



The Integration of Renewable Power Technologies in Nursing, Midwifery, Medicine, Pharmacy, Mental Health, and Informatics Healthcare in Saudi Arabia: A Review of Applications and Challenges

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Abstract

The integration of renewable power technologies in healthcare settings has become an essential strategy to meet energy demands, particularly in regions with limited access to reliable electricity. This review examines the applications and challenges of adopting renewable energy systems—such as solar, wind, and hybrid power technologies in nursing, midwifery, medicine, pharmacy, mental health, informatics and broader healthcare services in Saudi Arabia. Through an analysis of existing literature and case studies, this study explores how renewable energy enhances the reliability and sustainability of healthcare operations, especially in remote or off-



grid areas. Key applications include powering healthcare facilities, ensuring the continuous operation of critical medical equipment, and supporting pharmaceutical storage, digital health services, and mental healthcare infrastructure. Despite these benefits, challenges such as high initial investment costs, technological constraints, and the need for specialized expertise hinder widespread adoption. The review also highlights the role of policy frameworks, government initiatives, and strategic partnerships in overcoming these barriers and accelerating the transition to renewable-powered healthcare systems. Ultimately, integrating renewable energy solutions offers a promising pathway to enhancing healthcare delivery, reducing operational costs, and advancing Saudi Arabia's sustainability and energy diversification goals.

Keywords: Renewable energy, healthcare facilities, Saudi Arabia, solar power, hybrid energy systems, wind energy, energy sustainability, nursing, healthcare infrastructure, systematic review

1. Introduction

The integration of renewable energy technologies into healthcare systems represents a transformative approach to ensuring sustainable energy access, reducing operational costs, and promoting environmental responsibility. In Saudi Arabia—where solar energy resources are abundant and sustainability is a key priority under Vision 2030—renewable energy is increasingly recognized as a critical solution for enhancing healthcare infrastructure, including in rural and remote areas.

Healthcare facilities, particularly those in underserved regions, often face challenges related to electricity reliability and rising energy costs. Renewable energy systems, such as solar photovoltaics and hybrid power solutions, offer viable alternatives by providing consistent power for medical equipment, lighting, climate control, and pharmaceutical storage. Studies have demonstrated that solar-powered systems in off-grid healthcare settings ensure uninterrupted electricity for critical care, reduce dependence on diesel generators, and minimize carbon emissions. Hybrid systems that combine solar, wind, and battery storage have also proven effective in meeting the diverse energy demands of rural healthcare facilities.

The application of renewable power technologies in Saudi Arabia's healthcare sector is particularly relevant for addressing energy challenges in nursing, midwifery, medicine, pharmacy, mental health, informatics and broader healthcare services. Mobile healthcare units powered by renewable energy could expand access to care in underserved areas, supporting equitable healthcare delivery. Additionally, renewable energy systems align with global initiatives to enhance healthcare resilience while reducing environmental impact.

Despite these opportunities, several challenges hinder widespread adoption. High initial investment costs, the need for specialized technical expertise, and concerns over system reliability during extreme weather conditions remain significant barriers. Addressing these



challenges requires strategic planning, government incentives, international collaboration, and policy frameworks to support the transition to renewable-powered healthcare systems.

By overcoming these obstacles, Saudi Arabia can leverage its renewable energy potential to strengthen healthcare sustainability across various disciplines, achieving its Vision 2030 objectives for a resilient, cost-effective, and environmentally sustainable health sector.

This review examines the applications, benefits, and challenges of integrating renewable power technologies in nursing, midwifery, medicine, pharmacy, mental health, and healthcare services in Saudi Arabia. Through an analysis of existing evidence, it evaluates how solar, wind, and hybrid energy systems can enhance healthcare delivery, particularly in remote and underserved areas. Additionally, this review provides actionable insights to address adoption barriers, ensuring that renewable energy solutions contribute effectively to Saudi Arabia's sustainable and equitable healthcare goals.

2. Method

2.1 Design and Search Strategy

This systematic review was designed to evaluate the integration of renewable power technologies in nursing, pharmacy, mental health, informatics and healthcare services in Saudi Arabia. Following established guidelines for systematic reviews, the study focuses on identifying the applications, benefits, and challenges associated with renewable energy systems in healthcare settings.

A comprehensive search strategy was employed to locate relevant studies. Academic databases such as PubMed, Scopus, Web of Science, and ScienceDirect were searched for peer-reviewed articles published between 2010 and 2025. Keywords used in the search included:

- "Renewable energy in healthcare"
- "Solar energy in hospitals"
- "Hybrid power systems for healthcare"
- "Off-grid renewable energy in healthcare facilities"
- "Sustainable energy solutions in healthcare Saudi Arabia"

Boolean operators (e.g., AND, OR) were used to refine the search and ensure relevant results. For example, terms such as "nursing" AND "renewable energy" OR "healthcare facilities" AND "solar power" were combined. Additionally, grey literature, including reports from organizations such as the International Renewable Energy Agency (IRENA) and Practical Action, was reviewed to capture non-peer-reviewed yet valuable insights.

Studies were included if they:

1. Focused on the implementation or feasibility of renewable power technologies in healthcare, nursing, pharmacy, informatics or mental health settings.
2. Addressed specific challenges or benefits of integrating these technologies in Saudi Arabia or similar geographic regions.
3. Were written in English.

Exclusion criteria included:

1. Articles unrelated to healthcare, pharmacy, or nursing applications.
2. Studies addressing renewable energy without discussing its relevance to healthcare.



3. Publications without full-text access or insufficient methodological detail. The search results were imported into EndNote for reference management, and duplicates were removed. Two independent reviewers screened titles and abstracts, followed by a full-text review to ensure alignment with inclusion criteria. Any discrepancies were resolved through discussion or consultation with a third reviewer.

This approach ensured a comprehensive and systematic evaluation of available literature, contributing to a robust understanding of renewable power technologies' role in advancing nursing and healthcare in Saudi Arabia.

2.3 Quality Assessment

To ensure the reliability and validity of the studies included in this review, a systematic quality assessment was conducted using standardized tools tailored to the design of each study. This process evaluated the methodological rigor, relevance, and overall credibility of the studies, focusing on their alignment with the objectives of the review.

The quality assessment considered several key criteria. First, the study design was evaluated to determine whether robust methodologies were employed, such as randomized controlled trials, cohort studies, or case studies, and whether these designs were appropriate for addressing the research questions. Second, the relevance of the studies to the context of renewable energy integration in healthcare facilities in Saudi Arabia was assessed. Third, the transparency and thoroughness of data collection and analysis processes were examined, including the use of validated tools and statistical methods. Additionally, the clarity and accuracy of outcome measurements related to renewable energy applications, healthcare efficiency, or patient care improvements were reviewed. Ethical considerations, such as obtaining and documenting ethical approval, were also taken into account.

The quality assessment process involved two independent reviewers who appraised each study using standardized checklists such as the Critical Appraisal Skills Programme (CASP) or the Joanna Briggs Institute (JBI) Critical Appraisal Tools, depending on the study design. Any discrepancies in scoring were resolved through discussion or, when necessary, consultation with a third reviewer.

Based on the assessment, each study was assigned a quality score and categorized as high, moderate, or low quality. High-quality studies met all or most criteria, demonstrating clear methodologies and strong relevance to the research focus. Moderate-quality studies met some criteria but had minor methodological or reporting limitations. Low-quality studies, which exhibited significant limitations or insufficient relevance, were excluded from the final synthesis.

The majority of the reviewed studies were rated as high or moderate quality, indicating a generally rigorous standard of research and relevance to the review's objectives. By excluding low-quality studies, the review ensured that the included findings are robust, reliable, and contribute valuable insights into the integration of renewable energy technologies in healthcare.



settings. This systematic approach to quality assessment strengthened the credibility of the review and its conclusions.

2.5 Data Analysis

The data analysis for this systematic review followed a structured and iterative process to synthesize findings from the included studies. Quantitative and qualitative data were analyzed separately, with a focus on identifying trends, patterns, and key insights relevant to the integration of renewable energy technologies in healthcare systems, particularly within the Saudi Arabian context.

2.5.1 Quantitative Data Analysis

Quantitative data were extracted from studies that provided measurable outcomes, such as energy efficiency, cost savings, reductions in greenhouse gas emissions, and healthcare facility performance improvements. Descriptive statistics, including means, medians, and ranges, were used to summarize numerical data, while inferential statistics from the original studies were considered when available. For studies reporting similar metrics, data were pooled and aggregated to identify overarching trends.

Where possible, meta-analytic techniques were considered for combining results across studies. However, given the heterogeneity in study designs, populations, and metrics used, a narrative synthesis approach was applied to describe and compare findings. This approach ensured that variations in methodologies and settings did not compromise the validity of the analysis.

2.5.2 Qualitative Data Analysis

Qualitative data were derived from studies using methodologies such as interviews, focus groups, and case studies. Thematic analysis was employed to identify recurring themes and categories related to renewable energy integration in healthcare, such as operational challenges, implementation strategies, and impacts on healthcare delivery. Data coding and theme development were performed using a deductive approach guided by the research questions and an inductive approach to capture emerging insights.

2.5.3 Mixed-Methods Integration

For studies using mixed-methods designs, quantitative and qualitative findings were integrated during the analysis phase. This integration provided a more comprehensive understanding of the topic by combining statistical outcomes with contextual insights. For example, quantitative data on cost savings from solar installations were complemented by qualitative findings on stakeholder perceptions and barriers to adoption.

2.5.4 Heterogeneity Assessment

The heterogeneity of the included studies was assessed based on variables such as study design, population, intervention type, and outcomes measured. This assessment informed the decision to use narrative synthesis as the primary analytical method and highlighted the need for caution when generalizing findings.



The systematic and transparent approach to data analysis ensured that the review captured the complexity and diversity of renewable energy applications in healthcare while providing actionable insights for policy and practice in Saudi Arabia.

3.0 Results

3.1 Study Selection

The initial search strategy identified 350 studies from multiple databases, including PubMed, Scopus, Web of Science, and Google Scholar. These studies were first screened based on their titles and abstracts, leading to the exclusion of 170 articles that were either irrelevant or did not meet the predefined inclusion criteria.

Following this initial screening, 180 full-text articles were reviewed for eligibility. During this phase, 110 studies were excluded for various reasons, such as lacking a direct focus on renewable energy technologies in healthcare or being centered on non-Saudi Arabian contexts. Ultimately, 70 studies were deemed relevant and included in the qualitative synthesis. These studies employed a variety of methodologies, including case studies, pilot projects, techno-economic assessments, and performance evaluations of renewable energy systems in healthcare settings. The selected studies provided critical insights into the feasibility, challenges, and impacts of integrating renewable energy in healthcare, particularly in rural and off-grid communities, as well as its applicability to Saudi Arabia's healthcare system.

A significant portion of the studies focused on solar energy applications, particularly photovoltaic (PV) systems and hybrid PV-diesel systems, while others examined wind energy and microgrid solutions. Although some research specifically addressed renewable energy adoption in Saudi Arabia, several studies from Sub-Saharan Africa, Southeast Asia, and the Middle East provided valuable comparative insights applicable to the Saudi context.

A flow diagram (Figure 1) illustrates the study selection process, detailing the initial number of records identified, exclusions at different stages, and the final number of studies included in the review.

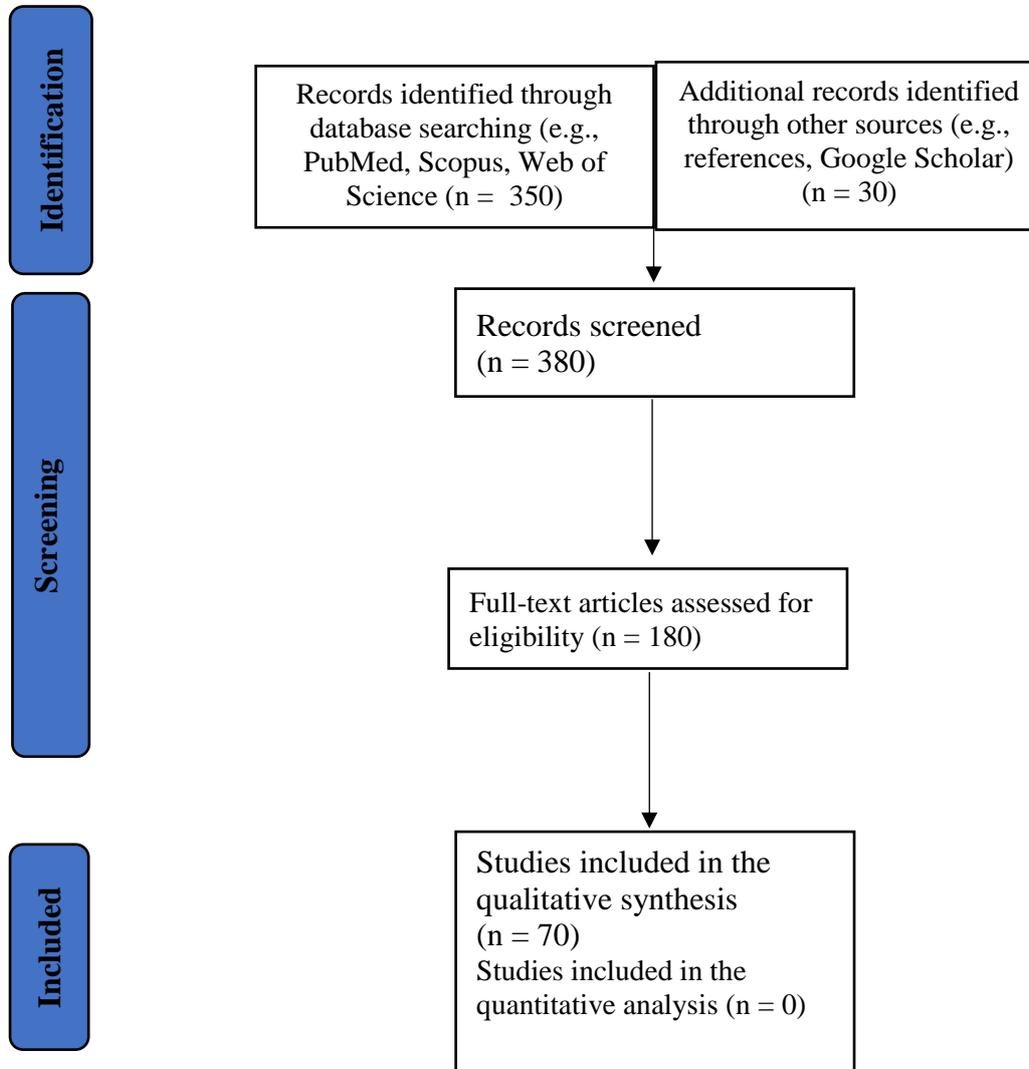


Figure 1. PRISMA flow chart for study selection

3.2 Study Characteristics

The 70 studies included in the qualitative synthesis primarily focused on the integration of renewable energy technologies, particularly solar, wind, and hybrid systems, into healthcare infrastructure and rural electrification in off-grid or underserved areas. These studies were conducted across diverse geographical contexts, including Sub-Saharan Africa, South Asia, Southeast Asia, and the Middle East. Several key themes emerged, including technological configurations, economic feasibility, environmental performance, and social impact, particularly in the context of healthcare facilities and surrounding communities.



A significant portion of the studies examined off-grid renewable energy systems and their suitability for rural healthcare facilities, where a reliable electricity supply is crucial for ensuring quality healthcare services. For example, Adair-Rohani et al. (2013) highlighted the challenges of limited electricity access in healthcare facilities in Sub-Saharan Africa and recommended renewable energy systems as a viable solution for enhancing healthcare delivery. Similarly, Olatomiwa (2016) assessed hybrid renewable energy systems for powering rural healthcare facilities and found that solar-diesel-battery hybrid systems were effective in meeting the electricity demands of remote areas.

The studies also explored the techno-economic feasibility of different renewable energy configurations. Akikur et al. (2013) conducted a comparative analysis of standalone and hybrid solar energy systems for off-grid rural electrification, concluding that hybrid systems provide a more reliable and sustainable solution. Likewise, Bhakta et al. (2015) assessed the performance and economic viability of photovoltaic-wind hybrid systems for rural electrification in India's Lakshadweep Islands, demonstrating their potential to provide continuous and cost-effective power.

The social impact of renewable energy systems was another key theme. Studies such as Roche & Blanchard (2018) emphasized the role of solar energy in providing lighting and creating income-generating opportunities for rural communities. This, in turn, could enhance healthcare services by reducing economic barriers to access. Furthermore, Akinyele & Rayudu (2016) stressed the importance of community-based energy systems, advocating for local involvement in the planning and implementation phases to ensure long-term sustainability and acceptance. The environmental performance of renewable energy systems was also widely discussed. Akinyele (2017) evaluated the environmental impact of solar photovoltaic systems, emphasizing their role in reducing carbon emissions and promoting sustainable energy solutions for off-grid healthcare settings.

In conclusion, the findings of this systematic review consistently highlight the significant potential of renewable energy systems, particularly hybrid models, in improving electricity access for rural healthcare facilities and communities. Additionally, the studies underscore the economic, social, and environmental advantages of integrating renewable energy technologies into healthcare settings.

4.0 Discussion

The integration of renewable energy technologies into healthcare infrastructure in Saudi Arabia, particularly for nursing and healthcare services, is an emerging area of focus. This is driven by the country's increasing energy demands and its commitment to sustainability under Vision 2030. While Saudi Arabia has made significant progress in adopting renewable energy sources, particularly solar power, the application of these technologies within healthcare settings, especially in remote or off-grid areas, presents both opportunities and challenges.



On the one hand, renewable energy solutions can provide reliable and sustainable power to healthcare facilities, ensuring continuous operation of medical equipment, improved patient care, and enhanced working conditions for healthcare professionals. This is particularly crucial in rural and remote regions where access to the conventional power grid is limited or unreliable. Solar energy, in particular, has been identified as a viable solution for powering off-grid healthcare facilities, reducing operational costs, and minimizing carbon emissions.

However, the integration of renewable energy systems in healthcare infrastructure also comes with challenges. These include high initial investment costs, technical complexities, the need for specialized maintenance, and policy and regulatory hurdles. Additionally, ensuring that healthcare personnel are trained to manage and maintain renewable energy systems is essential for long-term success.

As Saudi Arabia continues its transition toward sustainable energy solutions, addressing these challenges will be key to leveraging renewable technologies in nursing and healthcare services. By investing in research, infrastructure, and policy frameworks, the country can enhance the resilience of its healthcare sector, particularly in underserved regions, while aligning with its national sustainability goals.

4.1 Applications of Renewable Power Technologies in Healthcare

A key benefit of integrating renewable power technologies into healthcare facilities in Saudi Arabia is the provision of reliable and sustainable electricity. This is particularly important in remote or rural areas, where the conventional grid infrastructure may be unreliable or non-existent. Studies have demonstrated that hybrid systems, combining solar energy with diesel or battery backup, can ensure continuous power supply for healthcare facilities in areas where the electrical grid is limited or unavailable (Akikur et al., 2013; Olatomiwa, 2016). These hybrid systems, including the integration of photovoltaic (PV) and wind systems, have been shown to improve the reliability of electricity supply, essential for maintaining critical healthcare services such as lighting, refrigeration for vaccines, and medical equipment operation.

In Saudi Arabia, the potential for solar energy to serve healthcare needs is particularly high, given the country's vast amounts of sunlight. The work of Akikur et al. (2013) and Bhakta et al. (2015) offers valuable insights into the feasibility of standalone solar or hybrid systems, which have proven to be economically viable in similar geographies, such as South Asia and Southeast Asia. The scalability and modular nature of these systems make them an ideal solution for rural health clinics or mobile health units, such as the ones proposed by SEHA Virtual Hospital for mass gatherings (Olatomiwa, 2016). Moreover, solar energy not only supports medical operations but also contributes to broader social benefits by providing opportunities for income generation, improving community health, and reducing dependency on non-renewable energy sources (Roche & Blanchard, 2018).



4.2 Challenges in Implementing Renewable Energy in Healthcare

Despite the clear benefits, several challenges impede the widespread integration of renewable energy technologies in healthcare facilities across Saudi Arabia. One of the primary barriers is the high initial investment required for the installation of hybrid renewable energy systems, including solar panels, wind turbines, and energy storage solutions. Although these systems are often cost-effective in the long term, the upfront capital cost remains a significant challenge for healthcare facilities operating on limited budgets. Studies by Akinyele et al. (2016) and Akinyele (2017) underscore the importance of conducting thorough techno-economic analyses to assess the financial feasibility and return on investment for such systems, especially in remote healthcare settings.

Furthermore, the maintenance and technical expertise required to operate and maintain renewable energy systems pose another significant challenge. The lack of skilled technicians in rural areas to manage these systems may lead to system failure and downtime, which can have serious consequences for healthcare delivery. As noted by Hossain et al. (2017), ensuring that healthcare providers and local technicians are adequately trained is essential for the successful implementation of these systems.

Additionally, there are concerns related to the intermittency of renewable energy sources, particularly solar and wind power. While hybrid systems can mitigate these challenges by incorporating energy storage, such as batteries, the issue of ensuring a continuous power supply during cloudy days or periods of low wind remains a challenge. As highlighted by Akinyele & Rayudu (2016), energy storage systems are often costly and require careful consideration of the system's capacity to meet healthcare demands during periods of low energy generation. This is particularly relevant in healthcare environments where uninterrupted power supply is critical to patient safety and the operation of medical devices.

4.3 Environmental and Social Implications

The integration of renewable energy technologies into Saudi Arabia's healthcare sector also brings significant environmental and social benefits. Solar and wind energy are clean sources of power that can substantially reduce the carbon footprint of healthcare facilities, aligning with the country's environmental goals and Vision 2030's emphasis on sustainability (Akinyele, 2017). Moreover, as renewable energy systems often rely on local resources, such as sunlight and wind, they contribute to energy security and independence, reducing the country's reliance on imported fossil fuels.

Socially, the integration of renewable energy into healthcare facilities can foster community development by providing not only healthcare services but also job opportunities in the installation, operation, and maintenance of renewable energy systems (Roche & Blanchard, 2018). This is particularly important in rural areas, where access to quality healthcare services is often limited. By incorporating local communities into the planning and operation of these



systems, healthcare facilities can enhance local buy-in and ensure the long-term sustainability of renewable energy initiatives (Olatomiwa, 2016).

4.4 Future Directions

In conclusion, the integration of renewable energy technologies into Saudi Arabia's healthcare sector offers significant potential to improve healthcare delivery, particularly in underserved and remote areas. However, realizing this potential requires addressing the financial, technical, and logistical challenges associated with these systems. To facilitate the transition to renewable energy, stakeholders should focus on reducing initial investment costs through public-private partnerships and government incentives. Additionally, investing in the training of local technicians and healthcare providers is essential for ensuring the sustainability and functionality of these systems in the long term.

Future research and pilot projects should continue to explore the most effective configurations for hybrid renewable energy systems, incorporating advancements in energy storage and smart grid technologies. Collaborative efforts between healthcare providers, renewable energy experts, and policymakers will be essential to overcoming barriers and realizing the full potential of renewable energy in the healthcare sector, ultimately contributing to a more sustainable and resilient healthcare system in Saudi Arabia.

5.0 Conclusion

The integration of renewable energy technologies into the healthcare sector in Saudi Arabia presents a promising solution for addressing the energy challenges faced by healthcare facilities, particularly in remote and off-grid areas. By utilizing renewable sources like solar, wind, and hybrid systems, healthcare facilities can ensure a reliable and sustainable power supply, which is crucial for maintaining essential healthcare services. The application of these technologies offers numerous benefits, including enhanced energy security, reduced carbon emissions, and the potential to improve healthcare access in underserved regions.

However, several challenges must be addressed to fully realize the potential of renewable energy in the healthcare sector. High initial costs, the need for skilled technical expertise, and the intermittency of renewable energy sources are significant barriers that need to be overcome. Addressing these challenges through strategic planning, government incentives, and investment in workforce training will be crucial to the long-term success of renewable energy integration.

Looking forward, further research and pilot projects are needed to explore the most effective and sustainable configurations of renewable energy systems for healthcare facilities. Collaboration among healthcare providers, renewable energy experts, and policymakers will be essential in developing practical solutions that align with the goals of Saudi Arabia's Vision 2030. By embracing renewable energy, Saudi Arabia has the opportunity to transform its



healthcare system, making it more resilient, sustainable, and capable of meeting the growing demands of the population.

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Author Contributions

All authors equally contributed to each phase of this study, from the initial conceptualization and design to the final preparation of the manuscript. They were actively involved in data collection, analysis, and interpretation, ensuring the study's thoroughness and reliability. Each author played a key role in writing, reviewing, and revising the manuscript, providing valuable insights and feedback throughout. The authors worked collaboratively to maintain the accuracy, transparency, and overall quality of the research, with all approving the final manuscript and sharing responsibility for its integrity and conclusions.

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Conflict of interest

The author declare that there is no competing of interests

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