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Solar-Powered Led Phototherapy for Neonatal Jaundice in Resource-Limited Settings: A Comprehensive Review

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ABSTRACT

Neonatal jaundice remains a major cause of preventable morbidity and mortality in low- and middle-income countries (LMICs). This review evaluates solar-powered LED phototherapy as a sustainable and cost-effective intervention for managing unconjugated hyperbilirubinemia in neonates. A comprehensive literature review of studies published between 2000 and 2026 was conducted using databases such as PubMed, Scopus, Google Scholar, AJOL, and medRxiv. Data were synthesized using a thematic and narrative approach. Findings indicate that solar-powered LED phototherapy systems can achieve therapeutic irradiance levels of 45–80 μW/cm²/nm with extended battery autonomy and stable thermal regulation. These systems significantly reduce dependence on unreliable electricity, lower operational costs, and improve accessibility in rural settings. Evidence from Nigerian studies demonstrates their feasibility, safety, and effectiveness. Solar-powered phototherapy presents a viable solution for improving neonatal outcomes in resource-limited settings, with recommendations for large-scale implementation and policy integration.

1. INTRODUCTION

Neonatal jaundice is defined as the yellow discoloration of the skin and sclera resulting from elevated bilirubin levels due to red blood cell breakdown and immature liver function [1]. Bilirubin is a lipid-soluble pigment that undergoes hepatic conjugation for excretion; however, in neonates, this process is often immature, leading to unconjugated hyperbilirubinemia [2]. Physiological jaundice affects approximately 60% of term and up to 80% of preterm neonates within the first week of life [3]. Severe cases may progress to acute bilirubin encephalopathy or kernicterus, resulting in permanent neurological damage or death [4]. Globally, neonatal jaundice remains a significant health burden, particularly in LMICs. Studies estimate millions of cases annually, with a disproportionate number occurring in developing regions [5]. In Nigeria, neonatal jaundice contributes significantly to neonatal mortality rates [6]. Phototherapy is the standard treatment for neonatal jaundice, utilizing light in the blue-green spectrum (400–520 nm) to convert bilirubin into water-soluble forms for excretion [7]. However, conventional phototherapy systems are limited in low-resource settings due to high costs, maintenance challenges, and unreliable electricity supply [4]. Solar-powered LED phototherapy has emerged as a promising alternative, offering energy independence, affordability, and accessibility in rural healthcare settings. This review examines the underlying mechanisms of neonatal jaundice, principles of phototherapy, and the effectiveness of solar-powered systems.

2. MATERIALS AND METHOD

2.1. Analytical and statistical procedure

This study employed a comprehensive literature review methodology. Relevant data were collected from peer-reviewed articles, clinical trials, technical reports, and preprints published between 2010 and 2026. Databases searched included PubMed, Scopus, Google Scholar, AJOL, and medRxiv.

Inclusion criteria:

i. Studies on neonatal jaundice and phototherapy
ii. Research on LED and solar-powered phototherapy systems
iii. Clinical and implementation studies in LMICs

Data were analyzed using thematic and narrative synthesis focusing on:

i. Pathophysiology of neonatal jaundice
ii. Mechanisms and effectiveness of phototherapy
iii. Limitations of conventional systems
iv. Design and performance of solar-powered phototherapy

2.2. Sub Procedure

Previously published methodologies on neonatal phototherapy and bilirubin metabolism were reviewed and adapted. Emphasis was placed on comparing conventional phototherapy systems with emerging solar-powered technologies in terms of efficiency, safety, cost, and accessibility.

3. RESULTS AND DISCUSSION

3.1. Finding of research

Neonatal jaundice resulted primarily from the accumulation of unconjugated bilirubin due to increased red blood cell turnover and immature hepatic metabolic pathways in newborns [9]. Clinically, jaundice became apparent when serum bilirubin levels exceeded approximately 3 mg/dL [10]. Although often physiological and self-limiting, severe hyperbilirubinemia progressed to life-threatening complications such as acute bilirubin encephalopathy and kernicterus when left untreated [4]. Several risk factors were identified, including prematurity, infections, hemolytic disorders, and genetic predispositions [5]. These findings were consistent with earlier epidemiological studies, which highlighted the disproportionate burden of severe neonatal jaundice in low- and middle-income countries due to delayed diagnosis and limited access to effective treatment.

Phototherapy remained the cornerstone of treatment and functioned through three major photochemical mechanisms: configurational isomerization, structural isomerization, and photo-oxidation. Among these, structural isomerization resulted in the formation of lumirubin which was identified as the most clinically significant pathway because it produced a water-soluble compound that was rapidly and irreversibly excreted without requiring hepatic conjugation [8]. This observation aligned with previous studies, which emphasized that lumirubin formation contributed most significantly to the reduction of bilirubin levels during phototherapy. However, the efficiency of this process depended on several physical parameters, including the wavelength of light, irradiance intensity, distance from the neonate, and the extent of exposed body surface area [11].

Optimal phototherapy performance was achieved within the wavelength range of 460–490 nm, corresponding to the peak absorption spectrum of bilirubin [7]. Comparative studies showed that LED phototherapy systems outperformed conventional fluorescent and halogen devices in delivering this optimal spectrum. LEDs provided higher irradiance, reduced energy consumption, minimal heat production, and longer operational lifespan [12]. In contrast, fluorescent and halogen systems as shown in Plate 1 exhibited spectral inefficiency, higher thermal output, and faster degradation over time, which reduced treatment effectiveness and increased the risk of adverse effects.

Solar-powered LED phototherapy systems as shown in Plate 2 further enhanced these advantages by addressing the challenge of unreliable electricity supply. Evidence from implementation studies demonstrated that these systems maintained therapeutic irradiance levels between 45–80 μW/cm²/nm, provided extended battery backup, and ensured stable thermal conditions without causing hyperthermia [13]. Compared to conventional systems, solar-powered devices significantly reduced operational costs and eliminated dependence on grid electricity, making them particularly suitable for rural and resource-limited settings.

Findings from studies conducted in Nigeria showed that solar-powered phototherapy systems were effective, safe, and feasible for decentralized neonatal care [14]. These studies reported comparable clinical outcomes to standard phototherapy, including effective bilirubin reduction and improved treatment accessibility in underserved communities. Similar findings were observed in studies on filtered sunlight phototherapy, which demonstrated that alternative energy-based approaches could achieve non-inferior clinical outcomes when properly implemented and monitored.

From a critical perspective, this review indicated that solar-powered LED phototherapy represented a practical and scalable solution for neonatal jaundice management in resource-limited settings. However, despite the promising results, several limitations remained. Most studies were limited in scale, and long-term clinical outcomes, particularly neurodevelopmental effects, were not extensively evaluated. In addition, there was a need for standardization of device performance, irradiance monitoring, and clinical protocols to ensure consistent treatment quality.

The findings suggested that solar-powered phototherapy was not merely an alternative but a necessary advancement in neonatal care for regions with unstable infrastructure. The technology effectively addressed key barriers such as power instability, high operational costs, and limited accessibility. Nevertheless, successful large-scale implementation would require integration into national healthcare policies, adequate training of healthcare personnel, and continuous clinical evaluation to ensure optimal outcomes.

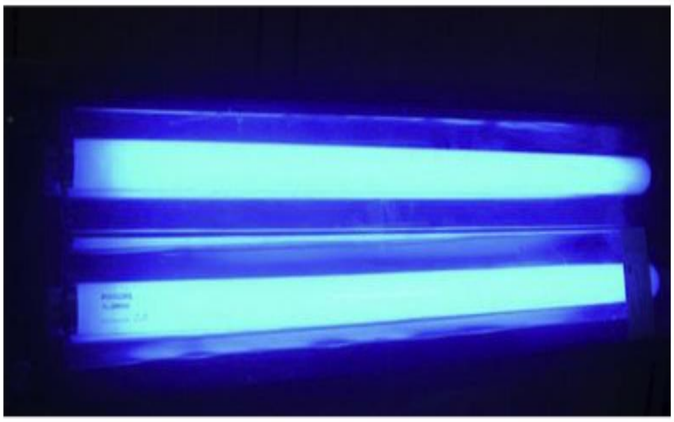

Plate 1: Phototherapy lamp with reflectors [14].

Plate 2: Solar-Powered Phototherapy Systems [15]

Table 1. *Comparison of Phototherapy Technologies*

Parameter	Fluorescent	Halogen	LED	Solar LED
Energy Consumption	High	High	Low	Very Low
Heat Production	Moderate	High	Minimal	Minimal
Lifespan	Short	Short	Long	Long
Cost Efficiency	Low	Moderate	High	Very High
Suitability (Rural)	Poor	Poor	Moderate	Excellent

4. CONCLUSION

Solar-powered LED phototherapy was identified as a sustainable and effective solution for managing neonatal jaundice in resource-limited settings. It addressed major challenges associated with conventional systems, including unreliable electricity, high operational costs, and limited accessibility. The technology demonstrated strong clinical effectiveness, safety, and affordability, making it suitable for widespread adoption in rural and off-grid healthcare facilities. Its implementation had the potential to significantly reduce neonatal morbidity and mortality. Future work should focus on large-scale clinical trials, long-term outcome evaluation, policy integration, and capacity building to ensure effective deployment.

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Conflict of Interest Declaration

The authors declare no conflict of interest.

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