in irradiance produces no added efficacy, we do not really know that a saturation point exists. Given that the conversion of bilirubin to excretable photoproducts is partly irreversible and follows first-order kinetics, there may not be a saturation point. Certainly, with existing equipment, there is no such thing as an overdose of phototherapy.

We use a fiberoptic pad together with a unit of special blue tubes placed 15 cm above the infant and have been able to achieve a 43% to 45% decline in bilirubin in nonhemolyzing infants in the first 24 hours. Thus, it is clear that when phototherapy is used in a therapeutic dose, a rapid decline in serum bilirubin concentration can be achieved. Compare these results with the data from the large National Institutes of Health collaborative phototherapy study conducted in the mid 1970s, in which the average decrement in serum bilirubin concentration in infants weighing more than 2500 g was about 15% in the first 24 hours.

Documentation of the efficacy of “intensive” phototherapy is not new, yet many infants who need phototherapy still receive minimal doses of light. In the days when the use of phototherapy was largely prophylactic, these doses were generally satisfactory and probably are adequate for most low birth weight infants. But when infants are admitted with very high bilirubin levels, we need to reduce them as soon as possible. In these infants, standard phototherapy is inadequate, and we now have both the understanding and the technology to permit us to deliver a highly effective, therapeutic dose of light.

Phototherapy Plus Pharmacology?

There are at least three pharmacologic interventions that will lower serum bilirubin levels, even in isoinmunized newborns, and each works by a different mechanism. Tin mesoporphyrin blocks bilirubin production; phenobarbital may increase bilirubin clearance; and intravenous γ-globulin, given to an isoinmunized infant, prevents the removal of sensitized red cells from the circulation. A combination of all three modalities together with intensive phototherapy should prove exceptionally effective in selected infants. If intensive phototherapy and tin mesoporphyrin are used simultaneously, only narrow-band blue lights should be used because of the risk of dermal photosensitivity.

Exchange transfusion has saved thousands of infants from death and brain damage, and it will probably remain an essential tool in occasional infants; but it will always carry some risk. The use of therapeutic doses of phototherapy combined, when necessary, with pharmacologic intervention should ultimately render exchange transfusion more or less obsolete. This, after all, was the original goal of phototherapy when it was first introduced nearly 4 decades ago.

APPENDIX

Measurements of phototherapy doses have confused us from the beginning, and with good reason—very few physicians are familiar with the biology and photochemistry of light, and fewer understand the methods available for measuring irradiance. It may be helpful to consider light as an infusion of discrete photons of energy that correspond to the individual molecules of a drug in a conventional medication. Absorption of these photons by bilirubin molecules in the skin leads to the therapeutic effect, in much the same way as binding of drug molecules to a receptor has a desired effect. Whereas drug dosages are conveniently measurable in units of weight, photon dosages are more difficult to measure and are expressed in rather less familiar terms, as explained below. For more detailed information, refer to studies by Ennever and ECRI.

Measuring Irradiance

Irradiance is measured in watts per square centimeter or microwatts per square centimeter. The irradiance in a certain wavelength band is called the spectral irradiance and is expressed as microwatts per square centimeter per nanometer. In the laboratory, spectral irradiance is measured with a precision instrument known as a spectroradiometer, which measures the flux of light over a series of discrete wavelengths. Clinicians and the manufacturers of phototherapy units usually use radiometers to measure the light output. Radiometers are relatively inexpensive and easy to operate, but unlike spectroradiometers, they take only a single measurement across a band of wavelengths—typically 425 to 475 or 400 to 480 nm. These bands of wavelengths are chosen because they represent the wavelengths at which bilirubin absorbs light maximally and will therefore undergo photochemical reactions to form excretable isomers and breakdown products.

Commercial radiometers measure the irradiance in the predetermined band but display the results as spectral irradiance (microwatts per square centimeter per nanometer). To do this, they simply divide the irradiance by the width of the wavelength band. Thus, a radiometer placed 30 cm below a phototheraphy unit might measure an irradiance of 400 μW/cm² in the 400- to 480-nm band (a width of 80 nm) and will provide a reading of the spectral irradiance of 400/80 = 5 μW/cm² per nanometer. Note, however, that under identical circumstances, a different radiometer that provided its measurement in the 425- to 475-nm band (a width of 50 nm) might display a spectral irradiance of 400/50 or 8 μW/cm² per nanometer. Thus, published data on spectral irradiance using different radiometers and different phototherapy systems cannot be compared. The only measurements that can be compared are those taken using the same radiometer and similar light sources. In its evaluation of radiometers, ECRI writes:

...the spectral characteristics of a radiometer-filter and detector are designed to ‘match’ the spectral characteristics of the bilirubin response curve; however, no accepted ‘standard’ curve is available. Therefore, the spectral response of any manufacturer’s radiometer is only an estimate of the
bilirubin response curve and varies from model to model and manufacturer to manufacturer. The radiometer calculates the effective irradiance of the light, which is the measured spectral irradiance of the phototherapy light source weighted by the "estimated" bilirubin response. The displayed irradiance value is, therefore, at best an estimate of the effective irradiance.12

Radiometers are probably not essential pieces of equipment for every nursery, but they are useful for the purposes of quality control—to check the irradiance levels of phototherapy units and compare them with previous measurements. A sudden drop in irradiance might alert staff to a problem, such as a damaged bulb or dirty reflectors, in the phototherapy unit. (For a more detailed discussion of radiometers see the study by ECRI.)13

Relationship Between Irradiance and the Distance Between the Infant and the Light Source

Figure 2 shows that the light intensity (measured as spectral irradiance) is inversely related to the distance from the source. The relationship between intensity and distance is almost (but not quite) linear. Thus, these data do not obey the inverse square law, which states that the light intensity should decrease with the square of the distance, because this law applies only to a point source of light. Phototherapy units do not provide a point source of light—the light source has some features of both a cylindrical and a planar source. Thus, the light intensity is a function of the distance but does not vary with the square of the distance.

Spectral Power

With fiberoptic phototherapy systems, the surface area of the infant exposed to phototherapy is assumed to be equal to the illuminated area of the fiberoptic pad. For example, the Ohmeda Biliblanket has a pad area of 134 cm² and a maximum average spectral irradiance of 400 to 480 nm of 22 µW/cm² per nanometer.12 Thus, spectral power is 134 x 22 = 2948 µW/nm or 2.9 mW/nm. For overhead lights, the whole surface of the infant facing the lights is assumed to be the surface area exposed and is calculated as follows: total surface area of a term newborn (length, 50 cm; weight, 3.5 kg) = 0.22 m² or 2200 cm². Assume that the anterior (or posterior) surface of the infant is approximately equal to one fourth of the total surface area, or 550 cm². Special blue tubes 15 cm above the infant provide an average spectral irradiance of 54 µW/cm² per nanometer and a spectral power of 550 x 54 = 29 700 µW/nm or 29.7 mW/nm. But infants are not flat, so all these calculations are approximations, at best. Clearly, in a supine infant, the irradiance reaching the anterior surface of the face, chest, and abdomen is substantially greater than that reaching the lateral surfaces of the trunk, face, and limbs. Irradiance to lateral surfaces (and, therefore, the spectral power) can be easily and effectively augmented by placing a reflecting surface (a white sheet or aluminum foil) within or around the bassinet so that light is reflected onto the infant's skin.19

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