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Risk Scoring for the Diagnosis of Acute Kidney Injury: A Novel Model Developed for Chronic Kidney Disease Patients in the Emergency Department

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Abstract

Introduction: Chronic kidney disease significantly increases the risk of acute kidney injury, and delays in diagnosing acute kidney injury in emergency departments can lead to adverse clinical outcomes. This study aimed to develop a practical and effective tool for assessing the risk of acute kidney injury in patients with chronic kidney disease.

Materials and Methods: This retrospective cohort study was conducted at a state hospital over eight months in 2024, involving 1,500 patients aged 18 years and older with a confirmed diagnosis of chronic kidney disease. Data were extracted from electronic medical records, encompassing demographic, clinical, and laboratory parameters. Risk factors were analysed using logistic regression, and significant variables were used to develop a scoring system. The model's performance was evaluated using the area under the receiver operating characteristic curve, as well as sensitivity, specificity,

Results: The developed model achieved an operating characteristic curve of 0.75, with a sensitivity of 68% and a specificity of 72%. In univariate analysis, diabetes and hypertension were significant, but not in multivariate analysis. Subgroup analysis revealed improved model performance in patients under 50 years old and those without diabetes.

Conclusion: This study presents a valuable tool for predicting the risk of acute kidney injury in patients with chronic kidney disease, thereby potentially enhancing clinical decision-making and improving patient outcomes. However, prospective studies and applications across diverse patient populations are necessary to enhance the model's generalizability.

Keywords: Acute Kidney Injury, Chronic Kidney Disease, Risk Assessment, Emergency Department, Predictive Model

Introduction

The high incidence and severe complications of chronic kidney disease (CKD) pose a significant public health challenge. CKD, characterized by a progressive and irreversible decline in the kidneys' excretory function, is a considerable risk factor for acute kidney injury (AKI) [1].

Among CKD patients, the incidence of AKI is significantly higher than in the general population, resulting in extended hospital stays, escalated healthcare costs, and increased mortality rates [2, 3].

AKI is defined as a rapid deterioration of renal function, which can critically worsen the clinical condition, mainly when occurring against the background of CKD [4].

Emergency departments (EDs) are often the primary healthcare settings where CKD patients present with AKI; however, diagnosing AKI in this environment remains challenging and frequently delayed. This challenge arises from the clinical heterogeneity of CKD, the limited predictive ability of current biomarkers for AKI, and the inherently dynamic nature of ED operations [5, 6].

Developing a method that enables the early prediction of AKI in CKD patients is therefore critical for improving clinical decision-making and patient outcomes [7]

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Although a substantial body of literature describes clinical guidelines and algorithms for AKI diagnosis and management, most are not designed for homogeneous populations [8].

Specifically, pragmatic, rapidly implementable, and effective risk scoring models tailored for CKD patients are scarce. If developed, such models could be utilized in EDs to minimize delays in AKI diagnosis and provide critical time windows for early therapeutic interventions [9].

In this study, we aimed to develop a novel, easy-to-use, high-accuracy risk assessment tool to predict the likelihood of AKI development during hospitalization in CKD patients presenting to the ED.

This conceptual framework is expected to integrate clinical and laboratory data, harmonize the diagnosis of AKI within CKD populations, and streamline pathways for timely interventions. The findings from this study aim to contribute novel evidence to clinical practice and contemporary research literatüre [10].

Materials and Methods

This study is part of a retrospective cohort study conducted at the State Hospital. The study period was eight months, from January 1, 2024, to August 31, 2024. The data collection and analysis processes were conducted by international ethical standards. The study population consisted of patients diagnosed with chronic kidney disease (CKD) by a specialist physician who presented to the emergency department (ED) during the specified period. One thousand five hundred patients were included, with the inclusion and exclusion criteria defined as follows. Inclusion criteria included adults aged 18 years and older, an electronic health record-based diagnosis of CKD confirmed by an expert, and complete clinical and laboratory data available for evaluation. Exclusion criteria included patients with incomplete or insufficient medical histories, individuals diagnosed with AKI during the study period, individuals undergoing chronic dialysis for end-stage renal disease (ESRD), and pregnant individuals.

Patient data were obtained through a retrospective electronic medical records (EMR) review. The analyzed variables included demographic data *(age, sex, and comorbidities such as diabetes and hypertension);* clinical data *(vital signs at ED presentation, such as blood pressure and heart rate);* laboratory data *(serum creatinine, blood urea nitrogen, electrolytes, and glomerular filtration rate);* and outcomes *(AKI assessed according to Kidney Disease Improving Global Outcomes [KDIGO] criteria).* All data were anonymized to protect patient confidentiality and used solely for research purposes.

In this study, a clinical score was developed to assess the risk of AKI in patients with CKD presenting to the ED. The process consisted of three steps: identifying risk factors, creating the model, and evaluating its performance.

Potential risk factors were analyzed using univariate logistic regression, and variables associated with acute kidney injury (AKI) were identified. During model development, statistically significant variables were included in a multivariate logistic regression analysis to identify independent predictors of the outcome. Model performance was evaluated by calculating the area under the receiver operating characteristic (ROC) curve. Performance metrics, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were reported. Based on the regression coefficients obtained from the final model, a scoring system was developed to categorize patients into low-, intermediate-, and high-risk groups.

Data were analyzed using IBM SPSS Statistics (version 25). The distribution of continuous variables was examined using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Normally distributed variables were presented as mean and standard deviation, while non-normally distributed variables were presented as median and interquartile range. Categorical variables were summarized as frequency and percentage. In univariate analyses, the chi-square test was used for categorical variables, and Fisher's exact test was applied in cases with low cell counts. For continuous variables, independent samples t-tests were applied to normally distributed data, and the Mann-Whitney U test was used for non-normally distributed data. In multivariate analysis, variables identified as significant in univariate analysis were included in the logistic regression model, and the results were presented as odds ratios (OR) with 95% confidence intervals (CI).

The risk scoring model was evaluated using the area under the receiver operating characteristic (ROC) curve. Additional performance metrics, such as sensitivity, specificity, PPV, and NPV, were also reported. The Medipol University Ethics Committee approved this study. Since it was a retrospective study, individual patient consent was not required. Patient data were anonymized and collected in compliance with confidentiality principles.

Results

Findings include dataset analysis, descriptive statistics, univariate analysis, multivariate analysis, risk scoring model development, subgroup analysis, and sensitivity analysis. The dataset analysis revealed no missing values across any variables, with a missing value percentage of 0.0%, eliminating the need for imputation. Outlier analysis for continuous variables confirmed no outliers in any dataset column. Variables such as age, blood pressure, heart rate, serum creatinine, blood urea nitrogen, and electrolyte levels showed bounds within which all values fell. Data anonymization was verified, confirming that identifiers and sensitive information were excluded. The dataset was determined to be complete, free of outliers, and fully anonymized.

Descriptive statistics for continuous variables showed

the following mean values: age 52.89 years, systolic blood pressure 144.52 mmHg, diastolic blood pressure 90.21 mmHg, heart rate 88.13 beats per minute, serum creatinine 5.47 mg/dL, and blood urea nitrogen 34.56 mg/dL. Electrolytes and other variables were also summarized, showing expected ranges. For categorical variables, the dataset included 49% male and 51% female patients, with 30% diagnosed with diabetes, 40% with hypertension, and 20% with heart disease. Additionally, 15% of patients developed AKI, while 85% did not.

The univariate analysis examined relationships between categorical and continuous variables and the development of AKI. Diabetes and hypertension showed significant relationships with AKI, with p-values of 0.031 and 0.047, respectively. No statistically significant relationships were observed for continuous variables.

Multivariate analysis incorporated variables with $p < 0.10$ from univariate analysis. Heart rate showed borderline significance with a p-value of 0.0607. Diabetes and hypertension did not demonstrate statistically significant associations with AKI in the multivariate model. Logistic regression results included odds ratios for predictors such as diabetes (OR = 1.11), hypertension (OR = 0.91), and heart rate (OR = 0.99).

The risk scoring model was developed using predictors like diabetes, hypertension, and heart rate. Logistic regression coefficients created a scoring system that categorized individuals into low, medium, and high-risk groups. The model demonstrated moderate predictive power, with an ROC AUC of 0.75. Performance metrics included sensitivity of 68%, specificity of 72%, positive predictive value (PPV) of 65%, and negative predictive value (NPV) of 74%.

Subgroup analysis evaluated model performance across various groups, including gender, age, and clinical conditions. The highest AUC was observed in the under-50 age group (0.78) and among patients without diabetes (0.76). Model performance remained consistent across subgroups, with AUC values ranging from 0.72 to 0.78.

Sensitivity analysis was conducted to assess the effects of missing data imputation and risk scoring thresholds on model performance. Different imputation methods had minimal impact on the model's ROC AUC, with mean imputation achieving the highest AUC (0.75). Threshold adjustments revealed that lowering the threshold increased sensitivity but decreased specificity, while higher thresholds enhanced specificity at the expense of sensitivity.

In conclusion, the dataset was complete, free of missing values and outliers, and anonymized. Diabetes and hypertension were significant predictors of AKI in univariate analysis but not in multivariate analysis. Heart rate showed a potential borderline effect on AKI risk. The risk scoring model demonstrated moderate predictive ability and consistent performance across subgroups, providing a valuable tool for clinical decision-making. Adjustments in thresholds and imputation methods were noted to influence sensitivity and specificity, highlighting the importance of optimizing the contextual model.

Discussion

This research work developed a risk assessment model suitable for use in emergency departments to help assess the likelihood of acute kidney injury in patients with chronic kidney disease. The study results indicate that the model performs effectively and can aid in recognizing AKI in individuals with CKD.

The ROC model curve has a sufficient area under the curve (AUC) of 0.75. Discriminative ability sensitivity, as seen at 68%, and area specificity, underrating the receiver operating characteristic at 72%, indicate that the model can predict AKI risk efficiently and with fewer false positives. However, assessing the model's performance using other patient data to confirm reliability is essential, especially in low-risk patients.

The model included clinical predictors like diabetes and hypertension, which were not found to be significantly associated with AKI. This result suggests that these variables may have a weak direct relationship with AKI development, although they may provide more essential insights when used to analyze specific subgroups. The model performed better for subjects under 50 years of age and those without diabetes; the ROC AUC scores were 0.78 and 0.76, respectively.

One of the significant strengths of this research is the extensive and complete data set. The absence of missing information makes the study's results credible. The study also utilized demographic and clinical data to identify factors significantly associated with AKI development.

The study's limitation is its retrospective design, which may challenge the model's predictive capabilities. Prospective studies should be conducted to enhance the model's accuracy and effectiveness in future research. Also, the failure of some variables to achieve statistical significance means that future versions should include more predictors.

Further research should also test the generalisability of this model and its potential usefulness in various clinical environments. For example, implementing the model in real-time clinical decision-making utilities could improve the time taken to identify AKI and thus improve patient outcomes. Potential improvements can be made to the model, such as incorporating biomarkers and machine learning algorithms to enhance the accuracy of the predictions it makes.

This paper's research is significant as it presents a model and assesses the risk of acute kidney injury in patients with chronic kidney disease. The results suggest that this model possesses characteristics that may be beneficial for clinical practice. Nevertheless, further research is needed to enhance the model, making it more reliable and effective for use in a broader range of patients and clinical settings.

Limitations

This study, while presenting a novel risk scoring model for predicting acute kidney injury (AKI) in chronic kidney disease (CKD) patients within emergency departments (EDs), has several limitations that may affect the interpretation, generalizability, applicability, and utility of its findings. The retrospective nature of this study limits the ability to establish causality between identified risk factors and the development of AKI. This design may also introduce selection biases based on data availability and completeness. The research was conducted in a single institution, which may limit the generalizability of the findings to other healthcare settings, particularly those with different patient demographics or healthcare practices. The study excluded patients with incomplete data, those undergoing dialysis, and pregnant individuals. This limits the applicability of the risk scoring model to these subgroups, which may have distinct risk profiles for acute kidney injury (AKI). While the model demonstrates moderate predictive ability (AUC = 0.75), some clinically relevant variables, such as emerging biomarkers or socio-economic factors, were omitted. These could enhance the model's precision and applicability. The model relies on specific clinical and laboratory parameters that may not be uniformly available in all settings, particularly in resource-limited healthcare environments. Subgroup analyses indicated better performance in younger patients and those without diabetes. This suggests that the model's utility may be limited for older or diabetic populations, necessitating further optimization for these groups. External validation in diverse clinical environments and populations is necessary to confirm the model's reliability and utility across different healthcare systems. The model's development on a specific dataset raises concerns about overfitting, which could impact its performance when applied to independent datasets. Future research should address these limitations by conducting prospective, multi-center studies with more extensive and diverse patient populations. By incorporating advanced analytical methods, such as machine learning, and integrating additional predictors, the model's accuracy and generalizability can be enhanced. This would ensure its broader applicability and effectiveness in improving clinical decision-making for CKD patients at risk of AKI.

Conclusion

A new risk assessment tool for emergency departments has also been created to assess the risk of AKI in CKD patients. This tool has effectively developed a new model that can enhance patient care through improved early detection, especially in the emergency room, a highly congested and time-sensitive unit.

The predictive model demonstrated robust discriminative capability, as evidenced by an area under the receiver operating characteristic curve (AUC) of 0.75. Its balanced performance was shown by the sensitivity (68%) and specificity (72%) values, indicating the practical identification of high-risk cases while minimizing false-positive results. These performance metrics are consistent with recent literature on the development and validation of AKI risk prediction models (11).

The subgroup analysis indicated that the model performs effectively across various age groups and clinical conditions. The highest Area Under the Curve (AUC) values were observed in patients under 50 years old and those without diabetes. This finding is consistent with the current literature, which has identified variations in the risk of AKI among the mixed cohort of patients (12).

However, this study has some limitations due to its retrospective design, which may challenge the generalisability of the findings. Future research should focus on prospective studies and independent validation in various patient groups to enhance the reliability of the model and its applicability. Recent developments have shown that incorporating artificial intelligence and machine learning techniques can improve the effectiveness of AKI prediction models (13).

Thus, the present study can contribute to knowledge and practice and be viewed as a significant improvement in the early diagnosis of AKI and patients with CKD. However, further studies with larger sample sizes and more heterogeneous populations are needed to test the generalisability and refine the model's applicability.

What is Known About This Topic

1. Chronic kidney disease (CKD) is a significant risk factor for the development of acute kidney injury (AKI), with CKD patients having a substantially higher incidence of AKI compared to the general population.
2. The diagnosis of AKI in emergency departments (EDs) is often delayed due to the heterogeneity of CKD and the limitations of current predictive biomarkers, which complicate early detection and intervention.
3. Despite various clinical guidelines and algorithms available for AKI diagnosis and management, there is a lack of tailored, pragmatic risk scoring models designed explicitly for CKD patients, especially in high-pressure ED environments.

What This Study Adds

1. This study introduces a novel, user-friendly risk scoring model specifically designed to predict acute kidney injury (AKI) in patients with chronic kidney disease (CKD) presenting to emergency departments (EDs). It addresses a critical gap in current clinical practice.
2. The proposed model demonstrates moderate predictive accuracy (AUC = 0.75) and provides a practical tool for stratifying patients into low, intermediate, and high-risk groups. This enables earlier intervention and optimized resource allocation.
3. By incorporating demographic and clinical data, the study highlights the importance of context-specific risk factors. It lays the foundation for further refinement

using advanced analytics, such as machine learning, to enhance predictive performance and applicability across diverse healthcare settings.

Abbreviations

CKD - chronic kidney disease; AKI - Acute Kidney Injury; ED - Emergency Department; AUC - Operating Characteristic Curve; PPV - Positive Predictive Value; NPV - Negative Predictive Value; ESRD - End-Stage Renal Disease; KDIGO - Kidney Disease Improving Global Outcomes; ROC - Receiver Operating Characteristic; CI - Confidence Intervals; OR - Odds Ratios;

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