Understanding Body Surface Area in Neonatal Phototherapy

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What is neonatal phototherapy?

Hyperbilirubinemia, a condition in which there is too much bilirubin in the blood, is the most common newborn condition requiring treatment. In the uterus, the fetus has extra red blood cells to carry oxygen and nutrients. After delivery, the red blood cells (RBC) no longer are needed. RBC break down, releasing bilirubin at a rate that may exceed the baby's ability to eliminate it. This excessive bilirubin can deposit in the skin, sclera, and mucous membranes causing them to appear yellow, or jaundiced. When the bilirubin level in the blood rises too high, the bilirubin can cross the blood-brain barrier and become neurotoxic, thus having the potential to cause lifelong neurological dysfunction or death. Newborn hyperbilirubinemia is treated with phototherapy, which converts bilirubin present in the superficial capillaries, interstitial spaces of the skin, and subcutaneous tissues into water-soluble isomers that are excretable without further metabolism by the liver.

The kinetics of phototherapy may be thought of in the same way as drug therapy, i.e., the dose response relationship of phototherapy is analogous to those of a medication administered to treat an illness. The dose delivered by a phototherapy device determines the efficacy of the treatment, and thus both dose and efficacy are determined by the amount of body surface area (BSA) treated and the spectral properties of the light used, such as peak wavelength, wavelength range, and irradiance delivered. Previous attempts to evaluate the efficacy of various phototherapy devices in the market with respect to BSA have fallen short due to inaccurate estimations of treated BSA. This paper proposes a new modality of calculating the treated BSA of a phototherapy device and offers a comprehensive comparison of leading phototherapy devices in the market.

What is treated BSA and why is it important for photo therapy?

Phototherapy is a multistep biomolecular process which involves the photoisomerization of bilirubin[1] found in the in the extravascular skin tissue and capillary flow. More skin exposure to the phototherapy light (treated BSA) results in faster photoisomerization of bilirubin and thus faster excretion.

Although prior research[2,3] established a strong relationship between the irradiance of phototherapy lights and efficacy of phototherapy, many investigators also highlighted the importance of treated body surface area as a key parameter in evaluating the efficacy of phototherapy devices.[4-7] When fiber optic devices do not cover enough BSA, or when overhead devices are not able to cause a sufficient fall of bilirubin levels,[2] clinicians tend to use "double" and "triple" phototherapy in an attempt to improve the phototherapy dose by increasing the treated BSA.

How can the effectiveness of phototherapy be calculated?

The term "spectral power" (measured in W/nm) was coined to normalize parameters of phototherapy across treated body surface area.[7] Spectral power is the product of phototherapy light irradiance in wavelength multiplied by the treated BSA:

When comparing the efficacy of various phototherapy devices, it is relatively simple to standardize the irradiance measurement by restricting the measurement window using the radiometer recommended by the phototherapy device's manufacturer. BSA is a 3-dimensional contour surface on a baby. Estimating BSA is a challenge requiring careful consideration to avoid the area of the skin receiving phototherapy receiving less irradiance than clinically needed.

Estimation of treated BSA of a baby, empirically, involves topographically mapping the 3-D surface of a baby onto a 2-D surface and then estimating the area of the resultant non-standard shape. Most studies comparing the efficacy of phototherapy devices have made a fair share of assumption(s): Maisels et al[7] assumes that with fiber-optic phototherapy systems, the surface area of the infant exposed to phototherapy is equal to the illuminated area of the fiberoptic pad. In contrast, with overhead lights the whole surface of the infant facing the lights is assumed to be the surface area exposed. This may not be true, because light decay in overhead devices obeys the inverse square law. Thus, a patch may be illuminated but receive sub-par amounts of irradiance and therefore be non-conducive for treatment. In another example, Dicken et al[8] assume that one-third of the area is estimated to be irradiated by the light source above the baby but does not offer a rationale. Finally, these studies, including the bench testing method proposed for evaluating the efficacy of phototherapy devices by Vreman et al,[11] do not account for the directionality of the light sources. The sides of the baby would receive less irradiance because they are not directly in-line with the light source. Such variance is difficult to capture numerically.

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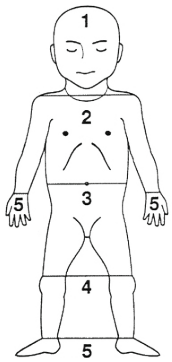
Figure 1. 3D scanned model of term and pre-term baby

Figure 2. Depiction of phototherapy of a term baby



Dermal Zone	Indirect Bilirubin (mg/100 mL)		
	Mean ± SD	Range	Observations
1	5.9 ± 0.3	4.3 – 7.9	13
2	8.9 ± 1.7	5.4 – 12.2	49
3	11.8 ± 1.8	8.1 – 16.5	52
4	15.0 ± 1.7	11.1 – 18.3	45
5		> 15	29

Figure 3. Cephalocaudal progression[9]

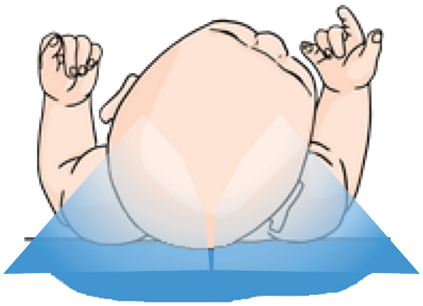


Figure 4. 3D light footprint of Skylife™

A new method for measuring treated BSA

The true treated BSA of a baby can be better estimated with the use of 3D-scanning technology. Here we propose a new method of measuring treated BSA and compare the treated BSA of the NeoLight Skylife™ phototherapy system with two competing devices. A 3D-scanned Computer Aided Design (CAD) model of term and preterm baby mannequins were used to map the true surface area of a baby. (Figure 1) The dimensions of Pamper diapers and Maxtec eye-masks were used to map the covered areas which would be untreated by phototherapy.

The phototherapy devices evaluated in this comparison included the NeoLight Skylife, the GE Giraffe Spot PT Lite, and the GE BiliBlanket. Spectral irradiance (µW/cm²/nm) measurements were made using a calibrated GE BiliBlanket Meter II (GE Healthcare, Fairfield, CT). This meter was selected due to its wide sensitivity range (400–520 nm with peak sensitivity at 450 nm), which overlaps the bilirubin absorption spectrum and allows evaluation of both narrow and broad wavelength band light sources. The testing environment exhibited an ambient irradiance of 0.1 µW/cm²/nm (in the radiometer sensitivity range). The baby mannequins were placed sequentially on the various phototherapy devices, and a side-view photograph was captured with an 8-megapixel camera. Automatic image they met this level of irradiance. The value 8.0 µW/cm²/nm is considered the minimum acceptable intensity for conventional phototherapy.[10] The points where intensity remained above 8.0 µW/cm²/nm were identified in the captured images, and the Red-Green-Blue (RGB) code of the point was used to draw a demarcation line (using Matlab® image processing module) along the posterior surface of the CAD models. The demarcation line was used to split the CAD model into two surface areas — treated and untreated. (Figure 2) To replicate a hospital setting, a diaper and eye mask were put on the mannequins but not shown in the figures. The blue area shown in Figure 2 represents the BSA covered by the respective phototherapy devices.

The BSA of various body parts was estimated, and the total treated BSA for term and preterm babies under various phototherapy devices was estimated by summing the treated BSA values for various body parts. The areas underneath the diaper and eye mask were subtracted from the treated BSA. The treated BSA was then represented as a percentage of the total BSA.

Comparison results and discussion

The treated BSA for term and preterm babies under NeoLight Skylife, GE Giraffe Spot PT Lite, and GE BiliBlanket are presented below in Table 1 and Table 2. Skylife has a significantly larger light source footprint (121.96 sq. in.) when compared to GE Giraffe Spot PT Lite (59.84 sq. in.) and BiliBlanket (20.76 sq. in.) and therefore offers superior light coverage to the legs, arms, and head. Furthermore, in addition to overall coverage, Skylife offers uniform head to toe irradiance. (Figure 5) Skylife delivers higher light coverage to the torso when compared to BiliBlanket, and higher coverage in the head compared to both Spot PT Lite and BiliBlanket. The slightly higher torso coverage shown by Spot PT Lite can be attributed to its irradiance of the anterior thoracic area, which is curved and represents a greater surface area compared to the back. The fiberoptic GE BiliBlanket has the smallest light source footprint and hence offers the least body surface coverage of the assessed devices. The BiliBlanket focuses its irradiance on the baby's back, leaving out a significant portion of the arms, legs, and head. Uniform irradiance of the various body parts is especially of interest because bilirubin deposition is not the same throughout the body, known to be higher at the head and decreasing directionally towards the toes (Figure 3).[9]

Table 1. Comparison of total BSA between devices across term and pre-term babies

Highest Median Lowest

Phototherapy device	Treated body surface area	
	Term baby	Preterm baby
Skylife™	40.26%	39.96%
GE Spot PT Lite	19.53%	22.95%
GE Bili Blanket	6.88%	12.13%

Table 2. Comparison of %BSA between devices for various body parts across term and pre-term babies

Highest Median Lowest

Phototherapy device	Term baby % BSA				
	Head	Torso	Arms	Legs	Overall
Skylife™	27.24%	48.09%	53.17%	66.42%	53.77%
GE Spot PT Lite	20.77%	54.92%	36.12%	7.65%	25.99%
GE Bili Blanket	6.47%	37.10%	2.38%	1.74%	9.20%

Phototherapy device	Pre-term baby % BSA				
	Head	Torso	Arms	Legs	Overall
Skylife™	41.65%	46.18%	56.03%	67.08%	56.06%
GE Spot PT Lite	30.67%	60.87%	45.59%	8.70%	32.13%
GE Bili Blanket	4.51%	38.80%	7.90%	21.64%	17.01%

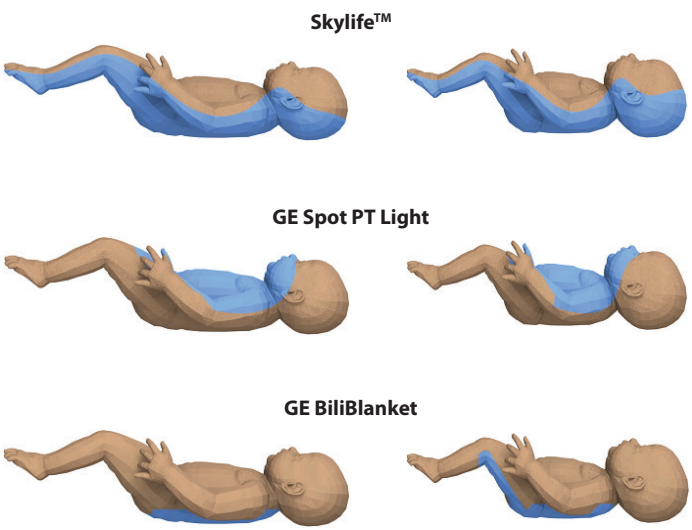


Figure 5. Visual comparison of treatment BSA coverage on term baby (left) and pre-term baby (right) between 3 marketed devices

The larger light foot print of Skylife can be attributed to the 3D light profile generated by directing the light onto the sides of the patient. (Figure 4) Numerous optical simulations were used to determine the positioning and spacing of lights in order to achieve the highest light footprint with the fewest lights. Unlike the light profiles generated by competing devices, this unique 3D light footprint also illuminates the sides of the baby uniformly from head to toe.

There are limitations to this comparison. The baby dimensions used in this study only approximate the average sizes of term and pre-term babies. The actual treated BSA will vary from patient to patient. Further, results will vary based on the size and type of diaper and eye-mask chosen. Regardless, the values of BSA presented in this paper represent good approximations to help physicians, nurses, and researchers understand the efficacy of various phototherapy devices.

Conclusion

Treatment BSA is a key parameter of effective neonatal phototherapy. This paper proposed a new 3D method for measuring BSA covered by phototherapy lights and compared BSA coverage of three currently marketed phototherapy devices. Skylife, through its unique 3D light profile, delivers the highest treatment BSA of the three devices compared. The additional BSA coverage may improve the efficacy of phototherapy by increasing the elimination rate of bilirubin, thus decreasing treatment time. These laboratory findings currently are being validated in clinical studies. Phototherapy with previously existing devices has an average treatment time of 48 hours.[12] A reduction in treatment time would reduce operational costs, allow a hospital to discharge babies earlier which could improve patient satisfaction, and free up beds allowing for additional admissions.

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