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Editor's comment: This paper considers the accuracy of the devices used to monitor the output of phototherapy sources used to treat neonatal hyperbilirubinemia. Clarkson and colleagues compared the performance of a series of commercial radiometers with reference to readings acquired by a spectroradiometer. The paper highlights the need for accurate measures of spectral irradiance from phototherapy devices in order to ensure the light levels to which the neonate is exposed are safe and effective.

Richard Black, Editor in Chief

Neonatal phototherapy radiometers: Current performance characteristics and future requirements

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ABSTRACT

Hand held radiometers provide a convenient means of monitoring the output of neonatal phototherapy treatment devices as part of planned programs of device maintenance and output monitoring. It was considered appropriate to determine the wavelength and angular response of a selection of such meters and compare their indicated values with that derived from spectral analysis of phototherapy light sources. This was undertaken using a Bentham DMc150 double grating spectroradiometer and a series of 10 nm band pass optical filters in the range 400–640 nm used in conjunction with a fiber optic light source. Specific meters investigated included a GE Biliblanket Light Meter II, a NeoBLUE radiometer and a Bio-TEK radiometer 74345 device. Comparisons were made of measurements made using the hand held meters and the Bentham DMc 150 system for a range of neonatal phototherapy treatment devices. The use of such meters is discussed in relation to applicable equipment standards and recommendations of intensive phototherapy from clinical groups such as the American Academy of Pediatrics and a specification for a spectroradiometer based measurement system is proposed.

1. Introduction

1.1. Phototherapy radiometers

It was considered appropriate to compare output measurements of neonatal phototherapy equipment made using a selection of hand held meters with determinations of device irradiance using a Bentham DMc 150 spectroradiometer (Bentham Instruments, Reading, UK). Table 1 indicates the specific phototherapy meters investigated.

The bandwidth of such meters is typically identified as the wavelength interval corresponding to 50% of meter wavelength sensitivity which is principally derived from the combined response of the filter element and the specific photo detector device utilized. Units of measurement used with phototherapy meters investigated include $\mu W\,cm^{-2}\,nm^{-1}$ and $\mu W\,cm^{-2}$, where a value of $\mu W\,cm^{-2}$ can be converted to $\mu W\,cm^{-2}\,nm^{-1}$ by dividing the meter reading in $\mu W\,cm^{-2}$ by the bandwidth of the meter. Similarly a value in $\mu W\,cm^{-2}\,nm^{-1}$ can be converted to $\mu W\,cm^{-2}$ by multiplying by the bandwidth in nm of the meter. In the example of the Bio-TEK Model 74345, a value of 480 $\mu W\,cm^{-2}$ would be equivalent to 10.9 $\mu W\,cm^{-2}\,nm^{-1}$ for a bandwidth value of 44 nm. The standards document BS EN 60601-2-50:2009 [1] relates to irradiance values within the wavelength range 400–550 nm as having the potential for neonatal phototherapy.

1.2. Clinical framework

Previous guidelines of the American Academy of Pediatrics [2] referenced an average level of 30 $\mu W\,cm^{-2}\,nm^{-1}$ within the wavelength band 430–490 nm – equivalent to 1.8 $mW\,cm^{-2}$ within the active bandwidth as part of 'intensive' phototherapy. A recent revision of this policy [3] references an average level of 30 $\mu W\,cm^{-2}\,nm^{-1}$ within the wavelength band 460–490 nm – equivalent to 0.9 $mW\,cm^{-2}$ within the active bandwidth. Maisels and McDonagh [4] identify specific pathways of bilirubin metabolism and indicate that the most effective wavelengths are probably between 460 nm and 490 nm through no specific evidence is cited for this observation. McDonagh and Lightner [5] describe the complex modes of photo disruption of bilirubin

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Table 1
Details of neonatal phototherapy meters investigated.

	Wavelength sensitivity range (nm)	Peak sensitivity wavelength/range (nm)	Bandwidth (nm)	Units	Maximum indicated value
GE Biliblanket Light Meter II	400–520[a]	450[a]	60[a]	$\mu W\,cm^{-2}\,nm^{-1}$	299.9[a]
NeoBLUE radiometer	420–500[a]	442–480[b]	62[b]	$\mu W\,cm^{-2}\,nm^{-1}$	150[a]
Bio-TEK model 74345	400–480[a]	453[b]	44[a]	$\mu W\,cm^{-2}$	1999

[a] Manufacturers' specification.
[b] Derived from product information.

in vivo, indicating the numerous factors which distinguish in vitro from in vivo wavelength responses. A recent study [6] has indicated a linear response of the rate of serum bilirubin reduction with delivered light dose, with no indication of a 'plateau effect' with progressively higher levels of incident light levels.

1.3. Models of radiometer response

With increasing clinical preference for 'greener' wavelengths for neonatal phototherapy, it is instructive to derive values of wavelength functions of phototherapy devices within the wavelength bands 430–490 nm and 460–490 nm which are independent of specific commercially available phototherapy radiometers.

A Gaussian response function $G_{430\text{–}490}(\lambda)$ with peak sensitivity at 460 nm and 50% bandwidth at 430 nm and 490 nm can be empirically described as

$$G_{430-490}(\lambda) = e^{-((\lambda-460)(\lambda-460))/(1300)} \quad (1)$$

Similarly a Gaussian function $G_{460\text{–}490}(\lambda)$ with peak sensitivity at 475 nm and 50% bandwidth at 460 nm and 490 nm can be empirically described as

$$G_{460-490}(\lambda) = e^{-((\lambda-475)(\lambda-475))/(338)} \quad (2)$$

In addition, 'top hat' functions $TH_{430\text{–}490}(\lambda)$ and $TH_{460\text{–}490}(\lambda)$ with unity value of response within the specific inclusive wavebands were also identified. Fig. 1 indicates characteristics of $TH_{460\text{–}490}(\lambda)$, $G_{430\text{–}490}(\lambda)$ and $G_{460\text{–}490}(\lambda)$.

These functions were used to derive components of irradiance within the specific wavelength functions for specific neonatal phototherapy devices as indicated subsequently in Table 4. Functions such as $TH_{430\text{–}490}(\lambda)$ and $TH_{460\text{–}490}(\lambda)$ can be directly measured by spectroradiometer devices such as the Bentham DMc150 system, where a value of irradiance is determined at individual wavelength values.

2. Method

2.1. Determination of angular response of phototherapy radiometers

The angular response of the indicated meters and the Bentham DMc150 system with a D6 detection head were determined using light from a fiber optic light source with a 4 mm cross section presented to the detector surface at angles from −90° to +90° at intervals of 10°. The 4 mm fiber optic light source provided a convenient means of generating high levels of optical output within the wavelength sensitivity range of the phototherapy meters. The distance between the tip of the fiber light source and the surface of the specific detector was 22 cm. This distance was identified as a compromise between allowing the phototherapy meters to

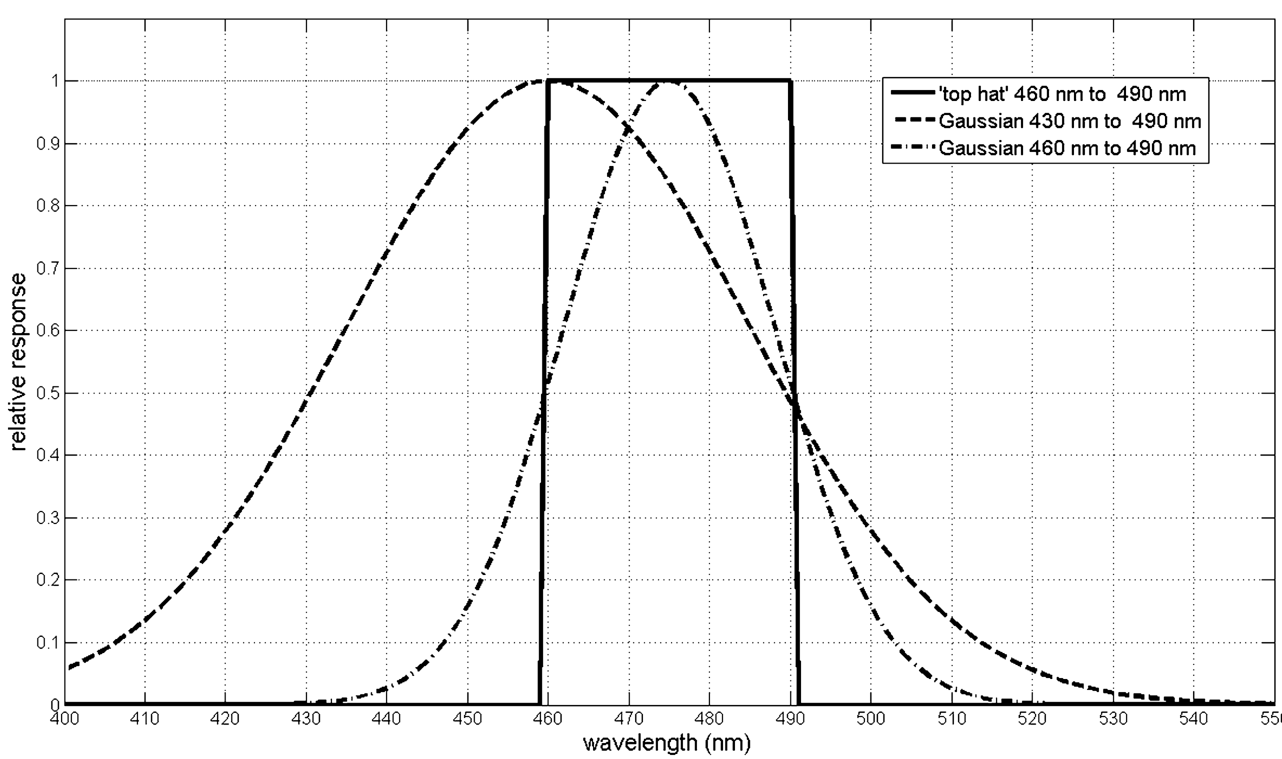

Fig. 1. Specific functions of 'top hat' 460–490 nm, $G_{430\text{–}490}(\lambda)$ and $G_{460\text{–}490}(\lambda)$. The function $TH_{430\text{–}490}(\lambda)$ is not shown.