ARTIFICIAL INTELLIGENCE IN KIDNEY DISEASE: A COMPREHENSIVE STUDY AND BIBLIOMETRIC ANALYSIS

Hinata Shakeel[1], Prof. Sonal Sood[2]

[1]Research Scholar, Department of Biomedical Engineering, Rayat-Bahra University, Punjab, India
shakeelhinata04@gmail.com
[2]HOD, Department of Biomedical Engineering, Rayat Bahra University, Punjab, India
sonal.sood@rayatbahrauniversity.edu.in

Abstract

This paper advances our knowledge of how artificial intelligence is influencing nephrology by fusing bibliometric methods with a narrative synthesis. It provides evidence-based insights that can help drive the creation of policies, assist academic research, and improve clinical practice. Additionally, it emphasizes how AI has the potential to revolutionize kidney treatment, cut down on diagnostic delays, and improve patient outcomes—particularly in environments with limited resources.

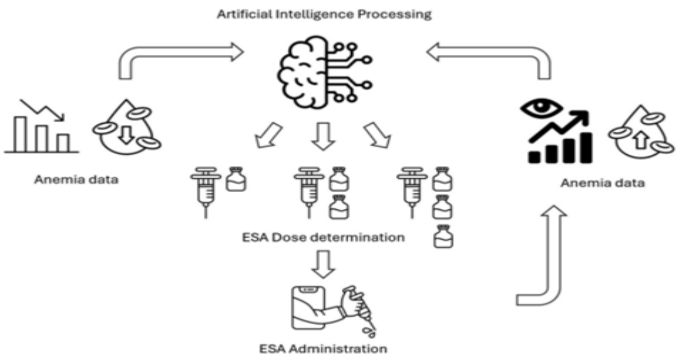
Key words: AI, ML, IDH, Big data, MAP, HR, UFR, DBP.

I Introdcution

Kidney diseases represent a significant global health burden, impacting millions worldwide. Chronic kidney disease (CKD) and acute kidney injury (AKI) are associated with high morbidity and mortality rates, posing challenges for timely diagnosis and effective treatment. Advances in AI have the potential to revolutionize the field of nephrology by enabling predictive analytics, personalized treatments, and efficient resource utilization. The intersection of AI and nephrology involves leveraging machine learning (ML), deep learning (DL), and other AI techniques to analyze complex datasets, optimize dialysis protocols, and enhance early detection of conditions such as CKD. AI tools can also identify at-risk populations, streamline clinical workflows, and improve patient outcomes. Because of its increased incidence and prevalence, kidney disease continues to be a global public health concern. Late-stage diagnosis, a lack of effective treatments for end-stage kidney disease (ESKD), and unequal access to healthcare are some of the current obstacles to addressing the burden of renal disease. Early identification is frequently hampered by the disease's asymptomatic character in its early stages, which results in postponed therapies and increased fatality rates. The only options available to people with ESKD are dialysis or transplantation. However, financial, regional, and organ availability limitations limit access to these choices. Previous studies have shown the urgent need to address these issues by identifying patients at an earlier stage.

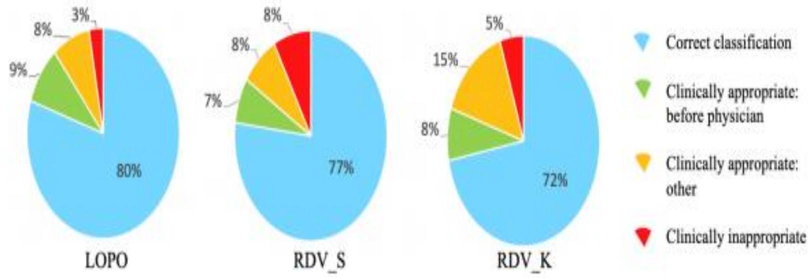
Diagnostics and Early Detection

- Artificial Intelligence in Kidney Disease: A Comprehensive **Study and Bibliometric Analysis (MDPI, 2023):** This study underscores the utility of AI-driven bibliometric analysis for identifying research hotspots and emerging trends in nephrology. Tools like natural language processing (NLP) are used to analyze vast academic databases for insights, helping researcher's pinpoint critical areas requiring attention.
- **Artificial Intelligence Supported Anemia Control System (AISACS) (arXiv, 2020):** Introduces an AI-powered framework for anaemia management in CKD patients, demonstrating improved diagnostic accuracy and treatment personalization. The system utilizes predictive models to determine haemoglobin levels and adjust erythropoietin doses accordingly, resulting in fewer complications and improved patient outcomes.

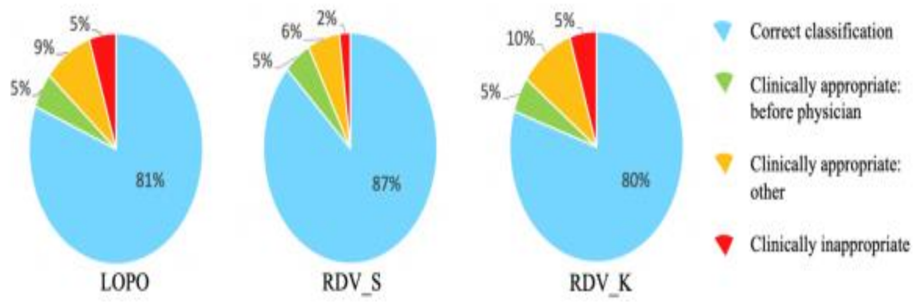


Precision Medicine and Treatment Optimization

- **Precision Dialysis: Leveraging Big Data and Artificial Intelligence (Kidney Medicine, 2024):** Highlights the role of AI in tailoring dialysis regimens using patient-specific data, improving outcomes and minimizing adverse events. Techniques such as clustering algorithms and predictive modelling have been utilized to identify optimal fluid removal rates and assess patient tolerability.



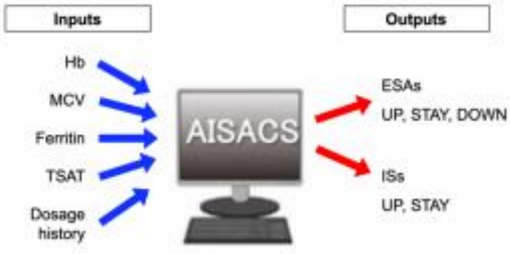
- **Review of Artificial Intelligence–Based Signal Processing in Dialysis (AKDH, 2022):** Explores the application of AI-enhanced signal processing techniques to monitor dialysis sessions, ensuring real-time adjustments for patient safety. The study discusses innovations like wearable sensors that continuously track physiological parameters, enabling timely intervention.



Predictive Analytics and Risk Assessment

- **Real-Time Prediction of Intradialytic Hypotension (Nephrology Dialysis Transplantation, 2023):** Demonstrates the efficacy of ML models in predicting intradialytic hypotension episodes, reducing complications through timely interventions. Algorithms trained on patient histories, vital signs, and treatment protocols have achieved high predictive accuracy, facilitating pre-emptive measures.

- **Deep De-noising Auto encoder-Based Non-Invasive Blood Flow Detection (arXiv, 2023):** Utilizes deep learning techniques to improve the accuracy of blood flow measurements, facilitating non-invasive monitoring. The model integrates raw signal data with noise-filtering techniques to deliver precise results, reducing the need for invasive procedures.



Bibliometric Analysis

Research Trends

A bibliometric analysis reveals exponential growth in AI-related nephrology research over the past decade. Topics such as predictive analytics, signal processing, and treatment optimization dominate the landscape. Key journals include Kidney Medicine, Nephrology Dialysis Transplantation, and emerging platforms like arXiv. An analysis of publication metrics how as significant increase in collaborations across disciplines, particularly between clinicians and data scientists.

$$R_{\text{TOTAL}} = \frac{\text{number of correct decisions}}{\text{number of input decision data}},$$

Geographical Distribution

Countries like the United States, China, and European nations are leading contributors to AI research in nephrology. Collaborative research initiatives and interdisciplinary approaches are prominent. Regional studies have highlighted disparities in access to AI technologies, with high-income countries leading in innovation, while low- and middle-income countries face challenges in adoption due to resource limitations.

II Problem Statement

1. Artificial Intelligence in Kidney Disease: A Comprehensive Study and Bibliometric Analysis.

Problem: The rapid growth of AI applications in nephrology lacks a systematic analysis to identify research trends and collaborative networks.

Solution: Conduct a bibliometric analysis to quantify scientific output, uncover research trends, and visualize collaborative networks in AI applications for kidney disease.

2. Precision Dialysis: Leveraging Big Data and Artificial Intelligence.

Problem: Despite advancements in hemodialysis, patient mortality rates remain unacceptably high.

Solution: Utilize big data and AI to develop personalized dialysis treatments, aiming to improve patient outcomes by tailoring therapy to individual needs.

3. Artificial Intelligence Supported Anemia Control System (AISACS) to Prevent Anemia in Maintenance Hemodialysis Patients.

Problem: Managing anemia in hemodialysis patients is challenging due to the complexity of medication dosing and the increasing patient population.

Solution: Develop an AI-supported system trained with data from experienced physicians to optimize erythropoiesis-stimulating agents and iron supplement administration, thereby improving anemia management.

4. Deep Denoising Autoencoder-Based Non-Invasive Blood Flow Detection for Arteriovenous Fistula.

Problem: Current methods for detecting arteriovenous fistula dysfunction are invasive and may not provide timely results.

Solution: Implement a deep learning model using denoising autoencoders to analyze non-invasive audio signals, enabling early detection of fistula issues.

5. Review of Artificial Intelligence Based Signal Processing in Dialysis: Challenges for Machine-Embedded and Complementary Applications.

Problem: The application of AI in dialysis signal processing is underexplored, limiting potential improvements in therapy individualization.

Solution: Review and assess current AI-based signal processing techniques in dialysis to identify opportunities for enhancing treatment personalization.

III Research Objectives

- To analyze critical physiological parameters during hemodialysis and develop an AI-based decision-support system capable of assessing the likelihood of Intradialytic Hypotension (IDH).

- To integrate Big Data and Artificial Intelligence techniques into a real-time framework that facilitates early-stage identification of IDH susceptibility and supports proactive clinical interventions.

- To design a non-invasive MATLAB-based graphical user interface (GUI) that enables healthcare providers to input patient vitals and obtain visualized IDH risk classification.

IV Methodology and Results

The dataset used for this study was synthetically generated to simulate hemodialysis session parameters, with all values constrained within clinically observed ranges documented in peer-reviewed literature and dialysis center reports. The selected features — systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), heart rate (HR), ultrafiltration rate (UFR), and treatment duration — were chosen based on their proven relevance in intradialytic hypotension (IDH) risk assessment. Statistical distributions for each parameter were modeled to reflect real-world variability, including correlations between features.

Missing values were eliminated, and Z-score normalization was applied to standardize inputs. Labels indicating IDH occurrence (0 = No IDH, 1 = IDH) were assigned in proportion to prevalence rates reported in clinical studies (~15% incidence per session). This approach ensures that the synthetic dataset is realistic enough for algorithm development while avoiding patient privacy concerns.

The dataset served as a foundation for model training, enabling evaluation of feasibility, feature relevance, and algorithmic performance prior to clinical trials with anonymized patient data.

Objective 1: To analyze critical physiological parameters during hemodialysis and develop an AI-based decision-support system capable of assessing the likelihood of Intradialytic Hypotension (IDH).

Step-by-Step Methodology

• Designed a dataset with features: SBP, DBP, MAP, HR, UFR, and Duration, each tied to IDH outcomes.

• Removed missing values and normalized inputs using Z-score normalization for model fairness.

• Used a custom script to standardize inputs across sessions.

• Split data into training and testing sets; stored test set appropriately.

• Created labels: 0 = No IDH, 1 = IDH, suitable for binary classification.

Results and Outputs

The dataset was successfully prepared and cleaned. It reflected realistic dialysis conditions with a slight class imbalance (~15.1% IDH cases). This dataset formed the foundation for machine learning model training.

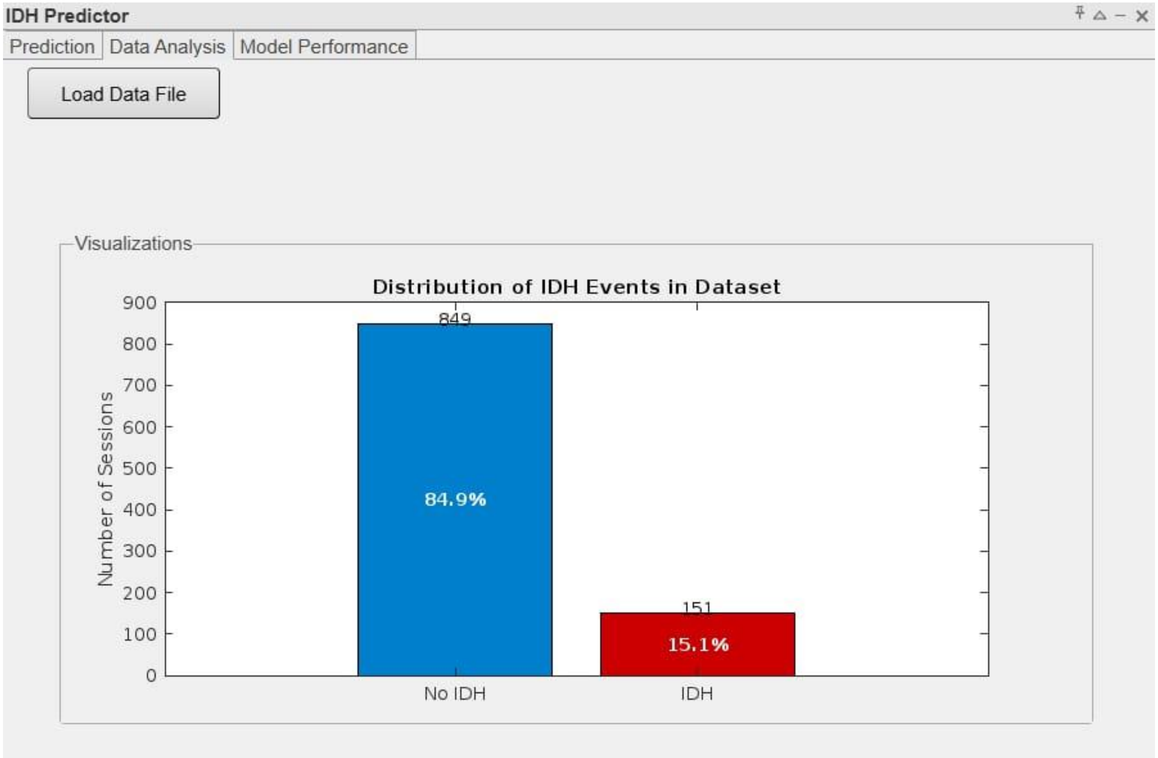


Figure 1: Distribution chart of patients with and without IDH in dataset.

Objective 2: To integrate Big Data and Artificial Intelligence techniques into a real-time framework that facilitates early-stage identification of IDH susceptibility and supports proactive clinical interventions.

Step-by-Step Methodology

• Used Random Forest (RF), SVM, and Logistic Regression models with 5-fold cross-validation.

• Trained models using a dedicated training script, evaluated their performance using accuracy and AUC.

• Random Forest was selected for final deployment due to higher AUC and specificity.

• Model was saved for integration.

• Performance was validated using standard metrics and visualization tools.

Results and Outputs

The Random Forest model achieved an accuracy of 84.5%, specificity of 100%, and AUC of 0.934, confirming its reliability for classification tasks in dialysis risk assessment.

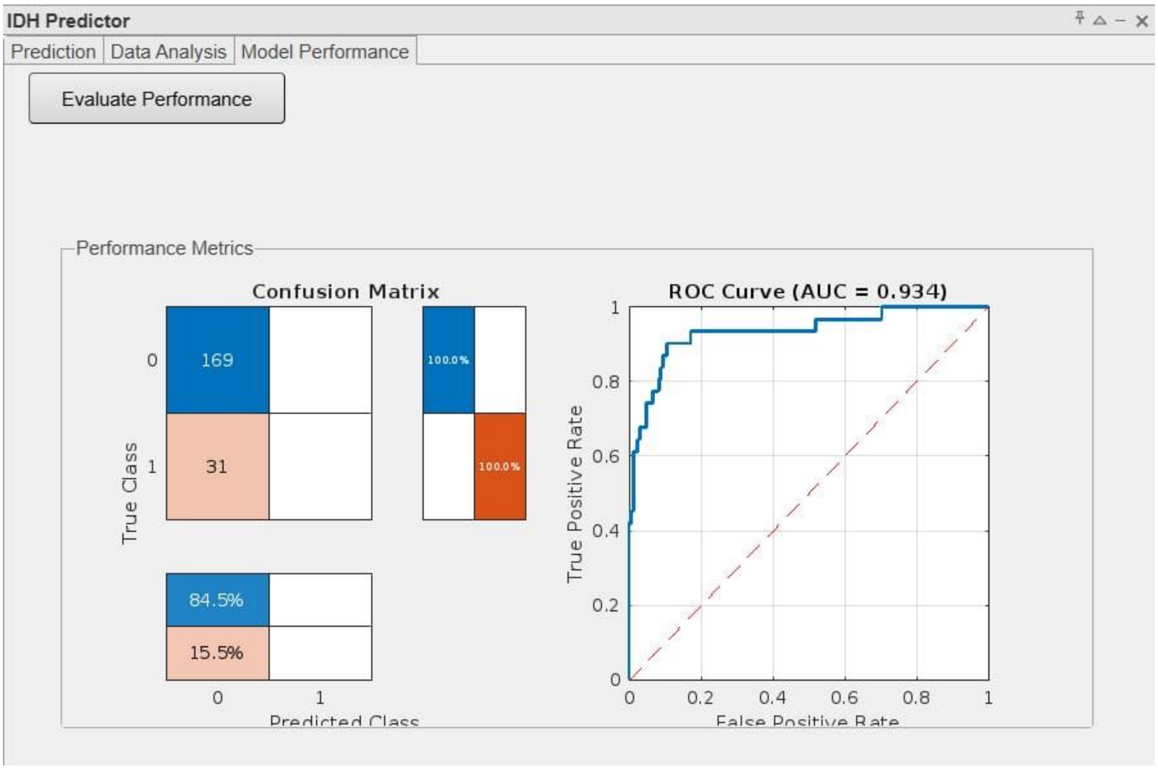


Figure 2: Model evaluation with a confusion matrix and ROC curve.

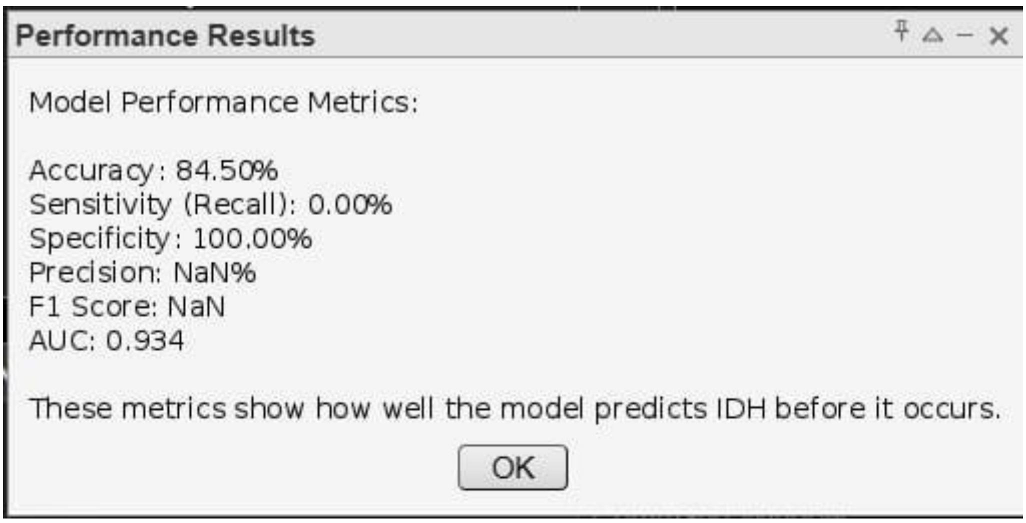


Figure 3: Performance metrics (Accuracy, Sensitivity and Specificity)

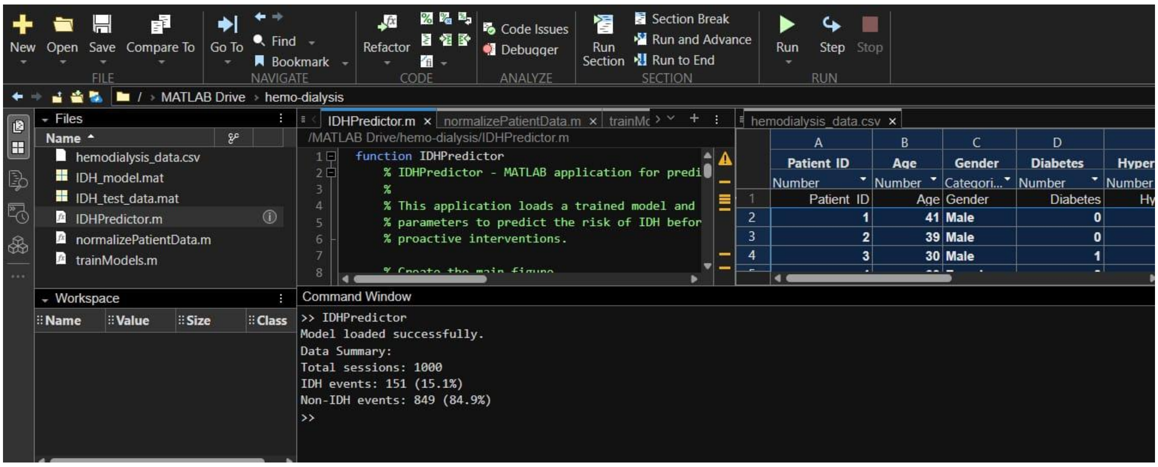


Figure 4: Matlab script loading the trained model and preparing for prediction.

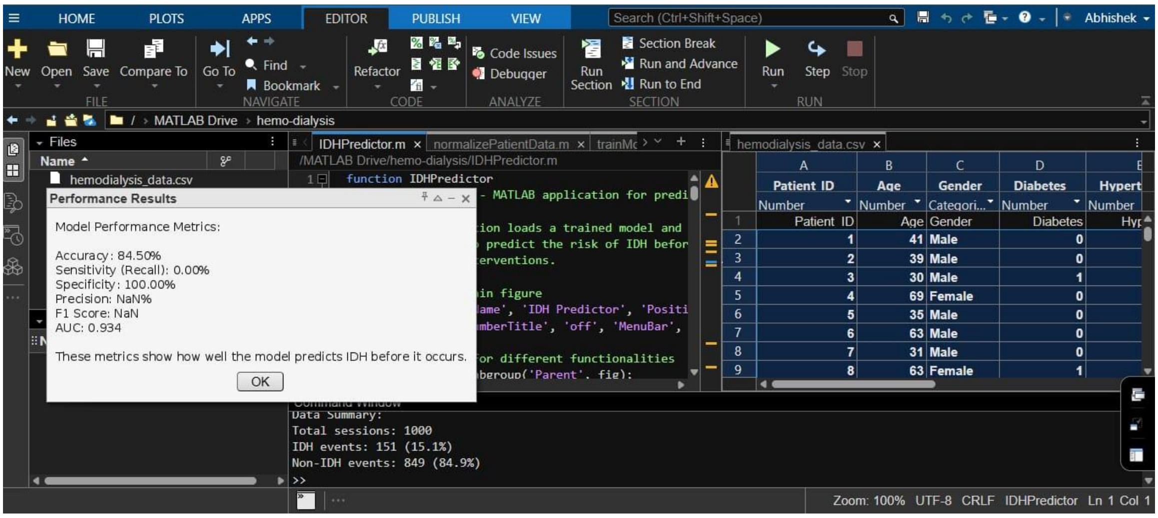


Figure 5: Matlab code that loads a model predicts IDH risks and plots predicted vs actual output

Objective 3: To design a non-invasive MATLAB-based graphical user interface (GUI) that enables healthcare providers to input patient vitals and obtain visualized IDH risk classification.

Step-by-Step Methodology

• Created GUI using MATLAB App Designer with fields for all 6 vital inputs.

• Loaded trained model inside GUI backend.

• Used a dial/gauge to show IDH risk classification in green/yellow/red zones.

• Displayed IDH probability (%) in real time along with classification label.

• Included separate tabs for data distribution and model performance visualization.

Results and Outputs

The GUI operated successfully with real-time response. Test inputs such as SBP=130, DBP=85, HR=90, UFR=2.5, Duration=4 produced a Low-Risk output (19.4%). GUI included usability-enhancing visuals like confusion matrix and ROC plots.

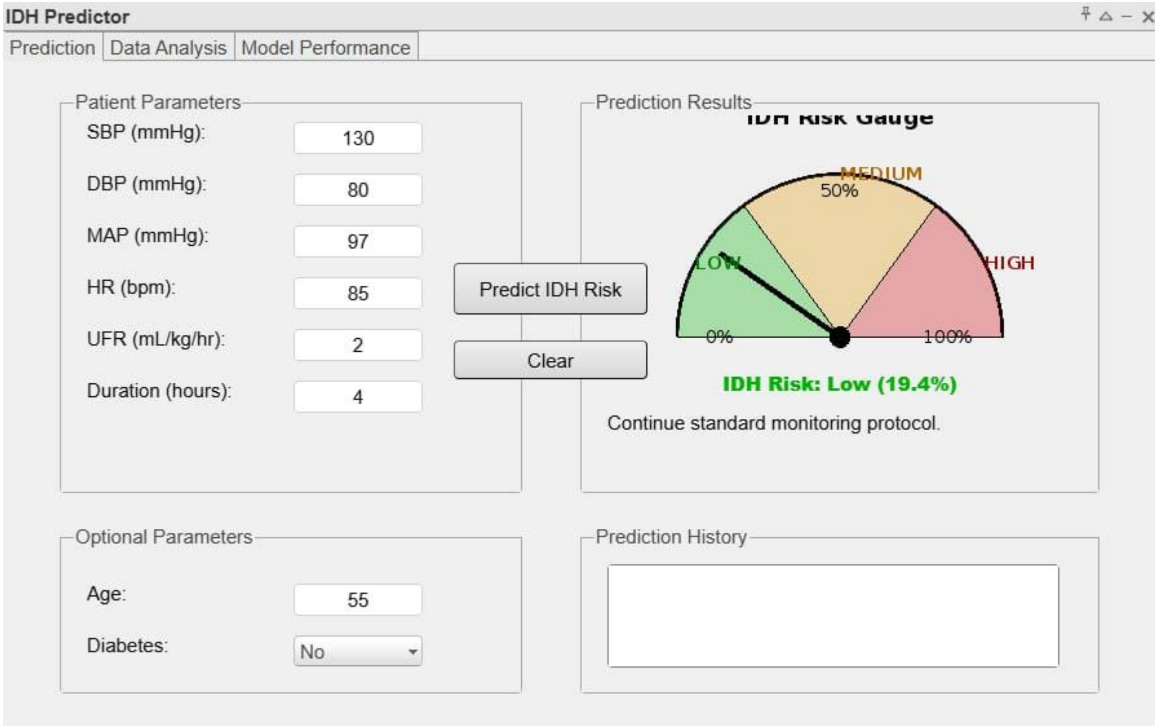


Figure 6: Model predicts IDH risk for a patient and shows a gauge.

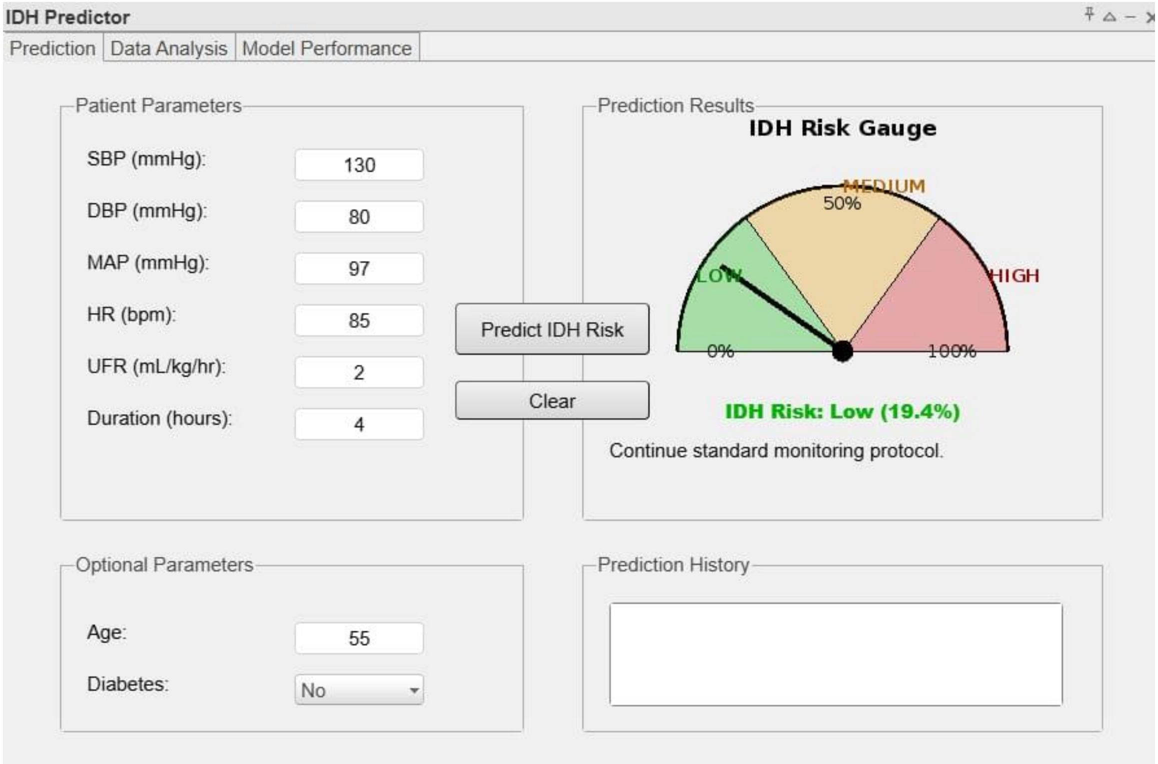


Figure 7: Example of prediction output for a patient (Low Risk).

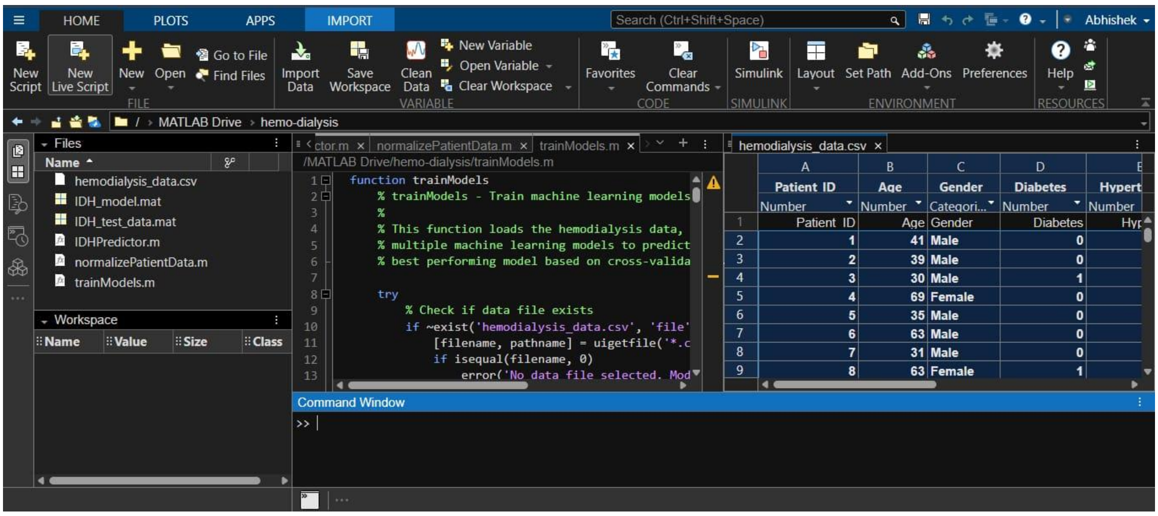


Figure 8: Script loading data set, validating it and preparing features for model.

V Limitations

While the dataset was designed using clinically grounded parameter ranges, it remains a simulated dataset and does not capture the full complexity of physiological interactions observed in real patients. As such, model performance on this dataset should be considered a proof-of-concept rather than direct evidence of clinical readiness. Other limitations include:

1. Absence of longitudinal patient data to capture session-to-session variability.
2. Potential underrepresentation of rare but clinically significant outlier cases.
3. Limited inclusion of comorbidities and other contextual clinical variables that may influence IDH risk.

To address these limitations, future work will involve:

1. Validation with large-scale, anonymized multi-center datasets.
2. Expansion of feature sets to include additional clinical variables.
3. Prospective clinical studies to assess real-time performance in dialysis units.

VI Conclusion and Future Scope

Conclusion:

The integration of AI into nephrology holds immense potential to advance patient care through precision medicine, predictive analytics, and optimized treatment protocols. AI-driven innovations, such as non-invasive diagnostic tools, real-time monitoring systems, and tailored treatment regimens, have already demonstrated tangible benefits. Continued interdisciplinary research, ethical considerations, and technological advancements will be pivotal in realizing this potential. By addressing current challenges and fostering global collaboration, AI has the capacity to transform nephrology into a more efficient, equitable, and patient-centered discipline.

Future Opportunities:

1. Development of explainable AI models to enhance clinical trust. AI algorithms designed with interpretability in mind will allow clinicians to understand the rationale behind predictions and recommendations.

2. Integration of wearable technologies and IoT devices for real-time patient monitoring. Advances in bio sensors and remote monitoring systems can significantly improve patient management.

3. Expansion of AI-driven telemedicine for remote care in underserved areas.AI-enabled platforms can provide diagnostic support and treatment recommendations in regions with limited access to nephrologists.

4. Collaborative frame works for data sharing and algorithm development, ensuring that

diverse patient populations are represented in AI training datasets.

References:

1. Lv, J.-C.; Zhang, L.-X. Prevalence and disease burden of chronic kidney disease. Adv. Exp. Med. Biol. 2019, 1165, 3–15.

2. Han, C.T.; Islam, M.M.; Poly, T.N.; Lu, Y.-C.; Lin, M.-C. A Meta-Analysis of Proton Pump Inhibitor Use and the Risk of Acute

3. Kidney Injury: Geographical Differences and Associated Factors. J. Clin. Med. 2023, 12, 2467. [CrossRef] [PubMed]

4. Luyckx, V.A.; Al-Aly, Z.; Bello, A.K.; Bellorin-Font, E.; Carlini, R.G.; Fabian, J.; Garcia-Garcia, G.; Iyengar, A.; Sekkarie, M.; Van

5. Biesen, W. Sustainable development goals relevant to kidney health: An update on progress. Nat. Rev. Nephrol. 2021, 17, 15–32.

6. Borg, R.; Carlson, N.; Søndergaard, J.; Persson, F. The Growing Challenge of Chronic Kidney Disease: An Overview of CurrentKnowledge. Int. J. Nephrol. 2023, 2023, 9609266. [CrossRef] [PubMed]

7. Wang, V.; Vilme, H.; Maciejewski, M.L.; Boulware, L.E. The economic burden of chronic kidney disease and end-stage renaldisease. In Seminars in Nephrology; W. B. Saunders: Philadelphia, PA, USA, 2016; pp. 319–330.

8. Chieh-Chen Wu, Md. Mohaimenul Islam, Tahmina Nasrin Poly, Yung-Ching Weng, Artificial Intelligence in Kidney Disease: A ComprehensiveStudy and Directions for Future Research. Diagnostics 2024, 14, 397. https://doi.org/10.3390/diagnostics14040397

9. Ehsan Nobakht, Wubit Raru, Sherry Dadgar, and Osama El Shamy, Precision Dialysis: Leveraging Big Data and Artificial Intelligence, Kidney Med Vol 6 | Iss 9 | September 2024 | 100868.

10. Toshiaki Ohara, Hiroshi Ikeda, Yoshiki Sugitani, Hiroshi Suito, Viet Quang Huy Huynh , Masaru Kinomura5, Soichiro Haraguchi6 and KazufumiSakurama, Artificial intelligence supported anemia control system (AISACS) to prevent anemia in maintenance hemodialysis patients

11. Li, Z., Liu, X., Tang, Z., Zhang, P., Jin, N., Eadon, M., Song, Q., Chen, Y., & Su, J. (2024). *TrajVis: a visual clinical decision support system to translate artificial intelligence trajectory models in the precision management of chronic kidney disease.* arXiv preprint arXiv:2401.08067.

12. Jawad, K. M. T., Verma, A., & Amsaad, F. (2024). *AI-Driven Predictive Analytics Approach for Early Prognosis of Chronic Kidney Disease Using Ensemble Learning and Explainable AI.* arXiv preprint arXiv:2406.06728.

13. Hossain, T., Sayed, F., & Islam, S. (2024). *Adaptive Local Binary Pattern: A Novel Feature Descriptor for Enhanced Analysis of Kidney Abnormalities in CT Scan Images using ensemble based Machine Learning Approach.* arXiv preprint arXiv:2404.14560.

14. Panda, K., & Mazumder, A. (2023). *Deep Learning for Polycystic Kidney Disease: Utilizing Neural Networks for Accurate and Early Detection through Gene Expression Analysis.* arXiv preprint arXiv:2309.03033.

15. Bihorac, A. (2023). *Research and writing.* Wikipedia.

16. Loupy, A. (2025). *Scientific work.* Wikipedia.

17. Hemofiltration. (2024). *Information technology and precision medicine have recently furthered the evolution of CRRT.* Wikipedia.

18. Renal replacement therapy. (2024). *Information technology and precision medicine have recently furthered the evolution of CRRT.* Wikipedia.

19. Borg, R., Carlson, N., Søndergaard, J., & Persson, F. (2023). *The Growing Challenge of Chronic Kidney Disease: An Overview of Current Knowledge.* International Journal of Nephrology, 2023, 9609266.

20. Nobakht, E., Raru, W., Dadgar, S., & El Shamy, O. (2024). *Precision Dialysis: Leveraging Big Data and Artificial Intelligence.* Kidney Medicine, 6(9), 100868.