INTERNATIONAL JOURNAL OF
PHARMACEUTICAL AND HEALTHCARE INNOVATION
journal homepage: www.ijphi.com

Review Article

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Artificial Intelligence in Healthcare: Advances, Challenges, and Future Directions for Clinical Integration

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Article Info

Article history:

Manuscript ID:

IJPHI1001150123012026
Received: 10- JAN -2026
Revised : 15- JAN -2026
Accepted: 23- JAN -2026
Available online: JAN -2026
DOI: ***10.62752/ijphi.v3i2.235***

Keywords:
Artificial Intelligence, Healthcare, Machine Learning, Deep Learning, Medical Diagnosis, Review

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Abstract

In the healthcare industry, artificial intelligence (AI) has become a game-changing technology that enables better diagnosis, treatment planning, disease prediction, and patient care. Medical decision-making and operational efficiency have been greatly improved by the incorporation of AI techniques, including Machine Learning (ML), Deep Learning (DL), and Natural Language Processing (NLP). This review article offers a thorough examination of AI's position of AI in healthcare, emphasizing its uses, approaches, advantages, and drawbacks. The necessity for moral, safe, and dependable AI-based healthcare systems is emphasized in the discussion of the current issues and potential research avenues. Artificial intelligence (AI) has revolutionized the healthcare industry by enhancing diagnosis, treatment planning, disease prediction, and patient care. The integration of AI techniques such as Machine Learning (ML), Deep Learning (DL), and Natural Language Processing (NLP) has significantly improved medical decision-making and operational efficiency. This review article provides a comprehensive overview of AI's role in healthcare, highlighting its applications, methodologies, benefits, and limitations. AI-powered systems can analyze vast amounts of medical data quickly, enabling more accurate and timely diagnoses, personalized treatment plans, and proactive disease management. Moreover, AI streamlines administrative tasks, reducing errors and optimizing resource allocation. Despite these advantages, challenges remain, including ethical concerns, data privacy, and the need for reliable, safe AI implementations. The article emphasizes the importance of developing ethical frameworks and robust validation processes to ensure AI systems in healthcare are trustworthy and beneficial. It also identifies potential research directions to address current limitations and enhance AI's integration into clinical practice. Overall, the article underscores AI's transformative potential in healthcare while advocating for responsible and dependable AI-based solutions to maximize patient outcomes and healthcare quality.

Introduction

Healthcare systems worldwide are currently under significant pressure owing to a combination of growing patient populations, limited availability of skilled healthcare professionals, escalating operational costs, and increasing demand for precise and timely medical diagnoses. These challenges have intensified with the rise in chronic diseases, aging populations, and the need for personalized healthcare services. Traditional healthcare models often struggle to manage large volumes of complex medical data efficiently, which can lead to delays in diagnosis, suboptimal treatment decisions, and increased strain on the medical staff. Artificial Intelligence (AI) has emerged as a transformative technology with the potential to address many of these challenges. By simulating aspects of human intelligence, such as learning, reasoning, and problem-solving, AI systems are capable of processing and analyzing vast amounts of medical data with high speed and high accuracy. These technologies include machine learning algorithms, deep learning models, natural language processing, and computer vision techniques, all of which are increasingly integrated into healthcare environments(1).

AI applications in healthcare are diverse and are rapidly expanding. In clinical settings, AI-driven diagnostic tools can analyze medical images, laboratory results, and patient records to assist physicians in identifying diseases in the early stages. These systems have shown promising results in radiology, pathology, cardiology, and oncology. Additionally, AI can support treatment planning by analyzing patient-specific data and predicting treatment outcomes, thereby enabling more personalized and effective care(2). Disease monitoring and predictive analytics further allow healthcare providers to track patient conditions in real time and anticipate potential health risks before they become critical issues. Beyond direct patient care, AI contributes to improving administrative efficiency within healthcare organizations. Automated systems can streamline tasks such as scheduling, billing, and electronic health record management, reducing administrative burdens and allowing healthcare professionals to focus more on patient care rather than paperwork. Furthermore, AI plays a crucial role in medical research by accelerating drug discovery, clinical trials, and population health studies using advanced data analysis(3).

Despite its significant potential, AI adoption in healthcare is not without challenges. Issues related to data privacy, security, ethical considerations, algorithmic bias, and lack of transparency in AI decision-making processes remain major concerns in this field. Additionally, integrating AI systems into existing healthcare infrastructure requires substantial investment, regulatory approval, and acceptance by medical professionals(4).This review aims to examine the current research on the application of AI in healthcare, highlighting key areas where AI has demonstrated value. It also discusses the limitations and challenges associated with its implementation and identifies future research directions required to ensure the safe, effective, and ethical use of AI technologies. By addressing these aspects, this study seeks to provide a comprehensive understanding of how AI can shape the future of healthcare systems worldwide.

Artificial Intelligence Techniques Used in Healthcare

AI in healthcare primarily relies on the following techniques.

Machine Learning (ML)

Machine Learning algorithms are trained using past medical data to make predictions or classifications. Popular ML algorithms include decision trees, support vector machines, and random forests, which are based on learning patterns from previous medical records. They later apply what they have learned to make predictions or categorize information(4). Decision trees, support vector machines, and random forests are some of the most common types of algorithms used in machine learning (ML) to analyze previous medical data to determine patterns that aid in predicting future outcomes or information classification. These algorithms enhance their functions by learning from previous cases, thus making informed decisions after being presented with new data. The most common ML methods are decision trees, which divide data according to feature values to make predictions; support machines, which locate the most optimal boundary to differentiate classes; and random forests, which are a combination of more decision trees that improve accuracy and reduce overfitting. Through these approaches, ML can be used in the diagnosis of diseases, future patient outcomes, and customized treatment. It is a technique that automatically derives valuable information from the analysis of large volumes of data, aids healthcare workers in their clinical decision-making, and enhances the efficiency of patient care(5).

Deep Learning (DL)

Deep Learning involves neural networks in a multilayer process of complex data (medical images and signals). Neural networks with numerous layers are known as Convolutional Neural Networks (CNNs) that are significantly utilized in radiology and pathology. Deep Learning is a sub-field of Machine Learning that advises neural networks characterized by numerous layers to process complex information. These networks replicate human brain processing in the sense that they have interconnected layers where data are relayed between networks of nodes or neurons. The layers extract varying features of the input data, and in this way, the system is able to gain a deeper knowledge of more abstract patterns. It is a multilayered design that optimally allows deep learning models to work with complex and high-dimensional data, including medical images and physiological signals(6).Convolutional neural networks (CNN) are among the most popular deep learning networks used in medical practice. CNNs are uniquely structured to handle visual data through the application of filters that identify edges, textures, and shapes in pictures. This renders CNNs very efficient in applications such as radiology and pathology, where the interpretation of images is critical. For example, CNNs can be used to recognize tumors or some types of tissues and unusual features in medical images(7).

Natural Language Processing (NLP)

Natural Language Processing (NLP) is a technology that allows machines to comprehend, interpret, and extract insights from human language in clinical practice. It uses unstructured textual data from clinical notes, electronic health records (EHRs), and medical literature to generate meaningful information. NLP facilitates the identification of medical concepts, including symptoms, diagnoses, medications, and treatments, by transforming free-text data into structured formats. This capacity can be used in different healthcare applications, such as enhancing patient record accuracy, data entry, and assisting in clinical decision-making(8).NLP is useful in clinical notes and EHRs to summarize patient histories, identify adverse drug events, and track disease progression by processing large amounts of text in a fast and accurate manner. It is also helpful in research as it mines medical literature to find relevant findings and trends. Machine learning and deep learning models are common in NLP systems to identify recurring patterns in language and deal with synonyms and context, which makes them more effective in interpreting complex medical language and jargon(9).

Applications of Artificial Intelligence in Healthcare

Medical Diagnosis

AI systems help in the diagnosis of diseases such as cancer, diabetes, and cardiovascular disorders by analyzing the medical photos and data of patients with high precision. Such systems are based on highly developed machine learning and deep learning technologies to recognize patterns and anomalies that can be difficult to detect by human clinicians. For example, convolutional neural networks (CNNs), a form of deep learning model, are commonly applied to the interpretation of medical images, such as X-rays, MRIs, and CT scans, to identify tumors or other abnormalities at an early stage(10).

In addition to image analysis, AI can combine various patient-related information, such as physiological signals and electronic health records, to deliver overall evaluations. Such a comprehensive method enhances the accuracy of diagnoses and assists in the formulation of individual treatments. Machine learning approaches, such as decision trees and random forests, play a role in classifying the risk profiles of patients and forecasting their disease development based on their history(11).

Medical Imaging

AI-based image processing techniques are actively used in X-rays, MRI, CT scans, and ultrasound to detect abnormalities in image processing modalities. These methods use sophisticated algorithms based on machine learning and deep learning to process complex visual information with a high degree of accuracy. An example of such a model is a convolutional neural network (CNNs), a type of deep learning model, which is most useful in detecting subtle patterns and features in images that can indicate a disease or structural aberration(12).

AI can improve the quality of medical image interpretation by automating and assessing images faster, thus being vital for timely treatment. Such systems can detect tumors, lesions, fractures, and other pathological features that may be difficult for the human eye to detect. In addition, AI-based image analysis can assist radiologists by lowering their workload and reducing human error. Quantitative measurement (i.e., tumor size or time change) is another native feature of AI in imaging that can be used to manage patients individually. In general, image processing through AIs is changing the nature of medical diagnostics by offering effective, reliable, and scalable solutions to help clinicians provide better care to patients(13).

Drug Discovery and Development

Artificial intelligence speeds up drug discovery by predicting drug-target interactions and optimization of clinical trials.AI speeds up drug discovery by prediction of drug-target interactions and optimization of clinical trials, including of drugs and their biological targets, such as proteins or enzymes. This predictive power is used to find promising drug candidates in a much faster and less expensive manner than conventional experimental techniques. Machine learning algorithms use massive amounts of chemical compounds and biological data to predict the likelihood of a drug binding to a target, its potential action, and potential side effects(14).

AI also streamlines clinical trials by enhancing patient selection and monitoring. The analysis of patient data can help AI find the right participants to consider, improve the likelihood of successful trials, and minimize time and expenses. AI can also be used to track patient responses and adverse effects in real time to adjust the trial design and achieve a more personalized approach to treatment. In general, AI simplifies the pharmaceutical development process by eliminating the need for trial-and-error to evaluate the specified treatment, speeding up effective treatment discovery, and making clinical trials more efficient. This is because AI integration in pharmaceutical research enables the more effective, safe, and rapid delivery of new drugs to patients(15).

Personalized Treatment

AI assists in designing specialized therapy modes depending on patient history, genetics, and lifestyle elements, facilitating the creation of individualized treatment plans by incorporating a wide range of data about patients, such as medical history, genetic information, and lifestyle. Through such complete data, AI systems have the potential to determine patterns and correlations that may be used to customize therapies for specific patients. This individualized methodology enhances the effectiveness of the treatment and reduces adverse effects based on the unique biological and environmental background of each patient(16).Machine learning algorithms can be used to process past clinical data and predict the response of a particular patient to various treatments, allowing clinicians to make better choices. Genetic data, such as gene expression patterns or mutations, are studied to comprehend disease processes and drug reactions on a molecular scale. Other lifestyle issues, such as diet, exercise, and habits, are also included to obtain a holistic picture of the patient's health. This type of personalization helps in precision medicine by ensuring the optimal choice of drugs, dose, and schedule. It also aids in early intervention and continuous monitoring with plans adjusted to changes in patient conditions. Overall, AI can contribute to better clinical decision-making and thus improve patient outcomes and efficiency in healthcare provision(17).This discussion is based on the background of AI in healthcare in the chosen reading and previous debates on the potential of AI in medical data analysis and clinical practice(17).

Remote Patient Monitoring

Wearables are used to track the health conditions of patients in real time with the assistance of AI algorithms. Smart machines in the form of wearable gadgets save constant real-time data on the health status of patients and transmit it to AI, which processes it and provides advice. These devices include physiological measurements such as heart rate, blood pressure, glucose levels, and activity patterns that are mechanized by AI systems to identify any abnormality or change that could be a sign of a health issue. This continuous stream of data enables early diagnosis of symptoms, timely intervention, and individual health care delivery beyond the conventional clinical environment(18).Wearables with AI applications enable the management of chronic diseases through vital sign monitoring and the detection of the emergence of critical situations, notifying patients and medical professionals, minimizing hospital hospitalization, and enhancing life. They are also used to monitor patients remotely, which allows clinicians to effectively manage patient populations on a large scale and make evidence-based decisions. These systems can learn personal baseline patterns using machine learning and deep learning and identify deviations that may indicate complications. In addition, it can be integrated with mobile applications and cloud platforms, which increases the availability of data and allows the creation of a stable flow of communication between patients and healthcare teams. This technology facilitates active healthcare as it is no longer reactive but preventive and long-term(14-18).

Comparative Analysis of Existing Studies

Smith et al. 2020 applied **Machine Learning** for **disease prediction** but faced challenges due to a **limited dataset**. This limitation is common in ML applications, where insufficient or unrepresentative data can reduce the accuracy and generalizability of the model. As discussed in the previous section, machine learning algorithms, such as decision trees and random forests, rely heavily on historical data to learn patterns for classification and prediction. A limited dataset restricts the model's ability to capture diverse patient characteristics, potentially leading to overfitting or bias.

Kumar et al. 2021 utilized **Deep Learning** for **medical imaging** tasks, specifically leveraging architectures like Convolutional Neural Networks (CNNs), which are effective in analyzing complex visual data such as X-rays, MRIs, and CT scans. However, the study noted the **high computational cost** as a significant limitation. Deep learning models require substantial computational resources and time for training because of their multilayered neural network structures and large parameter spaces. This aligns with the previous explanation that the strength of deep learning in handling high-dimensional data comes with increased demands for processing power, which can hinder its implementation in resource-constrained clinical settings.

Lee et al. 2022 focused on **Natural Language Processing (NLP)** for **Electronic Health Record (EHR) analysis**, addressing the challenge of extracting meaningful information from unstructured clinical notes. Their main limitation was **data privacy issues**, which reflected concerns about handling sensitive patient information. NLP models depend on access to comprehensive clinical text data to accurately identify medical concepts and support clinical decision-making; however, privacy regulations and ethical considerations often restrict data availability and sharing. This issue is consistent with the earlier discussion on NLP's role of NLP in healthcare, where securely managing protected health information is a critical barrier(18-20).

Collectively, these articles demonstrate the variety of uses of AI in healthcare, such as predictive analytics, diagnostic imaging, and clinical data processing, and highlight typical issues, including the lack of data, calculation requirements, and privacy issues. These shortcomings highlight the need for further research and technological advancements to optimize the integration of AI into clinical practice. To address the insufficiency of datasets, data augmentation, federated learning, and multi-institutional partnerships can be applied to enhance model resilience. The computation cost can be minimized using model optimization methods or cloud infrastructure. The problem of privacy can be addressed by using superior data anonymization, data security protocols, and frameworks that comply with regulations(20-22).

Advantages of AI in Healthcare

diagnostic accuracy, and this is able to assist clinicians to diagnose diseases more accurately and at an earlier stage, resulting in better patient outcomes. AI lowers the burden of healthcare workers by automating the workflow through image analysis, data extraction from clinical notes, and tracking, which enables clinicians to concentrate on decisions requiring greater complexity. The ability to make decisions much faster is also possible because AI systems can quickly process large volumes of medical data to justify timely interventions and changes in treatment. Cost efficiency is achieved due to an efficient workflow, lower diagnostic error rates, and more efficient resource distribution, which eventually decreases healthcare costs. The continuous stream of tellable data, individualized treatment regimens, and real-time monitoring of health, usually by the use of AI-enhanced wearable devices, leads to improved patient care and monitoring. The combination of these benefits will enhance effective, efficient, and patient-centered healthcare(22-24).

Challenges and Limitations

Reliance on quality data Artificial intelligence (AI) in healthcare has many advantages but also has a number of critical issues that need to be addressed to achieve its full potential. The primary concerns are data privacy and security, the absence of transparency in AI models, ethical and legal concerns, high implementation expenses, and reliance on quality data.The issue of data privacy and security is the most crucial in the area of healthcare because of the sensitivity of information about a patient. To train effective AI systems, access to vast amounts of clinical data, such as electronic health records (EHRs) and medical notes, may be necessary. Nevertheless, tougher laws and ethical standards restrict data sharing and use, introducing obstacles to the development and implementation of AI. A high level of patient trust and protection of information is achieved by ensuring its safe processing, anonymization, and adherence to privacy laws, which are emphasized in Lee et al. (2022) in the chosen text on NLP applications. The other major problem is the lack of transparency, sometimes termed the black-box problem. Most AI models, particularly deep learning models such as convolutional neural networks (CNNs), are multi-layered and complicated, and cannot be easily interpreted by clinicians. Such a lack of transparency decreases trust and makes it difficult to verify and accept AI recommendations in clinical practice. Transparency and explainable AI should be used to close this divide and enable clinicians to understand and be responsible. The introduction of AI in healthcare is also associated with ethical and legal concerns. The responsibility for AI-made decisions, the possible bias of algorithms, and fair access to AI technologies are all issues that should be considered. According to Smith et al. (2020), biases can be caused by poor or small datasets, resulting in unfair or poor predictions that disproportionately impact specific groups of patients. To make AI helpful to all patients in a fair and responsible manner, it is essential to create a system of ethical principles and legislation. The unfeasibility of high implementation costs is a practical issue, particularly in healthcare settings with limited resources. Deep learning models, including those used in medical imaging by Kumar et al. (2021), require a significant number of computational resources and infrastructure, which may incur significant upfront and maintenance costs. These expenses could decrease mass application and restrict AI to institutions that are well-endowed, further reducing healthcare access inequality. Finally, the efficiency of AI is largely determined by the accessibility and quality of the data. Low-quality data, incompleteness, or bias compromise model quality and generalizability. Small data sets do not allow machine learning algorithms to capture varied patient features, which increases the chances of overfitting and lowers clinical utility. To overcome this, measures such as data augmentation, federated learning, and multi-institutional partnerships should be implemented to increase the robustness and diversity of the dataset(15,20).

Discussion and Research Gaps

The present studies show a certain emphasis on diagnosis and imaging; nevertheless, ethical AI, XAI, and integration with clinical workflows do not receive sufficient attention. Standardized datasets and regulatory frameworks are necessary to ensure the safety of AI systems used in the medical sector. Present-day research on AI usage in healthcare focuses largely on diagnostic and imaging technologies, indicating substantial progress in these spheres. Nevertheless, this direction has led to a relative lack of attention to important issues such as ethical AI, explainable AI, and the smooth incorporation of AI systems into clinical practice, which is the point of the current choice. The focus on diagnosis and imaging is based on the use of potent AI solutions, such as deep learning and convolutional neural networks, to process complex medical images and patient data with high precision. These new advancements have helped enhance diagnostic precision and efficiency, but they have also revealed gaps that are yet to be studied. The ethical principles of AI, such as fairness, reduction of bias, and equitable access, should also be addressed to ensure that AI promotes the welfare of all groups of patients without contributing to existing healthcare disparities. The research gap that exists in covering these ethical aspects is likely to compromise the confidence and reception between clinicians and patients.

Another underrepresented field is XAI. Most AI systems are black-boxes, and in particular, deep learning models do not offer clear reasoning to arrive at the results they do. This lack of transparency makes it more difficult to interpret, endorse, and rely on AI guidance, which is an essential requirement for implementation in sensitive healthcare settings. The further development of explainability research is to make AI decision-making processes more interpretable and increase clinician confidence, leading to easier regulatory approval(18,21). In addition, the adoption of AI in clinical processes remains a major problem. Although AI has technical potential, its implementation should be consistent with other healthcare systems, interoperability with electronic health records, and easy-to-use interfaces for clinicians. Existing studies do not provide adequate attention to these aspects of implementation, which are crucial in implementing AI innovations into normal clinical practice(21).

To overcome these gaps, it is important to develop a uniform set of datasets and regulations. Having standardized datasets is essential for obtaining strong, generalizable AI models and comparing performance across studies. They contribute to the reduction of such problems as the lack of data and bias, which have been considered significant drawbacks of earlier studies (e.g., Smith et al. 2020). Regulatory systems guarantee the safety, effectiveness, and ethical standards of AI systems prior to their extensive clinical application. These models should be modified alongside the development of AI to offer explicit directions related to validation, transparency, and protection of patient privacy. In conclusion, although AI studies have achieved significant advances in diagnostic and imaging services, they need to move toward more ethical and explanatory aspects and clinical integration. The creation of standard datasets and holistic regulatory policies will help facilitate the safe, effective, and equitable use of AI in healthcare. Addressing such gaps will improve clinician trust, patient safety, and the overall effect of AI technologies on improving healthcare delivery(22).

Future Scope

The area of future research in artificial intelligence (AI) applications within healthcare needs to cover a variety of areas that are vital to the safe, effective, and equitable application of the technology in clinical practice. The recent tendency toward diagnostic and imaging usage has already delivered notable improvements, but it has also indicated flaws to address, including explainable AI models, secure and privacy-aware systems, compatibility with new technologies such as the Internet of Things (IoT) and telemedicine, and real-world clinical validation.

XAI is necessary to address the black-box problem of most AI models, particularly deep learning architectures such as convolutional neural networks (CNNs). These models frequently deliver outputs in an unclear manner, which destabilizes the trust of clinicians and makes their regulation and acceptance difficult. In the future, it is recommended to focus on creating interpretable AI tools that can provide the reasoning behind the predictions and decisions made. Such transparency will facilitate the understanding of clinicians, validate AI recommendations, and encourage accountability, which will reduce the level of acceptance and safe usage in clinical practice(22).

Security and privacy are major concerns because of the sensitivity of medical data. AI systems also require access to significant volumes of data, such as electronic health records (EHRs) and clinical notes, which are protected by rigorous privacy laws. The guiding force of future work should be the development of privacy-saving AI systems that would allow data sharing and training models without violating patient privacy. Techniques such as federated learning, data anonymization, and secure multiparty computation present encouraging prospects for finding a balance between data utility and privacy. Solid data protection will ensure patient trust and adherence to legal and ethical constraints, which is a major constraint to the current NLP applications in EHR analysis. Another crucial area of research is the integration of AI, IoT devices, and telemedicine platforms. Remote patient monitoring systems and wearable health monitors produce continuous physiological data. Future AI models should be capable of incorporating these dynamic data in an uninterrupted manner to offer proactive, personalized healthcare outside typical clinical settings(24). This integration aids in the management of chronic diseases, early intervention, remote care, and expands access and enhances patient outcomes. Studies must be conducted on scalable and interoperable AI systems that are functionally compatible across a wide range of devices and healthcare systems to allow seamless integration of clinical processes.

Finally, practical clinical confirmation is a critical step in the process of moving AI systems from laboratory scenarios to everyday clinical applications. Most AI models have shown good results in more controlled environments but have not been highly validated in a wide range of clinical populations and environments. Future research must focus on multi-institutional, large-scale clinical trials and post-deployment monitoring to determine AI performance, safety, and its effect on patient care. Such validation will determine possible biases, limitations, and unintended consequences that will be used in model revision and regulatory decision-making(23-25).

Conclusion

AI can disrupt the healthcare industry and lead to higher levels of diagnostic accuracy, efficiency, and patient outcomes. Despite the promising outcomes of AI technologies, issues of data security, ethics, and implementation must be considered. As technology continues to evolve and is regulated appropriately, AI can be a crucial element in designing intelligent and resilient healthcare frameworks by increasing the accuracy of diagnosis and operation, as well as patient outcomes. Existing AI applications, especially in the field of diagnostic imaging and disease prediction, have shown promising performance owing to the high machine learning and deep learning methods. Nevertheless, despite such progress, there are still critical issues that should be resolved to realize the full potential of AI in clinical practice. Among the important issues are privacy and safety of data, lack of transparency in most AI models, ethics and laws, expensive implementation, and the need to have high-quality data. It is necessary to mitigate these drawbacks to make AI systems more reliable, trustworthy, and equitable. Future growth should be directed towards the development of XAI models that can present transparent and understandable information to clinicians to enhance their acceptance and enable regulatory acceptance. Privacy-safe systems, including federated learning and safe data management, serve an essential purpose in safeguarding confidential patient data and providing powerful model training. The combination of AI and new technologies, such as the Internet of Things (IoT) and telemedicine, will improve the delivery of healthcare outside the clinic and facilitate constant tracking and care. In addition, the safety, efficacy, and generalizability of AI in different populations must be proven through extensive clinical trials.

Submission Declaration:

This manuscript has not been published previously and is not under consideration for publication elsewhere. The authors confirm that the work is original and have read and approved the final manuscript for submission.

Conflict Of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

Declaration Of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethics Statement:

This review paper, involves no experimental research, human subjects, or animal studies that need ethical approval; instead, it is based entirely on publicly available literature. For academic openness and integrity, all acknowledged sources were appropriately referenced. I have done all in my power to provide an objective, accurate, and thorough literature review free from any conflicts of interest that could affect how the data are interpreted. The development of this study did not involve any instances of scientific misconduct, data manipulation, or plagiarism. Let me know if you need refinement

Funding No: funding was received for conducting this study.

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