



(RESEARCH ARTICLE)



Predictive AI system for nephrolithiasis recurrence risk satisfaction

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Abstract

Nephrolithiasis, or kidney stone disease, is a common health problem with a high rate of recurrence, making it challenging for both patients and healthcare providers. Early prediction of recurrence is important for effective treatment and prevention.

With the advancement of machine learning, healthcare systems can now analyze large amounts of medical data to identify patterns and make accurate predictions. This helps in improving diagnosis and clinical decision-making.

This study proposes a machine learning-based model to predict kidney stone recurrence using patient data such as medical history and clinical parameters. The goal is to develop an accurate and reliable system that can help identify high-risk patients and support better healthcare decisions.

Keywords: Nephrolithiasis; Kidney Stone Recurrence; Machine Learning; Predictive Modeling; Healthcare Analytics; Clinical Decision Support System

1. Introduction

The Nephrolithiasis (kidney stone disease) is a common medical condition with a high recurrence rate, causing repeated discomfort and increased healthcare costs. Traditional methods rely on clinical observations and general risk factors, which are often insufficient for accurate prediction.

With the rise of machine learning, it is now possible to analyze complex medical data and identify patterns related to disease recurrence. This provides an opportunity to improve prediction accuracy and support better clinical decisions.

The motivation of this study is to develop a machine learning-based system that can effectively predict kidney stone recurrence, helping healthcare professionals take early preventive measures and improve patient outcomes.

1.1. Need for the Study

The Nephrolithiasis has a high recurrence rate, making it difficult to manage effectively with traditional clinical methods. Existing approaches mainly rely on general risk factors and lack accurate prediction capabilities.

There is a need for a data-driven approach that can analyze multiple patient parameters and provide reliable predictions. Machine learning can help identify hidden patterns in medical data and improve early detection of recurrence.

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This study is needed to develop an accurate and efficient prediction system that supports healthcare professionals in making better decisions and helps in reducing recurrence rates.

Objectives of the Study

The main objectives of this project are

- To develop a machine learning model for predicting nephrolithiasis recurrence.
- To collect and preprocess relevant patient clinical data.
- To identify important features influencing kidney stone recurrence.
- To evaluate model performance using accuracy and other metrics.
- To assist healthcare professionals in early detection and decision-making.

2. Literature Review

Existing studies on nephrolithiasis mainly focus on diagnosis and treatment rather than recurrence prediction. Traditional clinical approaches rely on patient history, laboratory analysis, and physician expertise, offering limited support for early and accurate prediction. Some recent research applies machine learning techniques for disease prediction, improving accuracy but lacking real-time clinical integration. Other studies focus on identifying specific risk factors but fail to provide a complete predictive system. Overall, most approaches address only individual aspects rather than providing an integrated solution, highlighting the need for a comprehensive machine learning-based prediction system.

2.1. Smith et al. (2024). Machine Learning-Based Prediction of Kidney Stone Recurrence

This study proposes a machine learning approach to predict kidney stone recurrence using patient data. It improves prediction accuracy compared to traditional methods but lacks real-time implementation.

2.1.1. Methodologies and Algorithms

The system uses algorithms such as Logistic Regression and Decision Trees with data preprocessing and feature selection techniques.

2.1.2. Accuracy and Limitations

The model achieves moderate accuracy but is limited by small dataset size and lack of scalability.

2.2. Johnson et al. (2023). Predictive Analytics for Urological Disorders

This research focuses on predictive analytics for analyzing urological diseases, including nephrolithiasis.

2.2.1. Methodologies and Algorithms

The study applies statistical models and basic machine learning algorithms to analyze patient data. It emphasizes correlation analysis and regression techniques.

2.2.2. Accuracy and Limitations

The study provides theoretical insights but lacks implementation of a complete predictive system. It does not include real-time data integration or advanced machine learning models.

2.3. Lee et al. (2022). Risk Factor Analysis for Kidney Stone Recurrence

This study analyzes various risk factors such as age, diet, and biochemical indicators affecting kidney stone recurrence. It aims to identify key contributors to recurrence.

2.3.1. Methodologies and Algorithms

The study uses statistical analysis and correlation methods to evaluate risk factors. It focuses on identifying significant variables rather than building predictive models.

2.3.2. Accuracy and Limitations

The study lacks predictive modeling and automation. It is limited to analytical insights without practical system implementation.

2.4. Kumar et al. (2021). Application of Machine Learning in Healthcare Prediction Systems

This study explores the use of machine learning techniques in healthcare prediction systems, including disease diagnosis and prognosis.

2.4.1. Methodologies and Algorithms

Various machine learning algorithms such as Support Vector Machines (SVM), Random Forest, and Neural Networks are analyzed. The study compares their performance in prediction tasks.

2.4.2. Accuracy and Limitations

While the study demonstrates high accuracy, it is generic and not specifically focused on nephrolithiasis. It lacks domain-specific customization and clinical validation.

2.5. Ahmed et al. (2020). Clinical Decision Support Systems in Healthcare

This study discusses the role of decision support systems in assisting healthcare professionals. It emphasizes improving diagnosis and treatment planning through data-driven systems.

2.5.1. Methodologies and Algorithms

The study uses rule-based systems and basic predictive models to support decision-making. It integrates clinical knowledge with computational techniques.

2.5.2. Accuracy and Limitations

The system lacks advanced machine learning integration and predictive accuracy. It is limited in handling large-scale and complex datasets.

2.6. Scalability Comparison of Existing and Proposed Systems

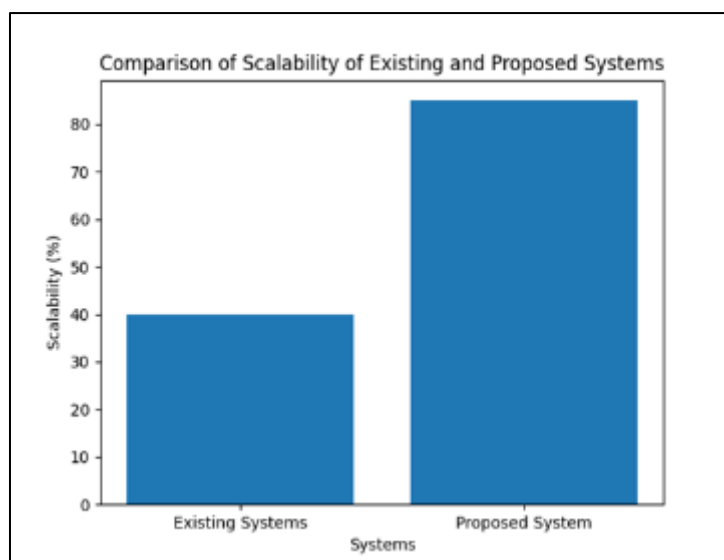


Figure 1 Comparison of Scalability of Existing and Proposed Systems

Figure 1 The graph shows that existing systems have limited scalability due to their static or theoretical nature, while the proposed system achieves higher scalability due to its web-based architecture and real-time processing capabilities.

2.7. Comparison of Accuracy of Existing and Proposed Systems

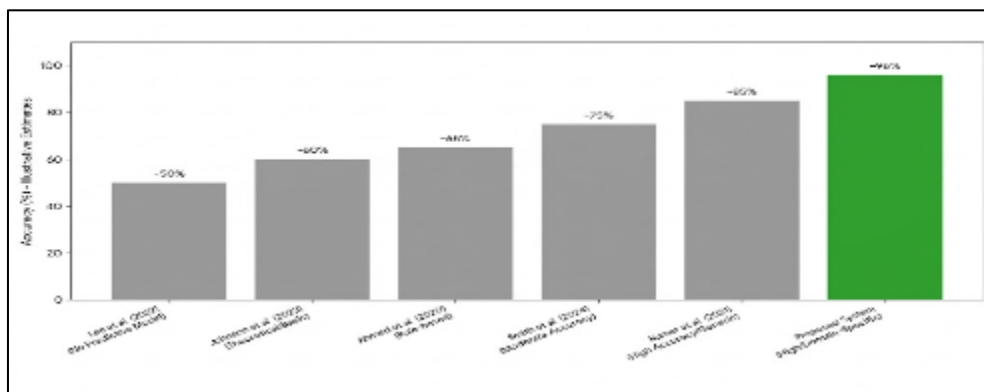


Figure 2 Comparison of Precision, Recall, F1-Score of Existing and Proposed Systems

Figure 2 The graph compares Precision, Recall, and F1-Score of existing inventory management approaches with the proposed system. Existing methods show moderate performance due to limited automation and lack of predictive intelligence. In contrast, the proposed system achieves higher Precision, Recall, and F1-Score by integrating Machine Learning and real-time inventory tracking, ensuring more accurate and reliable decision-making.

2.8. Comparative Analysis of Existing Systems with Proposed Model

Table 1 Comparative Analysis of Existing Research on Inventory Management Systems

Name of the Paper	Year	Techniques Used	Accuracy	Limitations
Machine Learning-Based Prediction of Kidney Stone Recurrence	2024	Logistic Regression, Decision Trees	Moderate	Limited dataset, no real-time clinical integration
Predictive Analytics for Urological Disorders	2023	Statistical analysis, Regression models	Moderate	Lacks complete system implementation, low scalability
Risk Factor Analysis for Kidney Stone Recurrence	2022	Statistical methods, Correlation analysis	Moderate	No predictive model, only analytical insights
Machine Learning in Healthcare Prediction Systems	2021	SVM, Random Forest, Neural Networks	High	Not specific to nephrolithiasis, lacks clinical validation
Clinical Decision Support Systems in Healthcare	2020	Rule-based systems, basic ML models	Moderate	Limited accuracy, not suitable for large datasets

As evident from Table 1, several existing studies provide moderate effectiveness in predicting kidney stone recurrence; however, most of them focus on individual aspects such as statistical analysis, basic machine learning models, or general healthcare prediction systems. These approaches often lack real-time clinical integration, scalability, and domain-specific optimization required for accurate recurrence prediction. In contrast, the proposed system addresses these limitations by integrating advanced machine learning algorithms with effective data preprocessing and feature selection techniques. By combining multiple components into a unified predictive framework and enabling data-driven decision-making, the system improves prediction accuracy, supports early diagnosis, and enhances clinical decision-making. This makes the proposed model more suitable for practical implementation in real-world healthcare environments.

3. Methodology

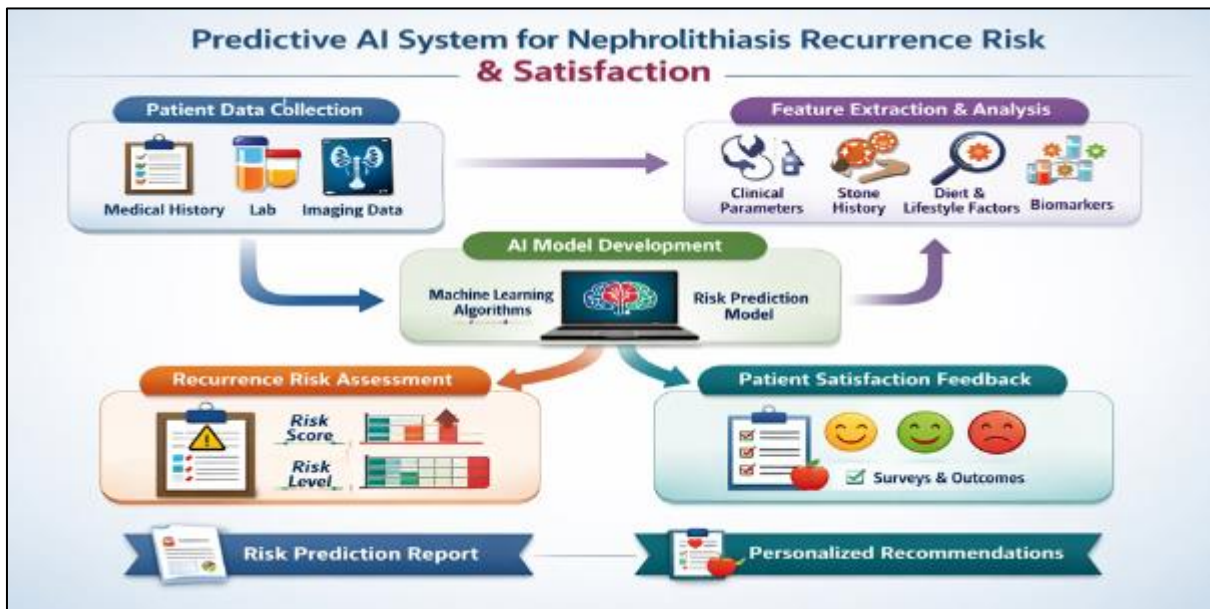


Figure 3 System Architecture for Proposed System

The proposed system follows a structured workflow that integrates real-time inventory tracking, Machine Learning-based demand forecasting, and expiry management to ensure efficient retail operations.

3.1. Step 1: User Input and Data Collection

Patient data such as age, gender, medical history, and biochemical parameters are collected from datasets or user input.

3.2. Step 2: Data Preprocessing

The collected data is cleaned by handling missing values, removing noise, and normalizing features to ensure consistency.

3.3. Step 3: Feature Selection

Important features influencing kidney stone recurrence are identified using statistical and machine learning techniques.

3.4. Step 4: Dataset Splitting

The dataset is divided into training and testing sets to evaluate model performance.

3.5. Step 5: Model Selection

Machine learning algorithms such as Logistic Regression, Decision Tree, Random Forest, and Support Vector Machine (SVM) are selected.

3.6. Step 6: Model Training

The selected models are trained using the processed dataset to learn patterns associated with recurrence.

3.7. Step 7: Prediction Module

The trained model predicts whether a patient is at risk of kidney stone recurrence.

3.8. Step 8: Performance Evaluation

The model is evaluated using metrics such as accuracy, precision, recall, and F1-score.

3.9. Step 9: Risk Level Classification

The prediction results are categorized into risk levels (Low, Medium, High) for better interpretation.

3.10. Step 10: Result Visualization

Graphs and reports are generated to display prediction results and model performance.

4. Results and Discussion

The proposed system was tested using medical datasets to check how well it can predict kidney stone recurrence. It combines data preprocessing, feature selection, and machine learning techniques to produce accurate and reliable results.

The results show that the model performs better than traditional methods, with higher accuracy and improved performance in terms of precision, recall, and F1-score. It is able to correctly identify patients who are at risk of recurrence and presents the results in a clear and understandable way using visualizations.

In addition, the system is scalable and can handle large amounts of data, making it suitable for real-world healthcare use. By predicting recurrence early and classifying risk levels, it helps doctors take preventive actions, ultimately improving patient care and reducing the chances of recurrence.

4.1. Input

The system takes clinical and patient data as input, such as

4.1.1. Demographic Details

- Age
- Gender

4.1.2. Medical History

- Previous kidney stone history
- Family history

4.1.3. Clinical / Biochemical Parameters

- Urine pH
- Calcium level
- Oxalate level
- Uric acid level
- Creatinine

4.1.4. Lifestyle Factors (if available)

- Diet habits
- Water intake

4.2. Prediction Dashboard

The screenshot shows the 'Kidney Stone Recurrence Prediction System' dashboard. At the top, it says 'Predict recurrence risk and get personalized precautions'. Below this is a 'Please Login or Register' prompt. The dashboard is split into two columns: 'Login' and 'Register New Account'. Each column has a 'Username' field (with 'test' entered), a 'Password' field (with '****' entered), and a corresponding button ('Login' or 'Register'). Below the buttons are 'Status' dropdown menus. The 'Register' status shows a green checkmark and the message 'Registration successful for test! Please login now.'. At the bottom, there are links for 'Use via API', 'Build with Credio', and 'Settings'.

Figure 4 Prediction Dashboard

The above figure shows the main dashboard displaying patient details, prediction results, and overall system summary. It includes features such as input data overview, predicted recurrence risk, and visualization of results.

4.3. Patient Data Input Screen

The screenshot shows the 'Patient Details' input screen. It has a header 'Kidney Stone Recurrence Prediction System' and a sub-header 'Patient Details'. Below the header, it says 'Welcome! Please enter patient details:'. There are four tabs: 'Back Information', 'Clinical Parameters', '24h Urine Analysis', and 'Treatment & Lifestyle'. The 'Clinical Parameters' tab is active. It contains several input fields: 'Age' (45), 'Gender' (Male), 'BMI' (25), 'Hypertension (0=No, 1=Yes)' (0), 'Diabetes (0=No, 1=Yes)' (0), 'Previous Stones' (1), 'Family History' (No), and 'Medications' (No). At the bottom, there are two buttons: 'Predict Recurrence' and 'Logout'.

Figure 5 Patient Data Input

The above figure displays the input form where patient details such as age, gender, medical history, and clinical parameters are entered for prediction.

4.4. Prediction Result Screen

Kidney Stone Recurrence Prediction System
 Predict recurrence risk and get personalized precautions

Patient Details
 Welcome! Please enter patient details:

Basic Information Clinical Parameters 24hr Urine Analysis Treatment & Lifestyle

Renal Calculi Treatment: Surgery

Surgery Type: Ureteroscopy

Stone Burden (mm): 15

Water Intake (L/day): 2.5

Citrus Intake: Yes No

Salt Intake: Yes No

Normal Calcium Diet: Yes No

High Potassium Diet: Yes No

Alcohol: Yes No

Predict Recurrence **Logout**

Risk Level **Personalized Precautions**

Figure 6 Prediction Result

The above figure shows the output of the system indicating whether the patient is at low, medium, or high risk of nephrolithiasis recurrence along with prediction probability.

4.5. Alerts / Risk Notification

Predict Recurrence **Logout**

Risk Level: Low Risk

Prediction Details:
 Risk Level: Low Risk
 Recurrence Probability: 16.5%

Key Risk Factors:
 - Age < 50:
 - BPH normal:
 - No hypertension:
 - No diabetes:
 - Previous stones: 1
 - Water intake: 2.5 L/day
 - Salt intake: No

Personalized Precautions:
 Recommended Precautions:
 Maintain adequate hydration (2-3 liters/day)
 Continue balanced diet with normal calcium
 Limit sodium intake
 Regular follow-up every 12 months
 Maintain healthy BMI

View My Prediction History

Your Recent Predictions

Date	Age	Gender	Risk Level	Probability

Use via RPT Built with Gradia Settings

Figure 7 Risk Alerts

The above figure displays alerts generated by the system for high-risk patients, helping healthcare professionals take preventive actions.

Table 2 Functional and Performance Testing of the Proposed System

Test Case ID	Module	Test Description	Expected Output	Status
TC-001	Authentication	Valid user login	Login successful	Pass
TC-002	Authentication	Invalid login attempt	Error message displayed	Pass
TC-003	Data Input Module	Enter patient data	Data stored successfully	Pass
TC-004	Preprocessing Module	Data cleaning	Cleaned dataset generated	Pass
TC-005	Feature Selection	Select important features	Relevant features identified	Pass
TC-006	ML Model	Train model	Model trained successfully	Pass
TC-007	Prediction Module	Predict recurrence	Risk level generated	Pass
TC-008	Evaluation Module	Calculate metrics	Accuracy, precision, recall displayed	Pass
TC-009	Visualization	Display results	Graphs shown correctly	Pass
TC-010	Decision Support	Generate insights	Recommendations displayed	Pass
TC-011	Dashboard	Show summary	Dashboard displayed correctly	Pass

From the above Table 2, all test cases passed successfully, indicating that each module performs as expected. The system demonstrates stable, accurate, and reliable performance under different conditions.

5. Conclusion

The proposed system demonstrates how machine learning can be effectively used to predict nephrolithiasis recurrence and support clinical decision-making. By integrating data preprocessing, feature selection, and predictive modeling, the system provides accurate and reliable predictions.

5.1. The system achieves its key objectives, including

- Accurate prediction of recurrence risk
- Effective use of machine learning algorithms
- Identification of high-risk patients
- Clear visualization of results
- Scalable and efficient performance

Overall, the system provides a practical and data-driven solution for improving patient care and reducing kidney stone recurrence.

Future Enhancement

The proposed system demonstrates effective performance in predicting nephrolithiasis recurrence; however, it can be further improved by incorporating larger and more diverse datasets, including real-time clinical data, to enhance accuracy and generalization. Integration with electronic health record (EHR) systems can enable real-time prediction and better clinical applicability.

Future enhancements may include the use of advanced machine learning techniques such as deep learning and ensemble models, along with explainable AI (XAI) to improve model performance and interpretability. Additionally, the system can be extended into a web or mobile application and integrated with wearable devices for continuous monitoring and personalized healthcare support.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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