

## Original Research Article

# Assessing the irradiance levels of phototherapy devices in Jos, north central, Nigeria

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## ABSTRACT

**Background:** Neonatal jaundice (NNJ) remains a major cause of neonatal morbidity and mortality in Nigeria with significant contribution to the global figures. Effective phototherapy can reduce the complications associated with NNJ. The effectiveness of a phototherapy device (PD) depends mainly on the emitted irradiance of the device. We, therefore, assessed the irradiance of the PDs in Jos, North Central Nigeria in order to determine the effectiveness of the devices and to highlight the need for routine assessment of irradiance levels of PDs in low-middle income settings.

**Methods:** This was a cross-sectional study involving 14 hospitals with a total of 38 functional PDs comprising of 25 (65.8%) locally fabricated, eight (21.0%) light-emitting diode (LED) and five (13.2%) conventional patented devices. The irradiance was measured using the BiliBlanket® light meter II.

**Results:** The irradiance of the PDs ranged from 2 to 102  $\mu\text{W}/\text{cm}^2/\text{nm}$  with a median value of 10.6 (IQR 6-18  $\mu\text{W}/\text{cm}^2/\text{nm}$ ). Sixteen devices (42.1%) had a suboptimal irradiance ( $<10 \mu\text{W}/\text{cm}^2/\text{nm}$ ); while only five (13.2%) provided irradiance at the intensive level ( $\geq 30 \mu\text{W}/\text{cm}^2/\text{nm}$ ). The mean distance between the babies and phototherapy lights was  $35.1 \pm 12.7 \text{cm}$  (range 15-70cm).

**Conclusions:** A significant proportion of the PDs in Jos delivered suboptimal irradiance which could reduce the effectiveness of the phototherapy. The irradiance of PDs needs to be assessed regularly and measures should be instituted to improve the irradiance to the optimum level in order to reduce the burden of kernicterus.

**Keywords:** Irradiance, Jos, Neonatal jaundice, Nigeria, Phototherapy

## INTRODUCTION

Neonatal jaundice (NNJ) remains a major cause of neonatal morbidity and mortality in Nigeria accounting for up to 35% of neonatal admissions and 14.1% of neonatal deaths.<sup>1-3</sup> Phototherapy and exchange blood transfusion (EBT) are the main treatment options for moderate and severe NNJ.<sup>4</sup> Effective phototherapy has been shown to reduce the complications associated with NNJ and the need for EBT-an invasive procedure.<sup>4</sup>

Ineffective phototherapy and late presentation of babies with severe jaundice have been identified as major reasons for high rates of exchange transfusion and high prevalence of kernicterus in Nigeria.<sup>1,5</sup> The effectiveness of a phototherapy device (PD) mainly depends on irradiance (light intensity) and spectral quality of the light.<sup>6</sup> A dose-response relationship exists between the irradiance level and serum bilirubin, such that as the irradiance level increases, there is an increase in the rate of reduction of serum bilirubin.<sup>7</sup> The American Academy

of Paediatrics (AAP) guideline recommends periodic checks of phototherapy devices so as to ensure that an adequate irradiance is being delivered.<sup>8</sup> Based on this guideline, minimally acceptable irradiance level is  $10\mu\text{W}/\text{cm}^2/\text{nm}$  and intensive range irradiance is  $\geq 30\mu\text{W}/\text{cm}^2/\text{nm}$ .<sup>8</sup>

Previous surveys in Southern Nigeria and some other low-middle income countries reported a generally low and suboptimal irradiance emittance with consequent risk of ineffective treatment of the jaundiced babies.<sup>9-12</sup> Prior to this study, the irradiance of PDs was not routinely checked in the hospitals in our part of Northern Nigeria; moreover, there is paucity of data on the irradiance of PDs generally in the Northern region. We therefore sought to assess the irradiance of the phototherapy devices in Jos, North Central Nigeria in order to determine the effectiveness of the devices and to highlight the need for routine assessment of irradiance levels of PDs in low-middle income settings, while encouraging the institution of measures to ensure adequate irradiance delivery.

## METHODS

### Study location

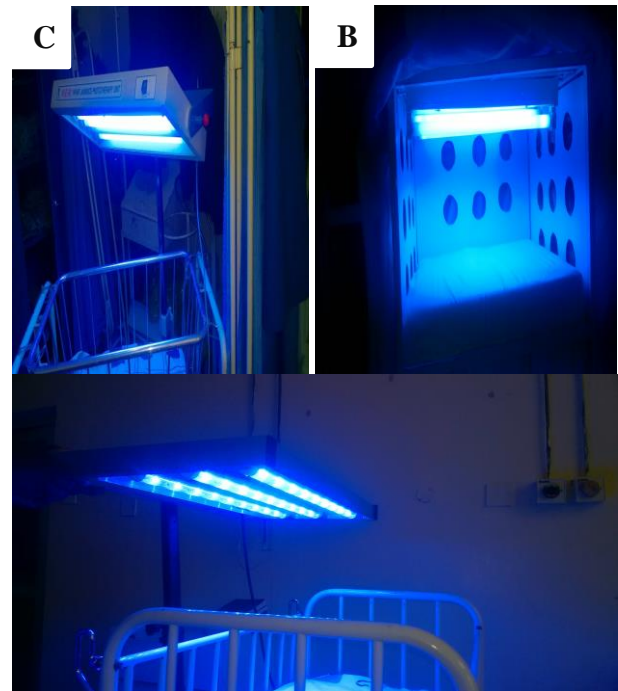
Jos, the capital of Plateau State is located in the North-Central zone of Nigeria. The population of the State was estimated at 3,206,531 in the 2006 census and Jos has a population of approximately 900,000.<sup>13</sup> It has two teaching hospitals and one specialist hospital which offer tertiary health care services. It also has several hospitals that offer secondary health care services. Phototherapy services were however, available only in 14 health facilities. These facilities receive referrals for phototherapy services from all other hospitals in Jos and other parts of the State, where no such services are available.

### Study population

All the 14 hospitals offering phototherapy services were identified during a prior unpublished audit exercise of health facilities offering neonatal services in Jos. There were a total of 38 functional phototherapy devices in these hospitals. These PDs were of three types, namely

- Conventional patented PDs-foreign made devices utilising regular blue fluorescent tubes (Toshiba Lighting FL18W/T8/DB, General Electric 20-W F20T12/B) arranged in parallel circuit within an adjustable head (Figure 1a).
- Locally fabricated PDs-locally made wooden boxes with regular blue fluorescent tubes (Maspion FL20SD/18W, Osram FL 20SB/18W) arranged in parallel circuit and fixed to the inner part of the roofs of the boxes (FIGURE 1b).
- Light-emitting diode (LED) device consisted of an open aluminium angle fixture fitted with three T8

tubes ( $60 \times 2.5$  cm) each containing nine equally spaced 3-W LEDs (Figure 1c).



**Figure 1: A) A conventional patented phototherapy device at default setting in a hospital. Note the angulation of the device; B) A locally fabricated phototherapy device; C) A light-emitting diode (LED) phototherapy device.**

### Study design

This was a cross-sectional study conducted between January and March 2015.

### Data collection

The irradiance of the phototherapy units was measured using the BiliBlanket® light meter II (Ohmeda Medical GE Healthcare; Fairfield, CT; USA). The spectral wavelength of the meter was 400-520nm and the irradiance range were  $0.1-299.9\mu\text{W}/\text{cm}^2/\text{nm}$ . No adjustment was made to the default settings of the devices at the different facilities. The meter was positioned at the newborn's abdomen height (i.e., about 10 cm above the mattress) and the irradiance measured at the centre of the illuminated area.<sup>10</sup> The values were reported in  $\mu\text{W}/\text{cm}^2/\text{nm}$ .

The irradiance value was categorised as 'suboptimal' if the value was less than  $10\mu\text{W}/\text{cm}^2/\text{nm}$  and 'optimal' if it was between 10 and  $29.9\mu\text{W}/\text{cm}^2/\text{nm}$ . Irradiance values greater than or equal to  $30\mu\text{W}/\text{cm}^2/\text{nm}$  were categorised as 'intensive'.<sup>8</sup> Irradiance at optimal and intensive levels was regarded as adequate while irradiance at suboptimal level was regarded as inadequate.

The distance from the illuminating surface of the light to the level of the baby was measured and documented in centimetres. When the measured distance was less than or equal to 15cm, it was classified as 'recommended' and a distance of 16cm to 50cm was classified as 'acceptable'. A distance greater than 50 cm was classified as 'not recommended'.<sup>8,14</sup>

The irradiance values of the phototherapy devices were thereafter communicated to the management of the participating hospitals, with the importance of adequate irradiance in the treatment of neonatal jaundice and the need to periodically check the irradiance of PDs being highlighted.

### Data analysis

Data obtained was analysed using Statistical Package for the Social Sciences (SPSS) version 21. The characteristics of the PDs and health facilities were presented in frequencies and percentages. The median irradiance values of the different types of PDs were compared using the Kruskal-Wallis test, while the relationship between the quality of irradiance versus types of PDs and health facilities was analysed using chi-square test. A p-value of <0.05 was taken to be statistically significant.

## RESULTS

The 14 hospitals comprised three (21.4%) tertiary and 11 (78.6%) secondary facilities. Two of the tertiary and one of the secondary facilities were owned by the government while the remaining 11 facilities were privately owned (Table 1).

Twenty-five (65.8%) of the 38 phototherapy devices were locally fabricated PDs, eight (21.0%) were LED devices and five (13.2%) were conventional patented devices. The light sources of the locally fabricated and conventional patented devices were regular blue fluorescent bulbs ranging in number from three to 10 bulbs per phototherapy unit. Reflectors (white lining) were used in 12 (31.6%) of the 38 phototherapy devices (Figure 1b and Table 1).

Irradiances of the phototherapy devices ranged from 2 to 102 $\mu$ W/cm<sup>2</sup>/nm with a median value of 10.6 (IQR 6-18)  $\mu$ W/cm<sup>2</sup>/nm. The median irradiances of the different types of phototherapy devices were 51.4, 10.4, 4.0 $\mu$ W/cm<sup>2</sup>/nm for LED, locally fabricated and conventional patented devices respectively with a statistically significant difference in the median irradiance values (p = 0.003) Table 2.

Sixteen (42.1%) of the total phototherapy devices had suboptimal irradiance (<10 $\mu$ W/cm<sup>2</sup>/nm); while only five (13.2%) provided irradiance at the intensive level ( $\geq$ 30 $\mu$ W/cm<sup>2</sup>/nm) Table 1. Seven (88%) of the eight LED units delivered adequate irradiance, compared with 14

(56%) of the 25 locally fabricated units and only one (20%) out of the five conventional patented phototherapy devices (p= 0.041) - Table 2. Using Bonferroni correction, LED was responsible for the variations seen. Seventeen (63.0%) of the 27 PDs in the private hospitals had adequate (optimal plus intensive) irradiance compared to five (45.5%) out of the 11 PDs in the public hospitals but the difference was not statistically significant (p = 0.323) Table 2.

**Table 1: Characteristics of the health facilities and phototherapy devices.**

Characteristics	Frequency	Percentage
<b>Type of facility</b>		
Secondary	11	78.6
Tertiary	3	21.4
Total	14	100.0
<b>Ownership of facility</b>		
Private	11	78.6
Public	3	21.4
Total	14	100.0
<b>Distribution of phototherapy devices by facility</b>		
Private	27	71.1
Public	11	28.9
Total	38	100.0
<b>Types of phototherapy device</b>		
LED	8	21.0
Locally fabricated	25	65.8
Conventional patented	5	13.2
Total	38	100.0
<b>Presence of reflector in phototherapy device</b>		
Yes	12	31.6
No	26	68.4
Total	38	100.0
<b>Categorisation of distance of phototherapy devices from the babies</b>		
Recommended	1	2.6
Acceptable	33	86.8
Not recommended	4	10.6
Total	38	100.0
Mean distance $\pm$ SD (range)	35.1 $\pm$ 12.7cm (15-70cm)	
<b>Categorisation of Irradiance delivery of the devices</b>		
Suboptimal	16	42.1
Optimal	17	44.7
Intensive	5	13.2
Total	38	100.0

The distance between the babies and phototherapy units ranged from 15 to 70cm, with a mean distance of 35.1 $\pm$ 12.7cm. Most (86.8%) of the devices were within the 'acceptable' distance (16 to 50cm) from the babies while only one (2.6%) device was within the 'recommended' distance ( $\leq$ 15cm) Table 1). The device at the 'recommended' distance delivered the highest irradiance value of 102 $\mu$ W/cm<sup>2</sup>/nm.

## DISCUSSION

The irradiance of over half of the PDs in Jos, Nigeria met the minimum recommended level ( $\geq 10\mu\text{W}/\text{cm}^2/\text{nm}$ ) by the American Academy of Paediatrics (AAP).<sup>8</sup> At this minimum level of irradiance, a 6-20% fall in serum bilirubin level can be achieved within a 24 hour period in the jaundiced neonates.<sup>15</sup> However, over 40% of the PDs in this study delivered suboptimal level of irradiance. This implies that, in full capacity use, two out of every five jaundiced neonates treated with these PDs may not be effectively treated. This is unacceptable because ineffective phototherapy prolongs morbidity, duration of hospital stay, increases the cost of treatment and may predispose to the development of acute bilirubin encephalopathy. The proportion of PDs with adequate irradiance in this study is higher than the 6%, 27.6% and 31% reported in previous studies in the Southern part of Nigeria and India.<sup>9-11</sup>

The reason for the higher proportion of PDs with adequate irradiance in this study could be partly due to

the differences in the types of the light sources of the PDs. Whereas 21% of the PDs in this study were light-emitting diode (LED), zero to one percent of the PDs in the previous studies were LED.<sup>9-11</sup> Light-emitting diodes light are known to provide greater irradiance than regular fluorescent tubes, (as was also demonstrated in this study) and the emitted irradiance also declines at a slower rate.<sup>16,17</sup>

The LED phototherapy are more effective because they provide light predominantly in the blue-green spectrum, the wavelengths at which light penetrates skin well and is absorbed maximally by bilirubin.<sup>18</sup> However, LED based phototherapy devices are expensive and may not be affordable to many low-income countries. Another reason for the higher proportion of PDs with adequate irradiance in this study could be as a result of the differences in the distance between the babies and phototherapy light sources. The distance between the babies and phototherapy bulbs (mean =  $35.1\pm 12.7\text{cm}$ ) in this study, though not at the recommended level, is shorter than the distance of 45cm and 45-60cm in the previous studies.<sup>9,11</sup>

**Table 2: Median irradiance of phototherapy devices and the relationship between the quality of irradiance versus types of health facilities and phototherapy devices.**

Irradiance measurement Parameters Median (IQR) ( $\mu\text{W}/\text{cm}^2/\text{nm}$ )		Kruskal-Wallis	P- value			
<b>Type of PD</b>						
Locally fabricated	10.4 (2-24)	11.76	0.003			
Conventional patented	4.0 (3-13)					
LED**	51.4 (7-102)					
ALL PDs	10.6 (6 - 18)					
<b>Quality of Irradiance</b>						
	<b>Adequate</b>	<b>Inadequate</b>	<b>Total</b>	$\chi^2$	<b>df</b>	<b>P-value</b>
	<b>Freq (%)</b>	<b>Freq (%)</b>				
<b>Type of PD</b>						
Locally fabricated	14(56.0)	11 (44.0)	25 (100.0)	6.40*	2	0.004
Conventional patented	1 (20.0)	4 (80.0)	5 (100.0)			
LED**	7 (87.5)	1 (12.5)	8 (100.0)			
Total	22(57.9)	16 (42.1)	38 (100.0)			
<b>Type of health facility</b>						
Private	17(63.0)	10 (37.0)	27 (100.0)	0.98*	0.323	
Public	5 (45.5)	6 (54.5)	11 (100.0)			
Total	22(57.9)	16 (42.1)	38 (100.0)			

Studies have shown that the closer the light is to the babies, the higher the irradiance delivered and the more effective is the phototherapy.<sup>8,19</sup> The AAP recommends that the light source should be placed at about a distance of 10-15cm or as close to the infant as possible provided the baby is not overheated.<sup>8</sup> This study found that the only device (LED) that was placed within the AAP recommended distance from the baby (15cm) had the

highest irradiance ( $102\mu\text{W}/\text{cm}^2/\text{nm}$ ), while the device that was placed at the 70cm distance delivered suboptimal irradiance ( $7\mu\text{W}/\text{cm}^2/\text{nm}$ ) despite being a LED device.

This study also showed that over half of the locally fabricated phototherapy devices (LFPDs) delivered adequate irradiance and the median irradiance for the LFPDs ( $10.4\mu\text{W}/\text{cm}^2/\text{nm}$ ) was higher than the values

( $1.9 \pm 1.1$ ,  $2.3 \pm 2.8$ , and  $2.87 \mu\text{W}/\text{cm}^2/\text{nm}$ ) reported for LFPDs in previous studies in Nigeria and Cameroon.<sup>9,10,12</sup>

The reason for this observation could be probably due to the fact that some of the LFPDs in this study had reflectors (white lining) and all have blue fluorescent tubes unlike in the studies conducted in Southern Nigeria and Cameroon.<sup>9-12</sup> The presence of reflectors has been shown to enhance irradiance delivery.<sup>20</sup> Likewise, blue bulbs emit higher irradiance than white light.<sup>18</sup> This study also found that the LFPDs delivered higher median irradiance ( $10.4 \mu\text{W}/\text{cm}^2/\text{nm}$ ) than the conventional patented PDs ( $4.0 \mu\text{W}/\text{cm}^2/\text{nm}$ ) despite that both device types utilised regular blue fluorescent tubes. Most (4 out of 5) of the conventional patented devices had suboptimal irradiance and this was probably due to poor knowledge of use and maintenance. Most of the conventional patented PDs were positioned at an excessive distance from the patients in spite of the fact that they have adjustable stands. Some of the devices were not well aligned (Figure 1a) to ensure that the illumination is centred on the patient; and the plastic screens encasing the bulbs were dusty in most of them. Some of the bulbs have not been replaced since the PDs were acquired due to unavailability of appropriate replacement bulbs. These findings underscore the need for adequate knowledge on the utilisation and maintenance of PDs so as to ensure adequate irradiance delivery. Addressing some of these commonly encountered poor knowledge and maintenance problems in resource constrained countries has been reported to improve irradiance of phototherapy devices.<sup>10</sup> Locally fabricated devices with adjustments that could enhance the level of irradiance delivery could be a better option than conventional patented PDs in resource constrained settings when purchase of LED phototherapy is not feasible. The parts of these LFPDs are readily available in most low-middle income countries.

Our study also revealed that the proportion of phototherapy devices with inadequate irradiance were more in the public facilities than the private facilities. This could be due to more funding and better management in the private hospitals than the public hospitals. The private hospitals are run as profit making ventures, unlike the public hospitals which are largely humanitarian. The private hospitals seem to offer better quality of services than government hospitals, however, for higher fees.

## CONCLUSION

A significant proportion of the PDs in Jos delivered a suboptimal irradiance which could reduce the effectiveness of the phototherapy thereby resulting in increased incidence of complications of neonatal jaundice, prolonged hospitalisation and increased cost of treatment. The irradiance of PDs needs to be assessed regularly and measures should be instituted to improve the irradiance to the acceptable level and possibly to the

intensive range. This will help to reduce the burden of kernicterus.

Measurement of irradiance alone may not completely determine the effectiveness of phototherapy as adequate irradiance may be generated but not delivered appropriately. Other determinants of effectiveness of phototherapy include the area of skin exposed, the amount of time the skin is exposed, and the bilirubin concentration in the tissues. A complete evaluation of effectiveness of phototherapy device therefore would involve measurements of the reduction of plasma bilirubin levels or duration of phototherapy with jaundiced newborns under carefully defined conditions. However, this study provides information on irradiance which is one of the key parameters that determines efficacy of PDs.

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