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Technical note

Use of a hand-held spectroradiometer for the measurement of neonatal phototherapy lamp outputs

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ABSTRACT

The measurement capability of a hand-held spectroradiometer for validation of phototherapy light treatment for neonates is described. This function is compared with that of a double grating monochromator system with photomultiplier detector, where parameters evaluated included wavelength accuracy and accuracy of irradiance within set wavelength intervals – 460 nm to 490 nm and 400 nm to 550 nm. Measurements carried out in a clinical setting revealed that the hand-held spectroradiometer provided an acceptable level of accuracy for determining output characteristics of the phototherapy devices investigated. It was observed that measurement errors were more significant for studies involving direct contact with light emitting surfaces. It was identified that the spectral resolution of the MSC15 device could act to degrade the accuracy of the device where narrow spectrum peaks occurred around the limits of specific identified bandwidths – such as at 460 nm and 490 nm. This was identified not to be an issue with typical light emitting diode phototherapy systems, where the spectral outputs do not contain narrow spectral components. The device lends itself also to use by clinical staff in the clinical environment to verify the output of phototherapy lamps. The availability of such hand-held spectroradiometer devices represents an advance on the use of output meters suppled by equipment manufacturers.

1. Introduction

Clinical guidance on the management of severe neonatal hyperbilirubinemia in the new born infant at 35 or more weeks gestation has been provided by the American Academy of Pediatrics (AAP) [1,2]. Neonatal phototherapy, however, continues to be a challenging area of clinical management [3–5], involving a wide range of clinical considerations. Embedded within a complex framework of clinical observation and parameter measurement, specific advice in the earlier publication [1] included phototherapy delivery within the wavelength range of 430 nm to 490 nm of an irradiance of at least 30 µW cm^{-2} per nm and equivalent to an irradiance of 1.8 mW cm^{-2} within the designated wavelength range. The later publication [2] subsequently modified the wavelength range to 460 nm to 490 nm. This wavelength range is indicated by Lamola and Russo [6] based on determination of light absorbance of adult blood samples loaded with bilirubin. The absorption of light by haemoglobin significantly influences the observed relative fraction of light absorbed where the peak of 'in vivo' absorption co-insides with a local minimum of absorption due to haemoglobin. The type of meters, however, provided by manufacturers for specific phototherapy lamp systems typically incorporate weighting factors related to an assumed action spectrum of 'in vitro' bilirubin and the authors of the earlier publication [1] describe how meters from different manufacturers would also tend to give different values for the same phototherapy spectrum. From a measurement perspective, and as a basis for evaluation of therapy regimes, there is a clear advantage in measuring the direct spectrum without any weighting factor.

The desirability of undertaking spectral measurement of neonatal phototherapy light sources [7] has been previously outlined. The ability to evaluate light output within defined spectral limits was identified to provide for a more flexible measurement system, rather than a meter with proprietary wavelength response parameters. A wide range of spectroradiometer systems are available which can provide such a measurement capability in the visible spectrum, though this includes a wide range of performance parameters such as system cost, spectral resolution and ease of use. Routine use has been made locally of a Bentham dmc150, spectroradiometer (Bentham Instruments, Reading, UK) which incorporates a double grating monochromator construction and a photomultiplier detector with a high signal to noise ratio. Such

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instruments, however, cannot be readily used by non specialist personnel and they cannot be considered portable.

While solid state spectral analysis devices have provided the advantage of more compact size and rapid measurement capability, they generally have poorer specification with regard to signal to noise ratio, spectral resolution and overall accuracy. The MSC15 hand held spectral output meter (Gigahertz Optik GmbH, Turkenfeld, Germany) has been compared in its performance with the Bentham dmc150 spectroradiometer using a range of specific phototherapy light sources. The MSC15 device covers the wavelength range 360 nm to 830 nm and determines the irradiance in units of W m^{-2} nm at single nm values. A range of derived parameters in photometry and associated measurement can be automatically calculated by the device and configured to be included in the set of indicated measured parameters. In relation to neonatal phototherapy measurements, the device calculates spectral irradiance in wavelength interval 400 nm to 550 nm in accordance with a specification of neonatal phototherapy equipment [8] and also the average irradiance per nm within the wavelength range 460 nm to 490 nm in accordance with current guidance of the American Academy of Pediatrics [2].

2. Materials and methods

Table 1 indicates the core specification of the MSC15 spectral light meter, where the derivation of the cosine error is referenced within a specific technical standard [9]. The standard CIE 214 [10] provides a framework for calculation of integrated irradiance values within wavelength intervals.

The MSC15 device is indicated in Fig. 1 in 'hand held' mode.

Where the MSC15 is presented with a narrow spectral line, it will indicate a broadened response with a full width half maximum of around 10 nm. The MSC15 incorporates a shutter which in the closed position allows setting of dark current detector values. The unit requests recalculation of dark current if a significant change in temperature of the unit is detected. The device can be operated as a hand–held device with display of a range of parameters of an individual captured spectrum but without storage of sequences of detected spectra. Data can also be stored using USB connection to a device running Windows (XP SP2, 7–32 bit, 7–64 bit) as GOS extension source files and with an option to export in ASCII and Excel^{TM} formats. In the Windows^{TM} environment, a display table of all computed parameters and display of spectral data is provided. The USB connection also charges the internal battery of the MSC15.

A Bentham dmc150 system was used to allow measurement of light spectra within the wavelength range 250 nm to 800 nm and where light was split using a two stage diffraction grating system, with the light signal being detected using a sensitive photomultiplier device. Comparison of captured spectra with a Bentham dmc150 system was undertaken using a range of specific phototherapy light sources. Measurements using the Bentham dmc150 were undertaken using a 2 metre quartz fibre bundle with dl80 cosine correction light collector. The Bentham dmc150 system was calibrated using a fan cooled CL6 calibration lamp which incorporated a quartz tungsten halogen light source with traceability to national UK standards. Output measurements of the MSC15 were undertaken using the CL6 lamp with the surface of the MSC15 detector in the position corresponding to the calibration values of the CL6 lamp and which was approximately 4 mm from the open aperture of the CL6 lamp. The MSC15 device is calibrated by the manufacturer with reference to the spectral irradiance of a 1000 W quartz-halogen-lamp whose output is traceable to the national standards of the Physikalisch-Technische Bundesan-stalt (PTB) in Germany. The nominal uncertainty of irradiance measurements within the active clinical wavelength range of interest is indicated as 4%. The wavelength accuracy of the MSC15 device was determined using an HG-1 Mercury Argon calibration source (Ocean Optics, Largo, USA) where the 3 mm output aperture of the HG-1 device was directly coupled to the light collector of the 2 metre quartz fibre bundle.

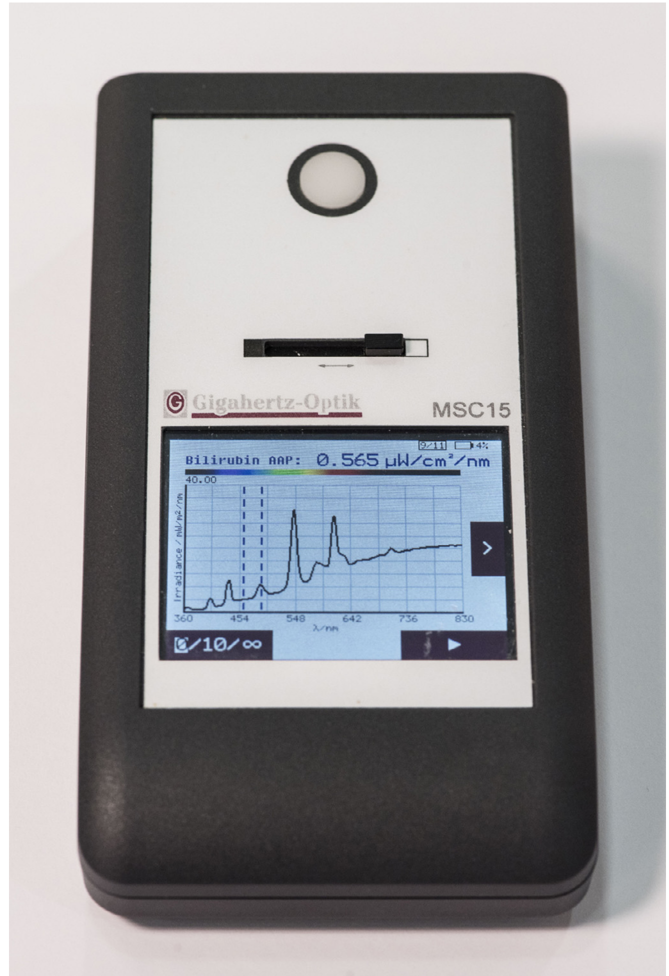

Fig. 1. Image of MSC15 spectral light meter shown in hand held mode with no USB connection.

Phototherapy light sources subsequently evaluated using the MSC15 device included a Giraffe® Spot PT Lite^{TM} phototherapy system (GE Medical Systems, Waukesha, USA), a Biliblanket Plus phototherapy device (GE Medical Systems, Waukesha, USA) and a neoBLUE® LED Phototherapy system (Natus Medical, Pleasanton, USA).

Table 1
Summary of specification of MSC15 device.

Wavelength sensing range	360 nm–830 nm
Detector type	Silicon
Spectral analysis technique	Grating
Dynamic range of detector (lx)	1–350,000
Cosine error	f2 value of <= 3% [9]
Diameter of measurement aperture	10 mm
Battery life	8 hrs
Interface	USB 2.0 (also charges unit)
Optical bandwidth	10 nm (FWHM value)

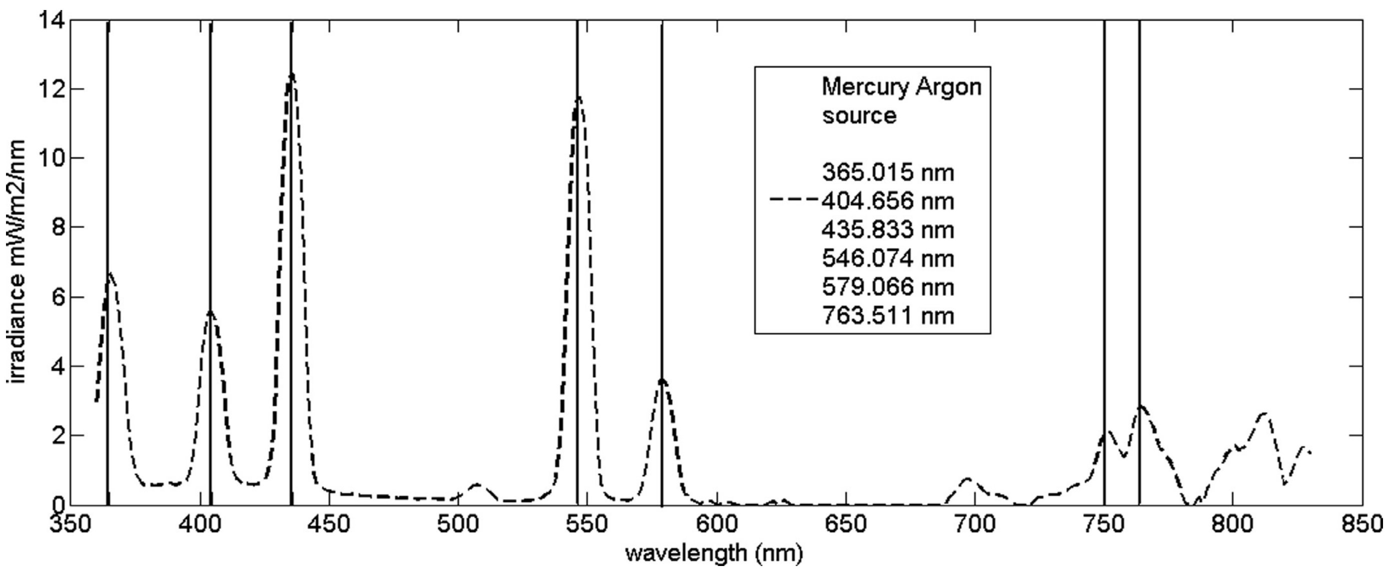

Fig. 2. Measured spectra using MSC15 device (dashed curve) and reference spectral lines (solid vertical) of an HG-1 Mercury Argon calibration source.

Table 2
Indication of degree of agreement between the peak indicated wavelength on the MSC15 and that of the corresponding reference wavelength of the HG-1 lamp unit.

Reference wavelength HG-1 lamp (nm)	Peak detected MSC15 wavelength (nm)	Delta (MSC15-reference) (nm)
365.015	365	−0.015
404.656	404	−0.656
435.833	435	−0.833
546.074	547	0.926
579.066	579	−0.066
763.511	764	0.489

3. Results

3.1. Wavelength accuracy

Fig. 2 indicates measured spectra and reference spectral lines of an HG-1 Mercury Argon calibration source (Ocean Optics, Largo, USA).

Table 2 indicates the degree of agreement between the indicated peak wavelength detected by the MSC15 and that of the reference wavelength where the mean ‘Delta’ value over the referenced six lines is -0.026 nm.

3.2. Spectral irradiance values

Fig. 3(a)(c) indicates typical spectral measurements for a range of phototherapy systems using the two spectral measurement devices, where vertical lines at 460 nm to 490 nm indicate the bandwidth recommended by the American Academy of Pediatrics [2].

Fig. 3(a) indicates close correspondence between the two spectroradiometer systems for the neoBLUE® LED Phototherapy lamp except that the Bentham dmc150 system has a slightly higher response at around 470 nm compared with the MSC15 device. In Fig. 3(b), the spectral profile of the Bentham dmc150 system is able to detect the narrow wavelength peaks around 450 nm ± 10 nm of the output irradiance of the Giraffe® Spot Lite™ system, while the MSC15 device is not able to provide such wavelength resolution. It is observed, however, the two spectroradiometers have approximately the same response within the wavelength range 460 nm–490 nm for the Giraffe® Spot Lite™ system. In Fig. 3(c), the detectors of both devices were in direct contact with the Biliblanket Plus device surface. The MSC15 device is typically recording a higher value of irradiance over the output wavelength range of the device. This is possibly a result of the cosine correction functions of the MSC15 device and the Bentham dmc150 system in this configuration, time variance of output of the phototherapy lamp system and also continuity issues in testing identical areas of Biliblanket Plus surface with the detecting apertures of the MSC15 unit and that of the Bentham dmc150 system.

Table 3 indicates details of measured irradiances values within specific wavelength ranges. The values 400 nm to 550 nm relate to the irradiance value referenced in the IEC product standard [8]. While the Giraffe®Spot Lite™ had the higher irradiance in wavelength range 400 nm to 550 nm compared with the neoBLUE® LED Phototherapy phototherapy lamp system, it had the lower irradiance in the waveband 460 nm to 490 nm compared with the neoBLUE® LED phototherapy lamp system.

For the Giraffe®Spot Lite™ device, the irradiance within the wavelength band 460 nm–490 nm agrees within 1% and that of the NeoBlue device within 7%. The corresponding values for the irradiance in range 400 nm–550 nm are 5% and 2%, respectively.

Table 3
Comparative measurements: neonatal phototherapy lamp systems.

	Biliblanket plus	Giraffe spot lite	neoBlue
400 nm–550 nm Bentham dmc150 mW m^{-2}	35237.0	40174.0	27098.0
460 nm–490 nm Bentham dmc150 mW m^{-2}	7731.0	5443.0	19296.0
460 nm–490 nm Bentham dmc150 μW cm^{-2} nm^{-1}	25.77	18.14	64.32
400 nm–550 nm MSC15 mW m^{-2}	40610.0	38380.0	26590.0
460 nm–490 nm MSC15 mW m^{-2}	9249.0	5493.0	17958.0
460 nm–490 nm MSC15 μW cm^{-2} nm^{-1}	30.83	18.31	59.86

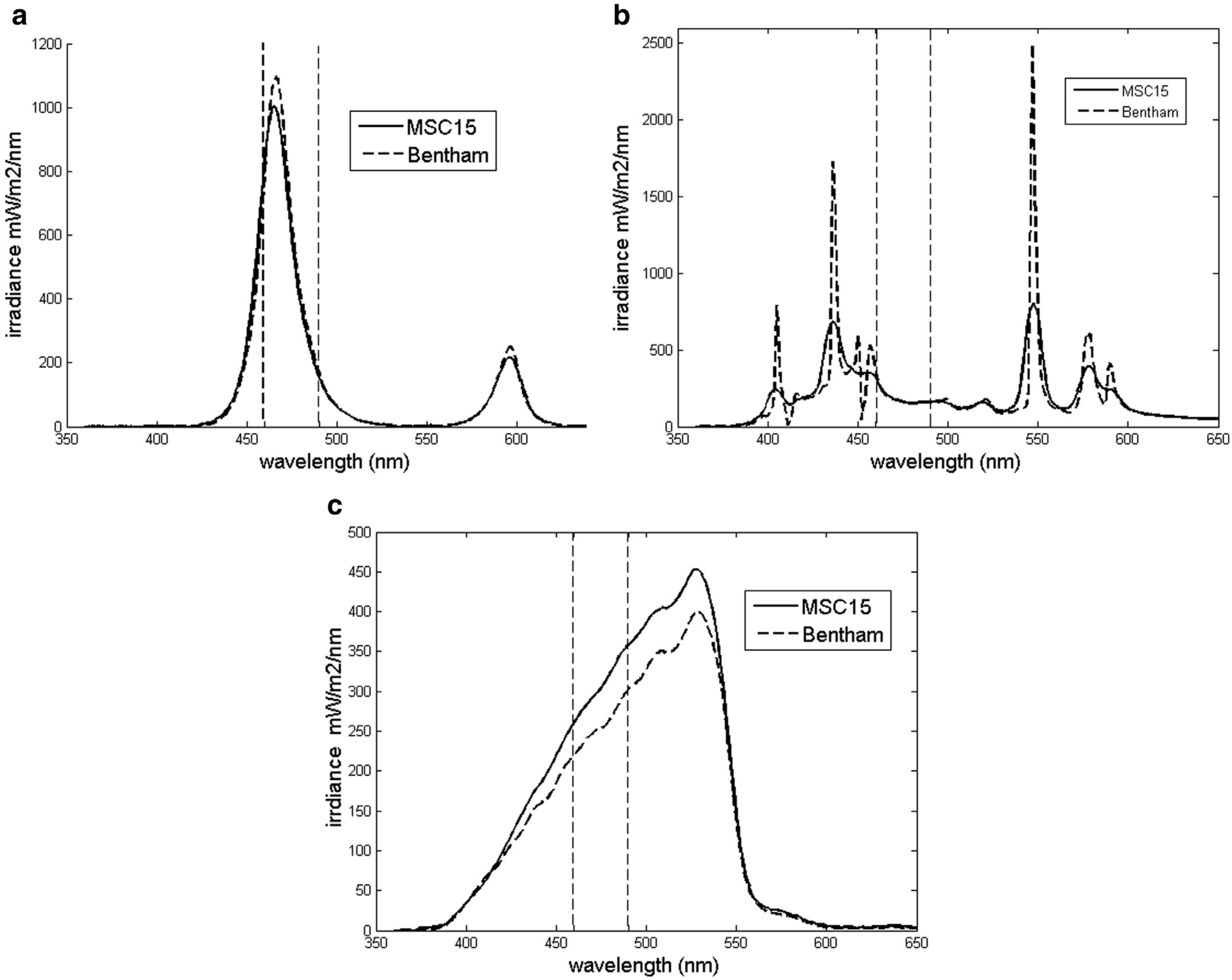

Fig. 3. (a) Spectral measurements of neoBLUE® phototherapy light system using the MSC15 and Bentham dmc150 spectroradiometer systems. (b) Spectral measurements of Giraffe Spot phototherapy light system using the MSC15 and Bentham dmc150 spectroradiometer systems. (c) Spectral measurements of Biliblanket phototherapy light systems using the MSC15 and Bentham dmc150 spectroradiometer systems.

4. Discussion

The MSC15 device is considered to have a valid measurement role for the determination of spectral output values of neonatal phototherapy devices though measurement errors were identified as more significant for comparison studies involving direct contact with light emitting surfaces. It was identified that the spectral resolution of the MSC15 device could act to degrade the accuracy of the device where narrow spectrum peaks occurred around the limits of specific identified bandwidths - such as at 460 nm and 490 nm, though this was not observed for the phototherapy systems investigated. The issue of spectral resolution was identified not to be an issue with typical light emitting diode phototherapy systems, where the spectral outputs do not contain narrow spectral components. The measurement role of the MSC15 can be considered to be relevant for maintenance organisations servicing phototherapy systems and also for use by clinical staff in the patient environment for verification that phototherapy systems are delivering effective phototherapy outputs.

CRediT authorship contribution statement

Douglas M. Clarkson: Conceptualization, Methodology, Data curation, Writing - original draft. **Prakash Satodia:** Funding acquisition, Investigation, Writing - review & editing.

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Conflicts of interest

None.

Ethical approval

Not required.

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