

A SYSTEMATIC LITERATURE REVIEW ON THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN ENHANCING CARE FOR KIDNEY DISEASES PATIENTS

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ABSTRACT: Chronic Kidney Disease (CKD) is a very long-term condition whereby the kidneys, over time, progressively lose some of their core functionality, resulting in waste accumulation within the body. It may progress silently, with manifestations in advanced stages, and can result in kidney failure that may necessitate dialysis or transplantation. It requires early detection for management. Artificial Intelligence (AI) has emerged as a transformative tool in the management of CKD, enabling more precise diagnosis, treatment optimization, and long-term care. The other way round, AI is a limb of Computer Science dedicated to developing systems that do what a human does intelligently. AI in healthcare has opened several breakthroughs in health care, especially in the management of CKD. Recent development related to AI, including machine learning, natural language processing, and predictive analytics, has gradually integrated all the stages in CKD care, from early diagnosis to treatment optimization, considering the significantly improved diagnostic accuracy and better patient outcomes. AI algorithms use huge datasets ranging from biomarkers to medical imaging in the early diagnosis of kidney dysfunction and provide timely interventions, facilities, and initiation of tailored treatment plans that improve patient outcomes and reduce healthcare costs. AI-based systems enhance decision support for clinicians, improving the management of dialysis and post-transplant care by predicting complications and providing real-time insights. Even with the possible advantages accruing from them, data fragmentation, quality issues, and ethical concerns over patient privacy and decision-making processes continue to be a problem. This review highlights the ongoing challenges related to AI model generalizability across diverse patient populations and the need for more transparent and standardized validation processes. Strong data management is required in this, with due adherence to ethical guidelines, so that AI makes its way into kidney care in a way that's fair and secure. Addressing these challenges requires cross-disciplinary collaboration between AI researchers, nephrologists, and policymakers to ensure safe and equitable integration of AI in clinical practice. The objective of the research is to systematically evaluate AI technology in CKD from a patient-centered perspective of care improvement for patients with CKD. Fourteen studies published from 2018 to 2024 were reviewed in the systematic review to learn how AI technology was incorporated to improve care for CKD patients. These studies demonstrate the increasing role of AI in identifying biomarkers, predicting disease progression, and personalizing treatment protocols. In addition, most of the research those were reviewed was published in Science Directory, IEEE Xplore and Emerald Insights database and done by

university students for improvement in the care of CKD patients using AI. The findings from this review suggest that while progress has been made, there is still a need for more rigorous validation and real-world evidence to fully realize the potential of AI in CKD management.

KEY WORDS: *Artificial Intelligence, Kidney Diseases, CKD, Healthcare*

1. INTRODUCTION

AI-based systems offer better decision support for clinicians, thereby improving dialysis management and post-transplant care through complication predictions and real-time insights. These technologies also enhance early-stage diagnosis and long-term patient management, especially in CKD.

AI will continue rapidly to change the face of healthcare and, similarly, will be doing so for chronic kidney diseases. Recent literature depicts how AI is improving diagnostic precision, personalizing therapy, and facilitating better patient outcomes in nephrology.

Díez-Sanmartín et al. (2021) identified the impact of AI and big data on treatments for end-stage renal disease; according to these authors, such technologies optimize effective analytics in patient management. In this line, Ho et al. (2024) add that up taking trends of AI and machine learning are revolutionizing kidney care by way of predictive analytics along with a decision support system.

Integration of AI with omics data has taken research on kidney diseases to the next level. Grobe et al. (2023) and Zhou et al. (2023) review how this integration of AI with omics approaches improves diagnostic precision and personalization of treatment. Grobe et al. (2023) focus more on the synergy of omics and AI, while Zhou et al. (2023) focus more on multi-omics integration, providing deeper insight into disease mechanisms.

It also extends to very specific conditions, such as kidney stones. Kianian et al. (2024) illustrate the use of AI-driven, patient-targeted health information in the management of kidney stone disease. Such specific applications are put into a broader perspective by works like Sawhney et al. (2023), who review various models of AI for early CKD prediction and evaluation.

The future of AI in kidney health looks bright. Nadkarni and Kotanko present, for 2022, and Elsevier BV, for 2024, the ever-evolving role of AI-from predicting survival rates in advanced CKD, as discussed by Dharmarathne et al. in 2024, to improving the diagnostic precision with explainable AI.

Early prediction remains a focus of prime importance. Pareek et al. (2023) used convolutional neural networks to predict CKD at an early stage. Savitha et al. (2022) presented a comprehensive review of machine learning algorithms for the diagnosis of CKD. Further, Khade et al. (2021) and Sameena and Rajashekar (2023) presented the advancement and comparative effectiveness regarding the usage of different AI techniques in the early-stage prediction of CKD.

The final contribution is by Hegde and Mundada (2022), who introduce hybrid generative regression-based deep intelligence and present state-of-the-art AI methods for the risk prediction of chronic diseases. These contributions enable us

to show that AI can bring about essential improvements in kidney disease management and patient care.

The following systematic review addresses 10 research questions based on 14 key studies that examine very important features of AI applications in CKD care. The research questions (RQ) guiding this review include:

RQ-1. How has artificial intelligence (AI) and big data influenced the treatment of end-stage kidney disease?

RQ-2. What are the current trends in artificial intelligence and machine learning in the management of kidney care?

RQ-3. How do omics technologies combined with artificial intelligence contribute to understanding kidney diseases?

RQ-4. What is the role of AI in providing patient-targeted health information for kidney stone disease?

RQ-5. How does the integration of AI and multi-omics approaches improve the management of kidney diseases?

RQ-6. What are the strengths and weaknesses of different AI models used for early prediction and evaluation of chronic kidney disease (CKD)?

RQ-7. What does the future hold for AI and machine learning in the field of kidney health and disease?

RQ-8. How can AI be applied to predict survival in patients with stage 4-5 chronic kidney disease (CKD)?

RQ-9. What are the advantages of using a machine learning-based interface with explainable AI for diagnosing chronic kidney disease (CKD)?

RQ-10. How effective are convolutional neural networks (CNNs) in predicting early-stage chronic kidney disease?

This systematic review provides a comprehensive assessment of how AI technologies are shaping kidney care, as well as identifying critical gaps and opportunities for further research. By addressing these research questions, this study shows significant value in informing the potential of AI to address specific challenges in CKD care, from early diagnosis to personalized treatment.

2. LITERATURE REVIEW

Artificial Intelligence has grown to become the cornerstone in chronic kidney disease management. The use of AI in health, especially in nephrology, brings immense advancement in early diagnosis, personalized treatments, and predictive analytics. This review summarizes some of the recent research on AI applications in the management of kidney diseases and further develops key recent advances and future directions.

2.1. Impact of AI and Big Data on End-Stage Kidney Disease

Díez-Sanmartín et al. (2021) give an overview of how the approach in the treatment of end-stage kidney disease has been changing with AI and vast data. The study by the authors further reveals that these AI technologies are creating capabilities for vast volumes of data processing in pattern identification and finding

trends that might be difficult to perceive through other means. It leverages predictive analytics with real-time data integration and opens up new frontiers for personalized treatments, optimized management strategies, and better clinical outcomes. If anything, it epitomizes AI's role in dealing with complex patient data and enabling personalized intervention.

2.2. Emerging Trends in AI and Machine Learning for Kidney Care

Ho et al. (2024) review current trends in AI and machine learning applications in kidney care. The authors highlighted that deep learning and reinforcement learning are considered some of the AI algorithms that advance predictive model development for the progression of CKD and treatments. The rapid growth in AI capabilities in Nephrology will in turn allow for much more precise risk stratification, earlier diagnosis, and personalized treatment plans as reviewed by this paper (Ho et al., 2024).

2.3. Integration of AI with Omics Data

So far, the integration of AI with omics data has taken kidney disease research to a new dimension. Grobe et al. (2023) review how omics technologies in combination with AI provide deeper insights into the molecular mechanisms of kidney diseases. AI models analyze complicated biological data and point out biomarkers and pathways associated with CKD that might help improve diagnostic accuracy and offer personalized treatment strategies. Zhou et al. (2023) further extend this to discuss multi-omics integration, extending the knowledge of kidney diseases by integrated analysis of multi-types of data into holistic models that enable improved interventions.

2.4. AI Applications in Specific Kidney Conditions

Kianian et al. (2024) have targeted the application of AI in the management of kidney stone disease. Indeed, their study proves that AI-driven health information systems are able to provide personalized advice and treatment recommendations for patients as individuals. Therefore, this approach elevates the level of adherence by a patient with prescribed treatment and the recurrence rate of kidney stones by providing recommendations in relation to one's condition and way of life. Kianian et al. (2024) further illustrate how AI applies in relation to specific kidney conditions.

2.5. Comparative Evaluation of AI Models for CKD Prediction

Sawhney et al. (2023) have presented a comparative review of AI models with respect to early prediction and assessment in CKD. The said article employed different kinds of AI algorithms for predicting the progression of CKD and its outcomes in patients, such as machine learning and deep learning models. This comparison would thereby give an idea of the relative strengths and weaknesses of each model; therefore, this comparison ensures meaningful insights are derived for its practical applicability and effectiveness in clinical settings. According to Sawhney et al. (2023), this is indeed an important comparison analysis that will help in decision-making regarding the selection of appropriate AI tools for the early detection of CKD.

2.6. Future Prospects and Explainable AI

While discussing the future directions of AI in kidney health, Nadkarni and Kotanko (2022) and Xue et al. (2022) present several emergent technologies of AI

that may further revolutionize the management in KD through diagnostic accuracy and personalization of treatment. According to Xue et al. (2022), explainable AI will help bring interpretability to the output of models, so necessary for clinical adoption. Explainable AI should bring insight into the decision-making process and build confidence with healthcare providers and patients (Nadkarni & Kotanko, 2022; Xue et al., 2022). The authors add to this discourse by narrowing down to ML-based interfaces with explainable AI towards CKD diagnosis emphasizing model transparency and user trust (Dharmarathne et al., 2024).

2.7. Early Detection and Predictive Modeling

The overall effectiveness in managing CKD is in early detection. Prediction on early detection of CKD using CNNs was done by Pareek et al. (2023) and demonstrated how the advanced AI technique enhances predictive accuracy for further intervention. The merit of CNN lies in its subtlety through medical imaging and other sources to aid diagnosis and treatment in their very nascent stage. A survey of machine learning algorithms used in the early detection and management of CKD was done by Savitha et al. in 2022.

2.8. Comparative and Advanced AI Techniques

Sameena and Rajashekar (2023) published a review on the recent advancement in AI application to kidney disease with particular emphasis on state-of-the-art techniques and their clinical relevance. They have explored new AI approaches that include hybrid models and ensemble methods for improved predictive accuracy and personalized treatment. Recently, a comparative study of multiple AI techniques in early CKD prediction was described by Khade et al. (2021) in terms of performance and applicability to various clinical scenarios. More recently, AI advancements in predicting the risk of chronic diseases have been introduced by Hegde and Mundada (2022), which include hybrid generative regression-based deep intelligence. Their studies show the new methodologies in AI innovations are transforming and there lies a hope for better outcomes on chronic diseases. Conclusion: The studies by Hegde and Mundada (2022), Khade et al. (2021), and Sameena and Rajashekar (2023) are some of these research works.

As identified from the reviewed literature, AI facilitates revolutionary deep management of kidney disease through enhanced diagnostic capability, personalized treatment, and early detection. In the case of nephrology, several important paradigms to improve care are related to the further integration of AI with omics data, advanced development of predictive models, and focusing on explainable AI. These advances determine possible contributions of AI to address complexity in kidney diseases and improve outcomes among patients through innovative and effective health care solutions.

3. METHODS

The method of Systematic Literature Review (SLR) involves an organized process through which the comprehensively and unbiasedly evaluates research evidence. An SLR starts with the definition of a clear research question, followed by the development of a detailed protocol indicating the scope of the review. It goes further to define inclusion and exclusion criteria, describes the search strategies, methods for data extraction, and quality assessment. The researcher then identifies the sources of data and formulates a search strategy that involves certain keywords

and Boolean operators in retrieving these studies from databases like Science Direct, IEEE Xplore and Emerald Insight. For instance, the succeeding step involves screening of titles, abstracts, and full texts in order to select those studies that meet the inclusion criteria. Following that, quality assessment determines the risk of bias and methodological rigor for studies that may be included using the Cochrane Risk of Bias Tool among other tools by Sterne et al. (2019). Data will be systematically extracted from each study based on pre-specified information as described in Bero (2020). Synthesis and analysis: After extraction, the data is synthesized and analyzed, where findings are summarized qualitatively or quantitatively, which might involve meta-analysis if appropriate (Munn et al., 2018). Then, the review is reported according to PRISMA to allow for transparency and reproducibility (Page et al., 2021).

Formulation of the research questions is an integral part of the SLR process because it sets at the outset the frames of reference of the research. Fig. 1 shows the six stages of the review methodology that were applied in this study. Fig. 1 highlights the process of merging a search strategy that emphasizes developing preliminary research. Even if this process is completed, it remains to create a method for determining the search terms, criteria and the initial it is to be correlated with such research as the SLR.

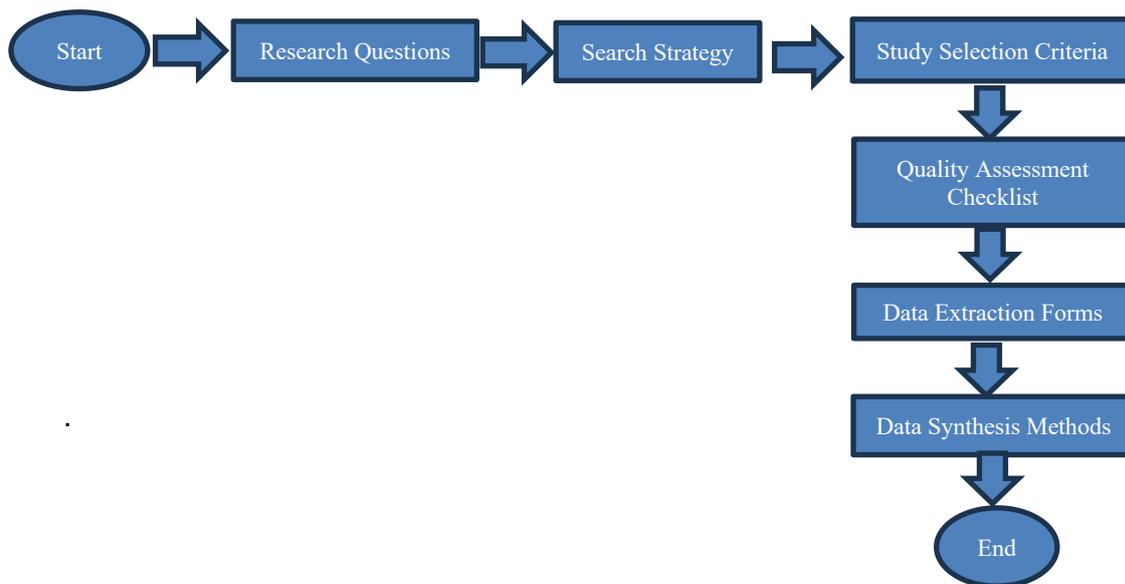


Fig. 1. Protocol review stages.

3.1. Inclusion and Exclusion Criteria

The articles that meet the inclusion and exclusion criteria listed in Table 1 will be analyzed for the review research.

3.2. Data Sources and Search Strategies

The search for articles to be considered in this systematic review began on 6 August 2024. The “ScienceDirect, IEEE Xplore, and Emerald” databases were employed to conduct a comprehensive search of published research to compile the

research articles for inclusion in this systematic review. The search terms utilized to find pertinent publications were predicated on the keywords in Table 2. Because keywords provide the foundation for accessibility to pertinent publications, proper keyword selection is critical for the selection of articles for inclusion in the systematic review (Costa & Monteiro, 2016). The search findings acquired using the already mentioned keywords provided.

Table 1: Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Must involve AI in kidney disease care	Article on AI application but not in kidney disease care
Must involve research framework	Articles without research framework
Must be written in English language	Articles published in languages other than English
Must be published between 2018 and 2024	

Table 2: Keyword search

Keyword search
“Application” & “Artificial Intelligence” & “Healthcare” & “kidney” & “CKD” “Diseases” “Patients”

Table 3: Final search results across the databases

No	Database	Count
1	ScienceDirect	748
2	IEEE Xplore	45
3	Emerald Insight	11
Total		804

The study involved accessibility to 804 articles (see Table 3). Despite retrieving numerous articles from three different databases, only 14 articles evaluating the inclusion and exclusion criteria were selected, and as well as due to time constraints.

3.3. Quality Assessment

After filtration, as shown in Table 4 below, seven items of the quality assessment checklist were used to further ascertain the quality of the research articles eligible for analysis. Quality assessment is as important as inclusion and exclusion criteria (Al-Emran et al., 2018). The quality assessment checklist is presented in Table 4.

Table 4: Quality assessment checklist

No.	Assessment Items
1.	Are the research aims clearly specified?
2.	Was the study designed to achieve these aims?
3.	Are the techniques considered by the study clearly specified?
4.	Is the research model reported?
5.	Are the data collection methods adequately detailed?
6.	Is the study context/discipline clearly specified?
7.	Do the results add to the literature?

The checklist was a modification of the recommendations from Kitchenham and Charters (2007); moreover, it was not intended to critically review any of the projects by the researchers. The questions were then scored on the basis of the standard three-point scale for scoring the questions: 1 point allocated to 'Yes', 0 points allocated to 'No', and 0.5 points allocated to 'Partially.' Any research could therefore receive from 0 to 7 points. The high general score from the research means that the research will be in a better position to answer the research questions. The quality assessment results of all the research are shown in Table 5, showing that all 14 studies met the quality assessment criteria, hence acceptable and competent for further analysis.

Table 5: Quality Assessment Results

Review	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total	Percentage
LR-1	1	1	1	0.5	1	1	1	6.5	93
LR-2	1	1	1	0.5	1	1	1	6.5	93
LR-3	1	1	1	0.5	1	1	1	6.5	93
LR-4	1	1	1	0.5	1	1	1	6.5	93
LR-5	1	1	1	0.5	1	1	1	6.5	93
LR-6	1	1	1	1	1	1	1	7	100
LR-7	1	1	0.5	0.5	0.5	1	1	5.5	79
LR-8	1	1	1	1	1	1	1	7	100
LR-9	1	1	1	1	0.5	1	1	6.5	93
LR-10	1	1	1	1	1	1	1	7	100
LR-11	1	1	1	1	1	1	1	7	100
LR-12	1	1	0.5	0.5	0.5	1	1	5.5	79
LR-13	1	1	1	1	1	1	1	7	100
LR-14	1	1	1	1	1	1	1	7	100

3.4. Data Coding and Analysis

The following characteristics of research methodology reliability were coded: (a) year of publication, (b) primary research area in AI in kidney disease care, (c) research methodology (example, interview, survey, experiment, etc.), (d) education level (University), (e) region, and (f) database (ScienceDirect, IEEE Xplore, Emerald Insight).

4. RESULT AND DISCUSSION

Answers to 10 research questions are provided based on 14 research topics published between 2018 and 2024 worldwide. Here are the 10 research questions with their answers.

RQ-1. How has artificial intelligence (AI) and big data influenced the treatment of end-stage kidney disease?

AI and big data have revolutionized the management of ESKD, allowing for more personalized and accurate care. For example, AI algorithms utilizing huge amounts of data from patient demographics, medical histories, and treatment outcomes provide disease and treatment protocol predictions. Machine learning algorithms, for example, look at the trends in data on patients so that complications-

for instance, cardiovascular events or infections-can be predicted and appropriate interventions made. This is data-driven and can enhance the accuracy of predictions but also helps in the personalization of treatments according to individual needs for better patient outcomes. In addition, big data analytics allows for the identification of trends and patterns that will guide new treatment strategies and updates in clinical guidelines toward better management of ESKD (Díez-Sanmartín et al., 2021; Nadkarni & Kotanko, 2022).

RQ-2. What are the current trends in artificial intelligence and machine learning in the management of kidney care?

The role of AI and ML is that these emerging trends in kidney care management are a reflection of the move towards more advanced and insightful data-driven approaches. One of the big trends, predictive modeling, drives AI algorithms to analyze large volumes of historical patient data to forecast the progression of kidney diseases and the likely outcomes of various treatment options. With this type of risk profiling provided, health professionals are able to institute treatment measures well in advance, hence more personalized. The emphasis also goes out on personalized medicine, where AI is supporting personalization of treatment through the aggregation of genetic information, lifestyle, and clinical data. Automating routine tasks, such as interpreting laboratory results and medical image interpretation, is becoming even more frequent, making diagnosis considerably more efficient and effective. Put together, these trends amount to more precise and effective kidney care from the stage of early diagnosis to ongoing management (Ho et al., 2023; Sawhney et al., 2023).

RQ-3. How do omics technologies combined with artificial intelligence contribute to understanding kidney diseases?

Integration of omics technologies with AI therefore provides overall framework toward the understanding of kidney diseases at the molecular levels. Omics technologies include genomics, proteomics, and metabolomics; those techniques responsible for the generation of massive volumes of data on genes, proteins, and metabolites related to both kidney function and pathology. AI algorithms interpret complicated data to bring into view the relationships and patterns in the datasets that cannot decipher by traditional methods of analysis. This synergy promotes accordingly the discovery of novel biomarkers for early diagnosis and monitoring of diseases, and clarification of the pathophysiological mechanisms underlying diseases. Coupled with that, AI-driven insights from omics data will further allow the development of targeted therapies and personalized methods of treatment, moving forward the field of the management of kidney diseases and improving the outcomes (Grobe et al., 2023; Zhou et al., 2023).

RQ-4. What is the role of AI in providing patient-targeted health information for kidney stone disease?

The integration of artificial intelligence has immense potential in optimizing patient-targeted health information related to the disease of kidney stones. It estimates the risk of nephrolithiasis formation in a patient by using his or her individual data, such as medical history, lifestyle factors, and genetic predispositions. These AI-powered tools proactively provide personalized advice regarding dietary changes, hydration strategies, and lifestyle modification for the prevention of stones. Other additional functions of AI-powered platforms are

personalized education and reminders for patients in adherence to better preventive measures for managing their conditions. This personalized approach further enhances not only patient engagement but also, in general, lifts the bar on the quality of disease management strategies (Kianian et al., 2024; Sameena et al., 2023).

RQ-5. How does the integration of AI and multi-omics approaches improve the management of kidney diseases?

AI integrated with multi-omics approaches allows a much more sophisticated and subtle view of the disease process in kidney diseases. Multi-omics technologies produce complete data on a variety of biological layers: genomic, proteomic, and metabolomic data. AI algorithms integrate diverse datasets that analyze and identify disease-specific biomarkers and pathways for more accurate diagnostics and prognostics. This holistic view enables treatment plans tailored according to the molecular signature of the individual, thus making the interventions at a focused and powerful standpoint. By combining AI with multi-omics, improvement in disease management is established apart from accelerating the process for discovering new therapeutic targets and strategies (Grobe et al., 2023; Zhou et al., 2023).

RQ-6. What are the strengths and weaknesses of different AI models used for early prediction and evaluation of chronic kidney disease (CKD)?

Different strengths and weaknesses are developed in different AI models regarding early prediction and evaluation of CKD. For instance, some of the key strengths of several AI models, such as deep learning and ensemble methods, are that these models can handle big and complex data; thus, they tend to perform better in terms of predictive accuracy. These models can catch small patterns and correlations which may not be depicted by traditional analytic methods. However, one of the most important weaknesses is overfitting, whereby models will perform well while being trained but cannot generalize well onto new or unseen datasets. Also, the nature of some AI models makes them so complex that a good interpretation is not warranted, which may be the limiting factor in its clinical application. Besides, the quality of the data feeding AI algorithms is crucial; poor or biased data will lead to suboptimal performance. These challenges need to be resolved in ensuring the effectiveness and reliability of AI in CKD management. This will be quite necessary according to Dharmarathne et al. (2024), Khade et al. (2021), and Sawhney et al. (2023).

RQ-7. What does the future hold for AI and machine learning (ML) in the field of kidney health and disease?

The future of AI and ML in kidney health and disease seems bright, with continuous innovation and enhancement in patient care. Some of the emerging trends include the development of sophisticated predictive models that integrate diverse data sources, including electronic health records, genomics, and real-time monitoring data to comprehensively provide a big picture on kidney health. Wearable technology will, in due course of time, provide monitoring in real time and continued feedback on renal function to highlight early warning signals of problems. Gravitation of explainable AI toward more transparency and interpretability of the AI models will help mainstream such systems into clinical practice. Personalized medicine will be an application of AI, in which treatment will be customized for the individual patient profile, thus offering effective and selective therapies. These are

the developments that are about to revolutionize the management of renal disease, hence assuring better outcomes and an improved quality of life for patients. This is a view by Dharmarathne et al. (2024), Nadkarni and Kotanko (2022), and Pareek et al. (2023).

RQ-8. How can AI be applied to predict survival in patients with stage 4-5 chronic kidney disease (CKD)?

Advanced analytics of data with stratification of risks using artificial intelligence can considerably enhance the prognosis of survival among patients with grade 4-5 CKD. AI models, utilizing an extensive range of patient data that includes clinical measurements, laboratory results, and treatment outcomes, have provided estimates on the survival probabilities. These models find all key risk factors associated with adverse outcomes and provide a risk score to further guide the prioritization of patients for care and treatment. AI-driven prognosis tools support high-risk patients by providing valuable insights in the management, offering tailored interventions toward better decision-making. This AI application improves the accuracy of the survival prediction, which enables better resource allocations and personalized care strategies (Nadkarni & Kotanko, 2022; Xue et al., 2022).

RQ-9. What are the advantages of using a machine learning-based interface with explainable AI for diagnosing chronic kidney disease (CKD)?

Such an interface for the diagnosis of CKD using machine learning with explainable AI confers several advantages. Explainable AI gives good transparency to clear insights into the complex decision-making process of AI models. This will allow the clinicians to gain insight into, and thus believe in, the recommendation of the system. This is better accepted and integrated into clinical practice. Furthermore, with explainable AI, clinicians are able to integrate such insights from the AI with their clinical knowledge for more informed decision-making. Integration enhances the entire process of diagnosis through broad clinical decisions. Because of this interpretation challenge, explainable AI models help health professionals by making it easy for them to adopt and rely on AI systems for the accurate and efficient diagnosis of CKD (Dharmarathne et al., 2024; Savitha et al., 2022).

RQ-10. How effective are convolutional neural networks (CNNs) in predicting early-stage chronic kidney disease?

In fact, the CNNs have done an excellent job in the early-stage prediction of CKD and form a paradigm for application in analyzing medical imaging data. Needless to say, CNNs are befitting to detect minute patterns and abnormalities in images like kidney scans or histopathological slides that indicate early-stage CKD. The fact that they are able to process and interpret even complex visual data enhances the possibility of the detection of early signs of the disease, which may not even be clearly visible to the human naked eye. The CNNs automate this diagnosis process, hence making it efficient and accurate. It helps improve diagnostic precision, early intervention, and better management of the disease in the case of early-stage CKD prediction using CNNs (Khade et al., 2021; Pareek et al., 2023; Sameena et al., 2023).

These 10 research questions review the several aspects of AI in kidney disease management. First is that AI and big data have impacted ESKD treatment by offering personalized medicine through predictive modeling and trend analysis.

Second, current trends of AI and machine learning in kidney care focus on predictive modeling, personalized treatment based on genetic and clinical data, and automating routine tasks to increase diagnostic efficiency. Third, the integration of AI with omics technologies-genomics, proteomics, metabolomics-has gone further in enhancing our understanding of the pathophysiology of renal diseases through biomarker identification, hence providing a comprehensive explanation for the mechanisms of the disease that ultimately allow for personalized therapies. Fourth, AI plays a huge role in the management of kidney stones through providing patient-specific recommendations regarding prevention based on the risk factors pertinent to the particular patient. Fifth, AI together with multi-omics approaches creates much better diagnostics and treatment due to analysis of various biological data layers. Sixth, although AI models developed for early prediction of chronic kidney disease show high predictive accuracy, several challenges are revealed concerning overfitting and limited interpretability. Seventh, the future for AI in kidney health is bright, inclusive of real-time monitoring with wearable technologies and more sophisticated predictive models. Eighth, AI has proved resilient in predicting the survival of patients with advanced CKD by analyzing comprehensive patient data to estimate risk and guide treatment. Ninth, integrating machine learning using Explainable AI into diagnosis raises transparency and clinician trust in AI-driven recommendations concerning CKD diagnosis. Finally, CNNs have great potential in the early-stage prediction of CKD, while the analysis of medical imaging data provides early detection both accurately and efficiently. To conclude, AI and machine learning are two major contributors to the development of kidney diseases for more personalized care, efficient, and accurate diagnosis, though challenges regarding data quality and model interpretability remain.

5. DISCUSSION

Artificial Intelligence in Kidney Disease Management represents the biggest leap forward in nephrology and is expected to ensure an improvement in diagnostics, treatment, and care given to patients. It has been reported in recent literature how AI and big data analytics created innovative steps for the treatment of end-stage kidney disease because of more personalized and effective management plans made possible with it. Machine learning algorithms, to this date, enable foresight into the course of a disease and optimization of therapeutic interventions for the particular needs of each patient, which may allow the improvement of overall outcomes in a patient. AI techniques, combined with omics data such as genomics and proteomics, have considerably further improved knowledge on kidney diseases at the molecular level by identifying novel biomarkers and targeted therapies. AI applications have indeed also been found adaptable to the management of some kidney conditions, such as kidney stones, whereby personalized recommendations have improved treatment outcomes. Comparisons made in various studies on different AI models for prediction CKD have indicated a significant improvement in model performance and clinical applicability, but further refinement will be required to overcome several limitations. Explanation: The development of explainable AI systems is highly crucial to bring about more transparency and build trust in the decisions made through AI, hence their wide application in clinical practice. This view is supported by the works of Dharmarathne et al. (2024) and Nadkarni and Kotanko et al. (2022).

6. FUTURE WORK

The future research on AI for kidney disease management should be directed to a number of key areas with a view to further enhancing its effectiveness and integration into clinical practice. It is, therefore, necessary that comprehensive models of AI are developed in the light of multi-modal data sources, namely, electronic health records, imaging, and genetic information, which would enhance diagnostic and personalized treatment accuracy. It is also important to consider the implementation and validation of AI tools in real-world settings. Various studies would be required to test the performance of the models across heterogeneous patient panels and health systems to guarantee their generalizability and usability. Ethical and regulatory considerations should be considered in using AI technologies responsibly, so that privacy, security, and ethics can be respected in the data. In addition, understanding and improving patient and provider acceptance of the AI technologies is going to be critical to successful integration. A process in which research is focused on factors that influence trust and engagement with the AI tools. Finally, the investigation and development of new techniques for AI, including hybrid and ensemble models, can further catalyze advances in predictive performance and patient care through novel solutions for a range of complex healthcare challenges. Ongoing investment in these areas will be important to maximize the full potential of AI in nephrology and improving patient outcomes.

Furthermore, interdisciplinary collaboration among researchers in AI, healthcare providers, and clinicians cannot be replaced in further validation and practical implementation of AI models in a wide range of healthcare settings. The research should focus not only on the technical improvement of AI but also on the smooth integration of AI technologies into the workflow of healthcare. This will involve very close collaboration with clinicians to tailor the AI systems to their needs and enable smooth adaptation of the AI tools in current day-to-day practices, ensuring that the tools meet both patient outcomes and healthcare workflows.

7. CONCLUSION

AI integration into kidney diseases has shown great promise in the revolution of handling such diseases. Artificial intelligence technologies, through the effort of machine learning and big data analytics, have greatly prepared new pathways toward better diagnosis, personalized treatment, and overall disease management. The integration of AI with omics data has illuminated the molecular mechanism of kidney diseases, thereby leading to the identification of biomarkers and target therapies. Different artificial intelligence applications have been found to be helpful in identifying certain specific conditions of the kidneys, such as kidney stones, by recommending tailored health information and treatment options for patients (Grobe et al. 2023; Zhou et al., 2023). Therefore, various comparisons of AI models pointed out their strengths regarding predictive accuracy and clinical applicability but also as continuous refinement and validation. In this respect, future emphasis needs to be given to the enhancement of AI models by comprehensive data integration, meeting the ethical and regulatory challenges, and ensuring better acceptance by patients and providers. Translating research into bedside clinical applications with newer AI techniques will be imperative in order to realize full benefits of AI in nephrology. Further transformation of kidney disease management is thus

achievable with AI and affords new opportunities for improving patient care in the future and furthering the science behind nephrology.

There is a further need for interdisciplinary research and collaboration in nephrology, data science, ethics, and healthcare management to fill the gaps in knowledge, assure real-world applicability, and respond to challenges in AI implementation. These collaborations will be very important in refining the AI tools for usability by clinicians, besides optimizing them for diverse healthcare settings. With AI becoming more and more advanced, efforts within these disciplines should be combined harmoniously in an effort to translate research findings into smooth clinical practice and maximize the full potential of AI in managing kidney diseases.

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APPENDIX

Article Id	Author	Year	Country	Database
RT-1	Díez-Sanmartín et al.	2021	Spain	Science Direct
RT-2	Ho et al.	2024	USA	Science Direct
RT-3	Grobe et al.	2023	Germany	Science Direct
RT-4	Kianian et al.	2024	USA	Science Direct
RT-5	Zhou et al.	2023	China	Science Direct
RT-6	Sawhney et al.	2023	India	Science Direct
RT-7	Nadkarni and Kotanko	2022	USA	Science Direct
RT-8	Xue et al.	2022	USA	Science Direct
RT-9	Dharmarathne et al.	2024	Australia	Science Direct
RT-10	Pareek et al.	2023	India	IEEE
RT-11	Savitha et al.	2022	India	IEEE
RT-12	Sameena et al.	2023	India	IEEE
RT-13	Khade et al.	2021	India	IEEE
RT-14	Hegde and Mundada	2022		Emerald Insight