A new solar-powered device for the treatment of neonatal hyperbilirubinemia in hardest-to-reach places tested in Nigeria

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ABSTRACT

Background Information: The treatment of hyper bilirubinaemia in faraway remote locations of the world, where grid electricity and specialist doctors are unavailable, is hampered by a lack of appropriate technologies that could be operable by basic-trained healthcare workers. Hence the urgent need for the development of simplified low-cost medical devices that could be deployable to the hardest-to-reach remote locations of the world.

Methods: Low-cost stable elements, components, and workpieces were targeted and applied in design to develop an applicable intensive phototherapy machine. Materials were sourced from in-country local markets to prototype the resultant device for capacity tests, and technical and safety assessments. The device was crafted to be solely solar energy dependent for power sustainability and climate-change mitigation in remote locations prior to ethical-approval and commencement of clinical trialling at University of Calabar Teaching Hospital Nigeria, to determine its efficiency in rapid breakdown of ‘severe’ serum bilirubin to a ‘mild’ benchmark level.

Result: The new device passed all technical safety assessments, delivering a total body irradiation treatment capacity of 45—158 μW/cm^2/nm with 460 nm light wavelengths across various aspects of the body of a neonate. The device utilises real-time solar-power whilst self-banking its private reserve energy, which could last for over 27 hours when no-real-time energy from the sun is available. All initial eleven patients enrolled during the first 3-months of trialling were safely and successfully treated within 17.8 ± 8.7 irradiation-hours with stable vital-signs and no injuries.

Conclusion: The new device is a potentially sustainable LMIC-solution for severe jaundice management.

Keywords: LMIC, severe jaundice, hyperbilirubinemia, exchange blood transfusion, neonate, climate change

Summary Box

This work findings are:

1. high intensity total-body-irradiation of up to 156 μw/cm^2/nm using 460nm light wavelength can safely treat severe neonatal jaundice without the need for exchange blood transfusion
2. generic locally-available solar panels and lead-acid batteries can be compatibly used to create 24/7 sustainable phototherapy power
3. the new device ideally reduced the need for up to 3 experts per treatment to zero
4. reduced treatment cost by >90% and hospitalisation from average 7 days to 18 hours
5. device will enhance future healthcare empowerment of basic rural health workers in treating severe jaundice at remote places—without experts and power infrastructure

1. Introduction

The low and middle-income countries (LMICs) of the world have remained the most vulnerable nations in GlobalHealth struggles to end high neonatal mortality rate globally. The often-sophisticated technologies deployed in the developed countries for the treatment of high-risk neonatal conditions are not sustainable in the LMICs, hence, the inability of these countries to eliminate preventable neonatal deaths in their countries [1]. It is the agenda of the United Nations to end high neonatal mortality across all regions of the world, yet most efforts at LMICs are concentrated in their big cities. However, it has been argued that a move towards “taking neonatal special care closer to the needy neonates in the faraway hinterlands”, where most of them are, would save many lives and drastically reduce corporate LMIC neonatal mortality rate [2]. Furthermore, many peculiar factors of expertise, technologies, and power supply continue to limit all LMICs’ efforts towards achieving this goal. It may remain impossible to “take neonatology to the hinterlands” without a deliberate effort to clearly isolate these LMIC factors and proffer their respective sustainable solutions. Previous research publications have tried to numerate some of these factors, such as:

(a) Lack of low-cost LMIC-specific technologies [1].
(b) Lack of adequately trained manpower as required for the specialist clinical and nursing needs in supporting remote regions of LMICs [3, 4].
(c) Lack of LMIC adequate grid power supply and road infrastructure for operating neonatal life-support devices and movement of non-resident healthcare workers to the remote locations, respectively [3, 5].
(d) The legitimate climate-change campaign to minimise total reliance on fossil fuel power generator.
(e) etc

Deliberate and carefully developed technologies—specifically tailored towards “taking neonatology to the LMIC hinterlands”, could possibly jumpstart benefits, including

minimisation of carbon pollution. It is well-known that Nigeria failed to achieve significant sustainable progress of the millennium development goal target (no.4) [6, 7]. Therefore, the development of simplified, green-powered low-cost technologies, implementable by indigenous rural healthcare providers, will both improve neonatal survival and save the planet. Neonatal hyperbilirubinemia (NHB) is one of the untreatable conditions in a typical LMIC-hinterland settlement. In specific terms, the treatment of NHB in remote places is limited by the high-cost burden of acquisition of sufficient standard medical equipment to accommodate most segments of the countries coupled with massive shortage or outright absence of specialist medical manpower in various regions of the LMICs—to carry out risky surgical procedures. In addition, the near absence of reliable road and power infrastructure hinder the broader implementation of effective notable solutions.

NHB is common in LMICs with high incidence in Nigeria [8, 9]. Standard interventions apply high carbon-footprint procedures—transport to city-based hospitals, average 7-days hospitalisation, and multiple surgically-skilled manpower. NHB is diagnosed when pathologic jaundice in the newborn is categorised as 'severe' at total serum bilirubin (TSB) levels >12 mg/dL (204 µmol/L) or 15 mg/dL as standards elsewhere [10]. The American Academy of Pediatrics (AAP) recommends TSB of 17–18 mg/dL as normal in term healthy newborns [11], however, in Nigeria, this level is regarded as dangerously high in pathologic situations—requiring the extreme 'gold-standard' treatment of 'exchange blood transfusion (EBT)'. Poorly treated NHB can lead to kernicterus spectrum disorder (KSD) and brain damage manifesting soon after the neonatal age [12]. EBT procedure is surgically invasive, expensive, and requires the expertise of highly skilled neonatologists or paediatric surgeons—unavailable requirements in typical rural areas of LMICs.

'Neonatology in the hinterland' for NHB may succeed if non-invasive sustainable alternative interventions for rapid breakdown of high TSB levels are developed and deployed—techniques, adequately accompanied by uncomplicated guidelines, easily operable by basic-trained healthcare attendants in rural areas. Total body irradiation (TBI) therapy, as applied in MTTS Asia's Firefly® device, is an intensive phototherapy treatment that has been previously deployed in some LMICs [13]. The technique is efficacious, safe, and relatively costs a fraction when compared to the invasive EBT/conventional-phototherapy treatment [14]. However, Firefly usage is subject to relatively unaffordable off-the-shelf device costs (US$3,200 equivalent in Nigeria) and electric power availability. Our study aim was to test a developed 'polite-ultralumen' intensive phototherapy device for NHB intervention in hardest-to-reach locations of the LMICs and to preliminarily assess this using the first n>10 patients treated.

2. Materials and Methods

2.1. *Initial considerations*

The concept of the new design was set to be driven by the well-known poor knowledge levels, financial, and infrastructural capacities of a typical rural community of an LMIC. The device was elected to operate through a low power and low-voltage supply.

The design targeted to eliminate the high carbon-footprint of conventional NHB treatment and account for treatment limiting factors at rural locations such as:

a. Diagnostic capabilities, before and during treatment
b. Sustainable power supply
c. Operational light rays for achieving the required high intensity of patient-irradiation
d. Simplified operational procedures
e. Maintainability by local LMIC technicians
f. Patient safety—including eye, couch, electrical and thermal safety
g. Overall device affordability, etc

The choice of manufacturing materials was driven by product cost-lowering via locally available and environmentally stable materials within the LMICs' open markets. The rest of components were competitively sourced as generic online versions. All materials were selected, designed, or remanufactured to achieve the considered product capabilities.

2.2. Basic system capacity and capabilities

The fundamental constraint determining the essential features of the new design was that the system could function in isolated far-removed locations of the world. Therefore, this must possess the basic capabilities of supporting the applicable diagnostic-estimation instruments which would accompany its use, adequate capacity for self-power-generation and storage, and production of high quality of intensive phototherapy irradiation for rapid breakdown of total serum bilirubin (TSB) in NHB.

Therefore, the light sources were designed to irradiate neonate's total body from top and bottom aspects (Figure 1A). A totally blindfolding eye-patch was produced out of thick cotton material for the protection of neonate's inner eye structures. The total irradiation summation at the level of the infant's bassinette was aimed to achieve >100 $\mu W/cm^2/nm$ targeted at the blood vessels around the trunk zone of the neonate. The strength of irradiation was aimed to reduce cranially and caudally away from the trunk, and laterally, sideways (Figure 1D). This was achieved by the positioning of four sets of a gang of thirty-two pieces, 460 nm wavelength light-emitting-diodes (LEDs) per set—each LED-gang requiring 6–7 watts of energy to deliver its full irradiation strength. Hence, both two light sources characteristically require up to 56 watts of energy for full irradiation intensity, plus losses.

LED-light gang: each = 12vdc,~7watts
Lamp assembly: 4 gangs, parallel wiring, rating = 12vdc,~28watts
Device lamps: two assemblies, parallel wiring, total rating = 12vdc,~56watts

2.3. The bassinette

The design of baby couch (bassinette) considered the need for a robust space to accommodate high incidences of big neonates presenting neonatal jaundice in the Nigerian population. The bassinette was a 'wind-gust' controlled vessel, designed and manufactured out of a high quality clear (transparent) acrylic Perspex, with deep protective four sides. The height of bassinette bottom from the lower-light source was set by the width of its two stands (Figure 1C). The bassinette incorporates a removeable airbag, for use when neonate requires a softer surface. The use of the airbag would increase the gap between the base-lamp and baby's dorsal margin, hence, could desirably reduce baby's contact temperature, but lower the resultant total irradiation.

2.4. Operating power

As a climate-action design, the product is solely solar-powered for its operations during the day or night. Therefore, the power assembly comprised of a roof-mounted parallel interconnections of two photovoltaic solar panels, each rated 12v 100w, generating up to 20 volts of terminal voltage during high sunlight intensity. This delivers up to 10 Amps of charging current during peak sunshine over the panels, and post-rectified to a steady direct current (dc) of 'no-load' terminal voltage of 13.5 volts. The steady supply was utilised in three ways by design: (a) energizing the LED-gangs in real-time to produce rays of 460 nm light wavelength (b) delivering external terminal of 12vdc, 2.5 amps current for operating suitably rated hand-held transcutaneous bilirubinometer, and (c) simultaneous recharging of its inbuilt battery storage—capacity, 100 ampere-hour (AH), which it automatically reverts to when the sunlight supplies from the solar panels become unavailable, especially after sunset.

The low-power consumption rate, by design, can allow up to 27 hours of device's full irradiation before automatic low-battery warning and eventual safe shutdown of the device (Figure 1B). This capability would enable the system to run uninterrupted throughout the day or night periods in Nigeria.

2.5. Patient diagnostics

The diagnoses and determination of neonate's TSB levels—prior and during treatment—would represent a challenge for NHB treatment in hardest-to-reach LMIC hinterlands since such remote locations would not provide medical laboratories for blood sample investigations. Therefore, hand-held, non-invasive transcutaneous bilirubinometer (TcB) device such as the BM-100A/100C Transcutaneous Jaundice Detector (David Medicals, Ningbo, Zhejiang Province, China) was selected as accompanying 'diagnostic-estimation' device—similar devices have been shown to produce clinically acceptable estimations [15—17]. Therefore, the power-chamber encapsulation of the new device was designed to feature the external connection interface (section 2.4) for powering and recharging of the accompanying TcB device, thereby eliminating the challenges of frequent search for reliable replacement batteries in such rural place.

2.6. Clinical trialling:

The manufactured prototype, as presented at the Neonatal Special Care Unit, University of Calabar Teaching Hospital (UCTH), was subjected to preliminary assessments for physical safety and functional appearance—judged by seven senior consultants. The device received >90% aggregate trialability score after independent assessments (range: 90%—98%). Therefore, the system was unanimously accepted for clinical trialling, following approval (UCTH/HREC/008/105) from the Research Ethics Committee of UCTH.

Inclusion/exclusion recruitment criteria: The trial protocol includes (i) Patient recruitment via carers' signed consent forms prior to treatment, without which a patient is excluded from treatment. (ii) Every neonate with pathologic bilirubin levels within the 'moderate' (>12 mg/dL) and 'severe' (>15 mg/dL) classifications could potentially be recruited. (iii) Patients whose point-of-admission (initial) laboratory tests returned a TSB value <12 mg/dL were discontinued and excluded. (iv) Patients with confirmed simultaneous presence of sepsis were disqualified and excluded.

Treatment protocol: The overall treatment assessment was carefully designed to align with the protocols of a previous multicentre comparative analyses jaundice study in which the UCTH neonatal Unit was a contributor, where the performances of the regular 'conventional overhead phototherapy/EBT' technique was assessed against the Firefly® total-body-irradiation technique [13]. This was to make it possible to directly compared the results from the new device against those of the regular EBT/conventional-phototherapy techniques as previously multi-studied across many Nigerian Centres [13]. Treatments were scheduled in a serially pre-numbered booklet for patient data collection to enhance accountability of all patients who would pass through the device.

Reduction rate of patient's TSB was monitored half-hourly. However, it was not possible to work in real-time with standard laboratory blood test results during the required half-hourly TSB measurement. Practice reality in Nigeria is that laboratory results may take days to arrive or may never arrive before patient's treatment is over. Therefore, "diagnostic approximations" using calibratable TcB device and visual skin examination is presently the most sustainable, real-time operational option. Standard laboratory blood test for TSB remained the only gold standard for confirmation/correction of TcB-approximations, particularly for the mandatory two blood samples collected—before treatment commencement and end of treatment. Therefore, for every patient case, initial (pre-treatment) TcB reading was recorded, and at the same time, blood sample was collected and sent off to the laboratory for the quantification of the initial (diagnoses) TSB. The laboratory result, upon arrival—often much later—was applied to adjust for a patient-specific recalibration of the TcB device and correction of all prior captured readings. This was necessary as the TcB readings could only be acceptable as 'approximations' until a real laboratory value was obtained and used to recalibrate the device for the specific patient, and particularly for clinical confirmation of before- and after-treatment TSB values.

Each patient's transcutaneous bilirubin level was collected half-hourly using the TcB device. At the same time, vital-signs were re-checked, and full bodily examination repeated and documented. Both the initial and final TSB was confirmed with laboratory-

assessed blood samples. Treatment was stopped after TcB reading becomes ≤11.5 mg/dL in any patient. All other standard protocols for UCTH-management of severe jaundice were strictly kept unaltered. Healthcare assistants as would be typically found in standard Nigeria's rural primary health centres were recruited for monitoring and data collection.

3. Results

The device prototyping was completed in two different attempts. The testing, adjustments, and re-testing processes yielded the satisfactory final model which maintained its thermal and functional stability throughout three independent sessions of a set 72 hours of continuously monitored operation.

The device achieved its 'operational simplification' requirement since this presents only one operational key—to switch ON/OFF—and to plug-in the TcB device for recharging. Typical rural health attendants were easily educated on indicative TcB reading for intervention and TcB reading for end of irradiation.

3.1. Power generation and irradiation output

The accompanying panels converted solar energy at currents up to 10.6 Amps at peak sunshine. During the set 72 hours of continuous function test, the solar-power generation and rectification assemblies delivered a steady dc load-terminal voltage of 13.1 ± 0.4 volts between sunrise and sunset throughout the three days. However, this dropped to average 12.7 ± 0.3 between sunset and sunrise. The top- and base-lamps delivered irradiation at full strength throughout the testing period—without fluctuations of values monitored at the trunk, crania/caudal, and lateral approximate locations as shown in Figure 1D. The device successfully utilised the solar energy in real-time to operate during the sunshine times, whilst utilising an average of 2.85 hours of peak sunshine to recharge its battery fully to ≥13.0v.

The irradiation profile of the device at bassinette platform level (30 cm from top-lamp and 5 cm from base-lamp), is plotted in Figure 1D. The maximum bassinette-baby dorsal contact temperature was 37.6°.

3.2. Initial clinical results

The first 12 patients to serially go on the device were seen between February—April 2024, having preadmission data ranges as follows: birthweight (1.9—4.3) kg, gestational age (35—41) weeks, initial TSB (12.5—25.4) mg/dL. The serial number 2 patient was eliminated for failing in one of the set criteria (Table 1). All eleven patients were successfully treated and discharged within 18±9 hours of irradiation with no associated vital-signs anomalies or bodily harm.

Throughout the initial three months of trialling the device power generation did not diminish, and storage or operational power meter reported functional voltage ranging between 13.2 volts (full charge – mainly during intense sunshine periods) and 11.6 volts

(86% charge – just before sunrise succeeding a predominantly cloudy day and all-night duty). The system generated above its minimum irradiation expectancy capacity of 100 μW/cm^2/nm throughout, including the times of its lowest (86%) operational power capacity.

Table 1: Patient pre-treatment data and preliminary overall success (bilirubin level reduction) rate

Patient No.	BW (kg)	GA (weeks)	Initial TSB (mg/dL)	Moved out TSB (mg/dL)	TSB drop (%)	Treatment Duration (hr)	Treatment speed (mg/dL/hr)	**Overall Outcome**
p001	3.1	38	15.8	11.5	27	16.83	0.26	**successful**
p002			ELIMINATED					
p003	3.1	35	18.5	11.3	39	25.5	0.28	**successful**
p004	3.3	40	25.4	11	57	14	1.03	**successful**
p005	2.8	40	22.2	11.6	48	28	0.38	**successful**
p001	na	39	14.2	11.3	20	20.5	0.14	**successful**
p007	4	41	17.6	11.2	36	35.5	0.18	**successful**
p008	na	40	15.3	9.9	35	13	0.42	**successful**
p009	4.3	38	12.5	10.6	15	9.5	0.20	**successful**
p010	1.9	36	13.1	10.9	17	8.5	0.26	**successful**
p011	3.6	38	12.7	9.3	27	9	0.38	**successful**
p012	3.3	39	16.1	10.7	34	15	0.36	**successful**
AVERAGE	3.3	38.5	16.7	10.8	32	17.8	0.35	
SD	0.7	1.8	4.1	0.7	13	8.7	0.24	
RANGE	1.9—4.3	35—41	12.5—25.4	9.3—11.6	13—57	8.5—35.5	0.14—1.03	

4. Discussion

This early report has showcased another potential step towards the successful empowerment of neonatal care at the hardest-to-reach locations of the LMICs, using Nigerian challenges as a case study. The potential conquest of NHB with near-zero carbon-footprint of this new device is a radical climate-action cum healthcare step ushering in a new era of hinterland's medical empowerment. In previous studies, a few crucial LMIC-tailored technologies have been published [18]—including support technologies for neonatal thermoneutral and respiratory needs, environmental and facility lighting, climate-resilient nursery, uninterrupted power supply, etc.

In the present design, the safety of the patient against potential skin-burns, eye-damage, and couch confinement failure were meticulously processed leading to several repetitions until the optimally functional version of the system was achieved. The system's high irradiation power around the neonate's trunk region could potentially lead to rapid build-up of heat within the bassinette, hence, necessitating the unique bassinette design—encouraging adequate air circulation.

The new device has demonstrated impeccable self-power generation and resilience,

having enough to operate during the day and night without failure throughout the first 3-months of trial. The 100% success rate of the first 11 treated patients is a remarkable promise for empowering rural health centres across LMICs, where public power utility infrastructure and paediatrics expertise are completely unavailable. In the context of the Nigerian standards, these patients were designating for the invasive exchange-blood-transfusion, which is climate-unfriendly, high-risk, and financially expensive to carry out, with extended days of hospitalisation. The potential ability to treat such patients right in the rural villages with this product will not only save lives and costs but will also save the climate from the high carbon footprints in neonate/carers travels to big city hospitals, their often-unaffordable city living costs during hospitalisation, and electric power guzzling in running the conventional treatment devices such as regular phototherapy machines. In a previous economic comparative study to determine the cost advantage of the use of total-body-irradiation (TBI) phototherapy—with the Firefly device, it was shown that the average treatment cost fell from an equivalent US$262 (EBT/conventional) to only US$52 (TBI)—being a reduction of 80% in treatment cost [14]. In the present new device, TBI intervention cost has further lowered by the elimination of electricity operational cost and average hospitalisation duration from 7 days (EBT/conventional) and 2±0.4 days (firefly TBI) to the new device's <1 day [13].

Comparative Cost Assessment. A typical Nigerian rural family dweller such as in Niger, Borno, or Taraba States etc, could be well over 150 kilometres away from the nearest city tertiary hospital where conventional intervention with regular phototherapy and EBT could be provided. The new device in a rural community primary-health-centre (PHC) does not require patients travelling to the faraway urban cities. Based on previous study [14], the EBT/conventional treatment cost of such a family could be (US$262 plus transport costs and 7 days of city-living expenses)—totally a possible equivalent of US$352 (about ₦598,000). In addition, the cost on the climate could include: (i) the vehicular carbon release of over four hours on return-trip (ii) carbon release on the commuting of the specialist doctors and nurses who carry out this treatment in the referral facility (iii) carbon release on average seven days power generators for operating conventional treatment devices, etc. However, none of these climate carbon-release costs is associated with the services of the new device as both the patient's family and the PHC health attendants are often local and would normally access the facility by walking a trekkable distance. Therefore, the comparative treatment costs on the family with the new device is only equipment maintenance/lifetime cost recovery, quantified at US$3/patient—based on over 50,000 life-hours of the treatment light source, which translates to <US$0.1/treatment-hour, and accounting for average 18 hours of treatment/patient and patient's share of PHC administrative cost—the primary equipment production/installation cost being US$3,900. This implies that the use of the current new device has comparatively lowered treatment cost by well over 98%—from ₦598,000/patient to <₦8,000—and generates no baggage of carbon emission to the environment.

Limitations and further studies

This trialling could have been of more benefit and educative as a multicentre assessment—involving up to three independent Nigerian tertiary hospitals. This was not possible because lack of sufficient funding at the trialling commencement did not allow

the manufacturing of more than one unit of the prototype. However, based on sub-climatic regions, five strategically located Nigerian tertiary hospitals have issued local ethical clearances and copies of the new device have been manufactured and installed at the SCBUs of the Federal Medical Centre (FMC) Asaba, Federal Teaching Hospital Lokoja, Federal Medical centre Keffi, the Amina neonatal Centre Minna, and Federal Teaching Hospital Yola (yet to be installed)—all in readiness for a national coverage independent assessment study to test the repeatability of the results from UCTH Calabar. These are planned to test the effectiveness, resilience, and efficiency of the device across the Nigerian sub-climates, with FMC Asaba carrying out additional randomised controlled comparative study of efficiency and cost effectiveness against other devices such as the MTTS-Firefly.

Lack of adequate funding limited the implementation of more than two laboratory blood sampling per patient during this study, for better validation of the half-hourly transcutaneous measurements. Poor funding also delayed the installation of some meteorological equipment for further understanding of the system's functional characteristics with changing weather situations. However, these are planned to be accomplished in subsequent studies.

Initial installation, later dismantling, or safe relocation of the new device requires knowledgeable local technical assistance to be caried out appropriately as the system incorporates solar hardware meant for outdoor permanent fixation. Hence, the system is not designed to be as mobile as being moved around the various rooms of a facility building away from its original installation space. These limit the device to be classified as 'portable'. However, once installed, lifelong operation is highly simplified and only down to flicking one ON/OFF button.

The study is continuing with research investigation of the device's technical stability, patient safety, and interventional efficacy with patient follow-up, which are scheduled in the trialling protocol for up to 50 participants. This will form the subject of further research report.

Conclusion

This research was set to confront two major global concerns (i) reduction of healthcare carbon release to mitigate climate change, and (ii) neonatal healthcare empowerment of hardest-to-reach places of the LMICs where the absence of specialist doctors and public power and road infrastructures would normally limit the survival of neonates against severe jaundice. The device so-developed has demonstrated high efficiency in its inbuilt features and excellent effectiveness in patient safety and degradation of serum bilirubin with 100% success rate over the first 11 jaundiced neonates treated. The new device has lowered the average treatment factors compared against the regular standard approach as follows: hospitalisation – 7 days to 18 hours; family cost – US$352 to US$3; senior medical manpower – three to zero; climate carbon cost – high to zero. This technique is promising the potentials for LMIC unhindered access to efficient intervention and drastic reduction of morbidity and mortality owing to severe neonatal jaundice.

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Statements

a. Contributorship of authors

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c. Competing interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Ethics statement

This clinical trial and the protocol thereof were assessed and approved by The Health Research Ethics Committee (HREC) of The University of Calabar Teaching Hospital Nigeria. Date: 16th February 2024, Approval Ref: UCTH/HREC/008/105, HREC Protocol number: UCTH/HREC/33/Vol.III/228, UCTH NHREC Reg. Number: NHREC/07/10/2012

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Legend

Figure 1: Diagrammatic representation of the new device

(A) lamp assembly (B) power-cabinet & solar wiring assembly (C) neonate bassinette (D) total irradiation output. Solar panels were commercial generic standard sourced from local market; the lamps were constructed out of internet-sourced generic chip-on-board (COB) light-emitting-diodes (LED) in series connection to yield 12v & ~7w rating and expected life of >50,000hrs; power storage was local market-sourced generic lead-acid 100AH car battery; overcharge protection was achieved via internet-sourced generic 12vdc MPPT charge controller while low-battery protection was constructed out of a modulated circuit 11v cutoff relay switch. TcB—supply to transcutaneous bilirubinometer charger unit, Lamp—supply to the LED lamp assemblies