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Artificial Intelligence in Nephrology- Its Applications from Bench to Bedside

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Artificial intelligence (AI) is a science of computer stimulated thinking processes and human behaviours, which involves computer science, psychology, philosophy and linguistics. AI helps to access large patients' datasets which it can acquire and store for further processing. Computer aided diagnosis (CAD) combines both medical image and computer image processing to characterise the pathology accurately as well as promptly. The utility of CAD has been evident in many clinical scenarios especially in skin cancer, breast cancer and lung cancer. AI helps to retrieve data on treatment protocols from various clinical trials, develop models based on treatment efficacy, predicts the best treatment protocols and improves patient management. Furthermore, AI has significant impact in the branch of nephrology, where it aids in alerting acute kidney injury (AKI), predicting chronic kidney disease (CKD), accelerating diagnosis and guiding management. While AI medicine is still in its nascent stage, in the future, AI will play a crucial role in clinical practice.

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Keywords: Artificial intelligence; nephrology; treatment protocols; machine learning; AI medicine.

1. INTRODUCTION

Worldwide, around 1 in 10 persons is affected with kidney diseases and the most common causes include diabetes, hypertension, obesity and aging. According to the global burden of diseases, 800 million people worldwide suffer from kidney diseases and the incidence is increasing [1]. Artificial intelligence (AI) is a science of computer stimulated thinking processes and human behaviours. It includes computer science, psychology, philosophy and linguistics. The key function of AI is to utilise databanks and extract valuable information.

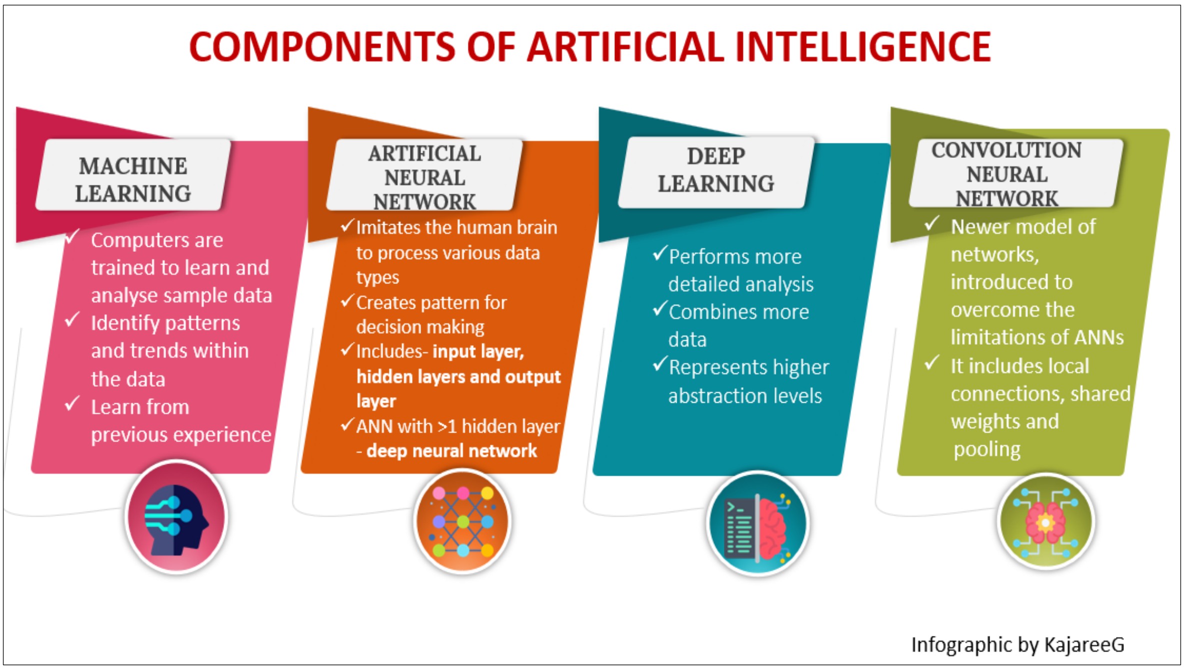


Fig. 1. Components of artificial intelligence

2. THE ROLE OF AI IN KIDNEY DISEASE

A. Predicting Systems

Prompt prediction of clinical worsening of patients plays an important role in supporting health care professionals. Delay in early diagnosis and treatment initiation in critical patients account for around 11% of hospital deaths.

- **Alerting Acute Kidney Injury (AKI):** AKI is frequently prevalent in ICU set ups, especially in elderly and perioperative patients. The incidence is 7-18% among hospitalised and 50% among ICU patients; it is reported to have increased by 11% per year [2]. Globally, there are reported deaths of 2 million patients due to AKI per year and the mortality rate is as high as 10-30% for uncomplicated AKI and 30-80% in those with multiorgan dysfunction syndrome [3]. It is crucial to recognise and prevent AKI early. Many scientists have tried to build models for early prediction of AKI which are summarised in Table 1.

- **Alerting Chronic Kidney Disease (CKD):** Globally 844 million people are affected with chronic kidney diseases, and around 1 in 10 patients are affected with CKD in India [7]. It not only increases morbidity and mortality; it poses a huge financial and administrative burden to the country. There should be prompt efforts to develop preventive and therapeutic measures to decrease the incidence and retard the progression of CKD.

Table 1. Summary of the various studies that enumerate the role of AI in predicting AKI

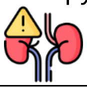
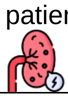
Study	Cohort size	Research type	AI algorithm	Conclusions	Limitations
Tomase et al. [4]	703782	Longitudinal data set	Recurrent neural network	Predicted **55.8% AKI episodes**, and **90.2%** of AKI episodes that required subsequent renal replacement therapy 	Retrospective study
Yin et al. [5]	8800	Retrospective, single center study	Machine learning method – random forest	Good predictive ability of development of **contrast induced nephropathy**	Non case control study
Zimmerman et al. [6]	23950	Retrospective study	Multivariate logistic regression, random forest, ANN	Model can predict AKI onset in **66%** patients 	Did not include comorbid diagnosis

Table 2. Summary of the various studies that enumerate the role of AI in alerting CKD

Study	Cohort size	Research type	AI algorithm	Conclusions	Limitations
Galloway CD et al. [9]	449380	Retrospective study	Deep neural network (DNN)	Detected **hyperkalemia in 88%** of CKD patients using two ECG leads	Retrospective study
Almansour NA et al. [10]	400	Retrospective study	Artificial neural network (ANN) Support vector machine (SVM)	Predicted **CKD** in early stages in **99.7%** of patients. ANN performed better	Limited number of patients
Lin SY et al. [11]	48153	Retrospective	ANN, RF (radiofrequency)	Predicted one year outcome following dialysis in the elderly population accurately in **81%**	No external validation
Kazemi et al. [12]	936	Retrospective	ANN	Predicted early detection of **renal stone** morphology in nephrolithiasis	Retrospective study

A pilot program (Electronic Diagnosis and Management Assistance to Primary Care in Chronic Kidney Disease; EMAP-CKD) was conducted in Australia that used e-technologies to detect chronic kidney disease. This software was built to identify patients having risk factors for CKD and formulate an appropriate screening test for the same [8]. Likewise, several scientists have studied AI for alerting the early complications of CKD which have been summarised in Table 2.

B. Computer Aided Diagnosis – Diagnostic Assistance

Computer aided diagnosis (CAD) is a technology that combines medical image and computer image processing to accurately characterise pathological lesions. The utility of CAD has been evident in cases of skin cancer, breast cancer and lung cancer. The various applications have been summarised in Table 3.

Table 3. Role of CAD in nephrology

Type of diagnosis	Evidence	Number of patients	Benefits
A. Imaging diagnosis 	1. Kanishka et al. [13] used automated segmentation method 2. Automated deep feature classification (DFC) 3. Identification and classification of CAKUT	244 patients of ADPKD 2400 patients of ADPKD	Provide TKV measurements in a fast and reproducible way Segmentation and computation of TKV Differentiate benign angiomyolipoma and oncocytoma from malignant renal cell carcinoma
B. Pathological diagnosis 	1.Better Banff scheme classification		Reduce intra and inter observer variability Reduces time
C. Make appropriate ICD codes 	1.Zimmerman et al. [6] used deep learning methods (demographics, lab results, and medications)	3	Predicted AKI onset in 66% of patients

C. Guiding Treatment

Large trials and meta-analyses help to formulate guidelines which help to form the basis of critical decisions in patient management. AI helps to integrate the results of multiple clinical trials, develop treatment protocols and help the clinicians in critical decision making. Hence, these are population based and adjustments have to be made on individual basis.

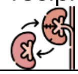
1. **Anemia Treatment:** AI has helped substantially in providing erythropoietin stimulating agents (ESA) dosing information to patients with anemia in CKD.

In 2014, Carlo et al used Machine Learning (Multilayer Perceptron, MLP) and linear model to choose appropriate ESAs doses. The MLP prediction model proved to be more effective in regards to hemoglobin prediction compared to previous models as the sensitivity proved to be more than 90% [14]. In 2018, Maria et al also used a model which helped to improve outcomes of anemia in CKD patients with reduced intake of ESA and less hemoglobin fluctuations [15]. These studies are limited by small sample size and less follow up period.

2. **Blood Pressure and Fluid Volume Management:** Hypertension is a highly prevalent condition (40-90%) in patients with end stage renal disease. To optimise blood pressure, clinicians often have to reduce the extracellular fluid volume by dialytic strategies which can predispose the patient to intradialytic hypotension. A multiple end point model predicting session specific Kt/V, fluid volume removal, heart rate and BP was predicted in 2019 by Carlo et al with a relatively accurate precision [16].
3. **Wearable Dialysis Devices**: The concept of wearable dialysis devices was first put forward by Martin et al by combining AI and regenerative devices [17]. It helps to store and retrieve data on real-time analysis of equipment alarms, dialysis parameters and patient-centric clinical parameters. These devices help to conduct continuous renal replacement therapy with effective hemodynamic balance. Implantable Renal Assist Device (iRAD) is another novel innovation which complements renal morphology and physiology. It resembles a biosimilar system by using micromachining techniques.
4. **Assistance of Needle Insertion**: An autonomous system combining robotics, AI, computer vision and image technology has been developed which assists in image guided robotic needle insertion for blood draws and intravenous insertions.

D. Evaluation of Prognosis – AI helps to analyse database, draw significant correlations between factors and outcomes, and assists in predicting prognosis (Table 4).

Table 4. Role of AI in evaluating prognosis

Disease	Study	Number of patients	Variables	Benefits
1. Chronic kidney disease mineral bone metabolism (CKD-MBD)	A. Mariano et al. [18]	1758 HD patients	Calcium, phosphate, parathyroid hormone	Prediction of **CKD-BMD** 
	B. Kleiman et al. [19]		Calcium, phosphate, parathyroid hormone, kt/v	Prediction of **calciphylaxis** in CKD 
2.IgA nephropathy	Liu et al. [20]	262 biopsy proven IgA cases	Oxford-MEST scores, C3 staining, eGFR	Prediction of **ESRD status in IgA nephropathy** 
3.Diabetic kidney disease (DKD)	A. Leung RK et al. [21]	119 patients of diabetic kidney disease and 554 patients with type 2 diabetes	Age, age of diagnosis, lipid parameters, genetic polymorphisms	Prediction of **DKD** 
	B. Arianna et al. [22]	1000 patients of T2DM	Age, gender, time from diagnosis, body mass index, glycated hemoglobin, hypertension, smoking	83% accuracy to predict DKD
4.Kidney transplantation	A. Lofaro et al. [23]	80 patients of renal transplantation		Predicting outcomes of recipients and donors 
5.CKD after AKI	Several studies are underway			Predict the risk of CKD after AKI

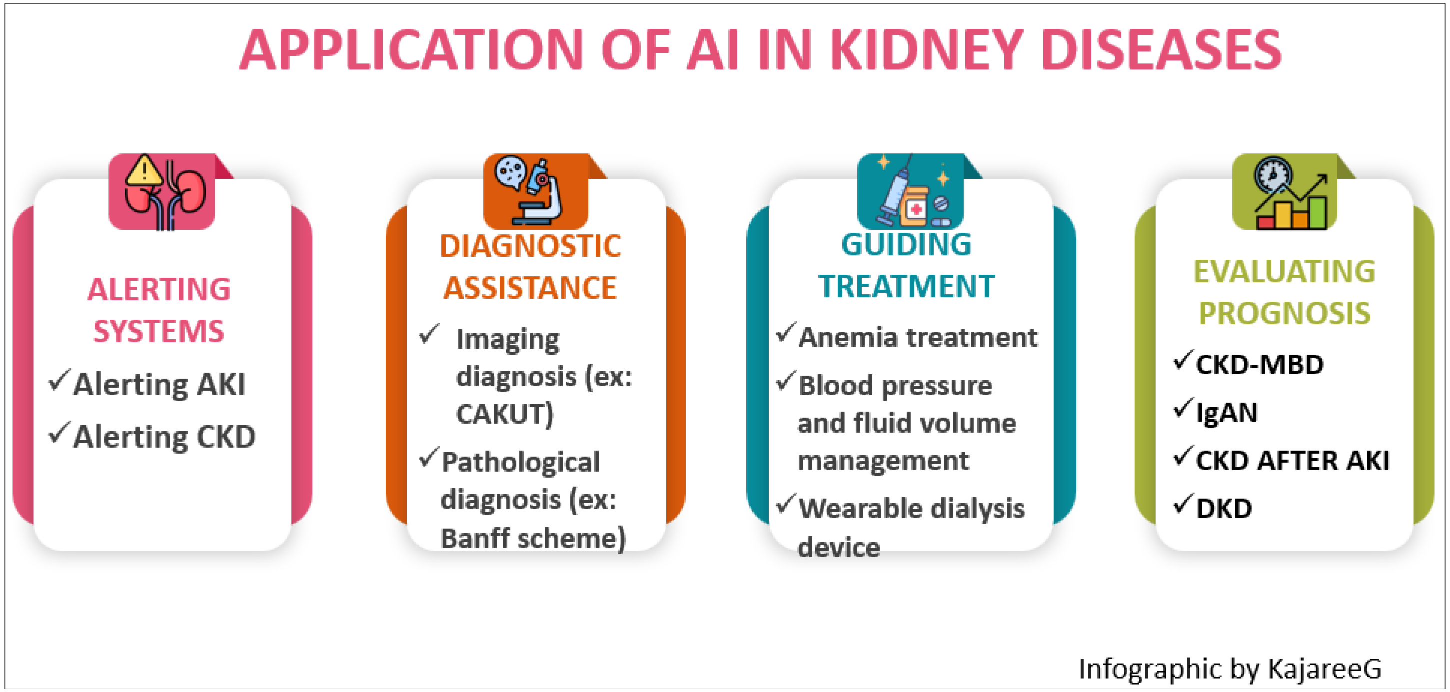


Fig. 2. AI applications in nephrology

3. CONCLUSION

The journey of empirical medicine to AI based medicine has traversed from evidence-based medicine and intelligent diagnosis. Future research directions of AI in nephrology include development of personalised treatment plans, remote patient monitoring, drug monitoring, predicting drug toxicities in kidney transplant recipients as well as predicting graft rejection. At the same time, AI can support but never replace the human touch that ultimately heals a patient (Table 2).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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