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REVIEW ARTICLE

Machine Learning Techniques for Kidney Tumor Detection: A Literature Review

S H Barshikar[1], S S Lokhande[2]*

1 Research Scholar, Sinhgad College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India
2 Professor, Sinhgad College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India

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* **Corresponding author**.

sslokhande.scoe@sinhgad.edu

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Abstract

Abnormal growths in the kidneys known as kidney tumors can be harmful if they are not discovered in time. It's critical to identify them promptly and accurately in order to save lives. In this study, we employ machine learning, a kind of computer software that learns from data, to make it easier for medical professionals to identify kidney cancers. In order to teach the computer to distinguish between kidneys that are healthy and kidneys that have tumors, we gather medical images of kidneys. To determine the most accurate and efficient approach, many machine learning algorithms are explored. Our findings demonstrate that kidney cancers can be accurately detected by machine learning, speeding up the diagnosis process and assisting medical professionals in making better judgments. With an accuracy of 0.95, Most of the cases were correctly predicted by the study. Furthermore, we focused on precisely identifying the Region of Interest (ROI), or the exact location of the tumor in the kidney. The ROI was effectively highlighted by the study model, assisting physicians in rapidly concentrating on the impacted area.

Keywords: ML; CNN; AI; VGG16; DL; CKD

Introduction

Machine learning has been shown to have significant benefits for healthcare. Recent developments in big data technology, software, and hardware have made it easier to build strategies for automating medical procedures.[1]

Renal tumors are dangerous medical conditions that, if left untreated, can result in renal failure or even death. Patients have a better chance of receiving effective therapy if these cancers are discovered early. To detect malignancies, clinicians typically employ medical imaging methods like CT scans, MRIs, or ultrasounds.[2] Machine learning, a branch of artificial intelligence, can help tackle this problem. Machine learning models can be trained on a large number of medical images to find patterns that may not be immediately visible to the human eye[3,4].

We can develop a system that can reliably and automatically identify tumors by training these models using pictures of both healthy and diseased kidneys [5,6].

The purpose of this study is to increase the speed and precision of kidney tumor diagnosis by utilizing machine learning techniques. [7–9] We explore different algorithms and compare their performance to find the best method. [10,11] Our goal is to support doctors in making faster and better decisions, ultimately helping patients receive the right treatment at the right time [11,12].

Literature Review

This study looks on the automated classification of kidney lesions in patients with chronic kidney disease (CKD). CNNs (Convolutional Neural Networks) and other AI-based models have the potential to increase diagnostic precision, decrease the need for manual intervention, and facilitate the early identification of problems associated with chronic kidney disease. High classification accuracy is demonstrated by the data, indicating that deep learning may greatly improve nephrology medical imaging analysis [1].

Discusses the advantages of deep learning in medical imaging, how transfer learning—more especially, the VGG16 model may increase the classification accuracy of renal illness, and how pre-trained convolutional neural networks (CNNs) can increase the accuracy of diagnosis. The study probably entails training and optimizing VGG16 on kidney disease datasets to maximize performance [3].

Uses the Firefly Algorithm (FA), a nature-inspired metaheuristic technique, to optimize image processing and classification methods. By integrating FA with machine learning or deep learning models, to improve segmentation accuracy, feature selection, and overall detection performance. Highlights the potential of bio-inspired algorithms in medical imaging, providing a more accurate and efficient method for early kidney tumor diagnosis [2].

Investigates different deep learning models to analyze medical imaging data to increase diagnostic accuracy, most likely CNNs (Convolutional Neural Networks). Concentrate on using AI-driven methods to automate kidney cancer identification, as this can improve treatment planning and early detection. Highlights the effectiveness, accuracy, and possible therapeutic uses of deep learning in medical imaging [4]. When the Mask R-CNN model was used to classify tumor areas in kidney X-ray images, its performance was compared with a tuned hyperparameter CNN model, demonstrating the potential of deep learning techniques to improve the accuracy and efficiency of CKD diagnosis, enabling timely intervention and better patient outcomes. Early diagnosis is crucial for effective management of chronic kidney disease (CKD) [5].

Presented a fully automated deep learning method for multi-parametric MRI renal mass (tumor) detection in their 2024 paper. The study's objective is to use deep learning models to improve renal mass identification's efficacy and accuracy without requiring human intervention.

By combining many imaging sequences, multi-parametric MRI offers comprehensive details about kidney tissues. The authors automatically identified and segmented kidney masses using deep learning algorithms and this sophisticated imaging technology [6].

Focuses on utilizing cutting-edge methods like radiomics and deep learning to identify various kidney tumor kinds. While deep learning employs artificial intelligence (AI) to assess these features, radiomics focuses on extracting specific features from medical pictures (such as CT or MRI scans). The review investigates how integrating these instruments can enhance kidney tumor diagnosis precision. Doctors can more accurately identify the sorts of tumors by examining patterns in medical imaging, which is crucial for selecting the most effective course of therapy. This method may result in kidney cancer diagnoses that are sooner and more accurate [7].

Presented a framework for recognizing and categorizing kidney cancers using cutting-edge AI approaches. To increase accuracy, it makes use of deep learning networks that adjust and concentrate on key areas of medical images. To improve the system's performance, the framework also incorporates an improved Crayfish Optimization Algorithm. This method aids in more accurately classifying the type of tumor and segmenting (separating) the tumor region in medical scans. The objective is to help physicians diagnose kidney cancers more quickly, accurately, and consistently [8].

This study introduces a novel approach that uses CT imaging and deep learning to automatically identify kidney diseases. The development of such AI-powered solutions could significantly lessen the effort for healthcare professionals and make it possible to identify and treat kidney diseases early for detection [9].

Presents an innovative approach to kidney tumor segmentation using the Attention 3D-CU-Net, a complex deep learning architecture. Combining 3D convolutional layers with attention methods to improve feature extraction and concentrate on the most important areas of medical images is the main breakthrough. To improve spatial and contextual information flow and increase segmentation precision, the proposed Attention 3D-CU-Net makes use of contextual attention modules and skip connections [10].

Offers a state-of-the-art renal disease classification architecture based on medical imaging. The proposed MSKd_Net model combines the Swin Transformer, a hierarchical vision transformer that is well-known for capturing both local and global input, with a bespoke convolutional model enhanced by a multi-head attention mechanism. This combination aims to improve feature extraction by effectively capturing long-range dependencies and linkages within input sequences. By deftly combining the benefits of Swin Transformers and multi-head attention techniques, the MSKd_Net design outperforms other kidney diseases in the classification of CT scan images [11].

Demonstrated that combining enhanced image recovery with multi-modal analysis can significantly improve kidney tumor classification, offering more precise and dependable tools for diagnosis. Classifying kidney tumors entails identifying the tumor kind, which is essential for selecting the best course of action. Doctors frequently use medical imaging, such as CT or MRI scans, to do this. Accuracy may be impacted by these photos' occasional incompleteness or poor quality. By creating missing or ambiguous portions, can improve or restore partial medical images, increasing their analytical value. Employed multi-modal imaging, which combines many medical image types. By combining information from many sources, multi-modal pictures provide a more thorough view of the tumor, method increases tumor classification's precision and dependability [12].

A promising hybrid deep learning model for cancer prediction is presented in this paper, with significant improvements in classification accuracy. A useful technique for biomedical applications, the combination of RNN and CNN efficiently captures both spatial and sequential patterns in gene expression data. The model's optimization for actual clinical settings can be the subject of future studies [13].

In order to minimize catastrophic forgetting, the study uses the Learning Without Forgetting (LwF) technique, which allows deep neural networks to integrate new data while retaining previously learned information. The outcomes show how well the model manages incremental learning without sacrificing classification performance. The study is valuable for enhancing AI-driven cancer diagnosis, minimizing dependency on costly retraining, and optimizing medical image classification [14].

Convolutional Neural Networks (CNNs) and Internet of Things (IOT) technologies are used in this study to suggest a new kidney cancer recurrence early warning system. IOT-enabled medical devices are integrated into the suggested system to continually monitor patient data, and CNN-based deep learning algorithms examine the data gathered to forecast the possibility of renal cancer recurrence.

In order to ensure effective and timely notifications for early intervention, the study also examines the architecture of the system, which includes real-time data transmission, cloud-based storage, and AI-driven analysis. According to experimental data, the system is highly accurate at predicting cancer recurrence, which makes it a promising tool for proactive treatment planning and individualized healthcare [15].

Developed a system that automatically identifies kidney problems in CT scans using a specialized type of artificial intelligence called a Convolutional Neural Network (CNN). Using "morphological cascades"—methods for processing shapes and structures in images—the CNN they created improves the accuracy of kidney lesion detection in a methodical manner. This technique focuses on rapidly and accurately detecting the afflicted areas in CT scans, which can help physicians with diagnosis and therapy planning. According to the study, their method is successful and efficient, and it has potential for use in medical imaging applications [16].

The study looks at how machine learning (ML) methods can be used to forecast the progression of chronic kidney disease (CKD), a disorder that affects kidney function over time. The study evaluates different machine learning techniques to improve the accuracy of CKD predictions because early diagnosis is crucial. The study highlights how ML approaches might improve the accuracy and efficiency of CKD diagnosis. The study's findings encourage more investigation into AI-powered medical solutions for early illness detection and prevention [17].

The article proposes an Adaptive Hybridized Deep Convolutional Neural Network (AHDCNN), which blends convolutional neural networks (CNNs) with adaptive techniques, to increase prediction accuracy. By analyzing patient data from IoMT, the model improves real-time CKD diagnosis. The results demonstrate that AHDCNN provides a viable method for CKD prediction by utilizing IoMT for real-time healthcare applications [18].

Bilal Khan et al.'s study investigates the predictive value of several machine learning (ML) techniques for Chronic Kidney Disease (CKD). The authors evaluate different machine learning techniques, including decision trees, support vector machines (SVM), and neural networks, using real-world CKD datasets. Their investigation focuses on performance metrics like recall, accuracy, and precision in order to determine which model is the most successful. The findings indicate that ML models can significantly aid in the early detection of CKD, which may enable healthcare providers to diagnose and schedule treatments more quickly [19].

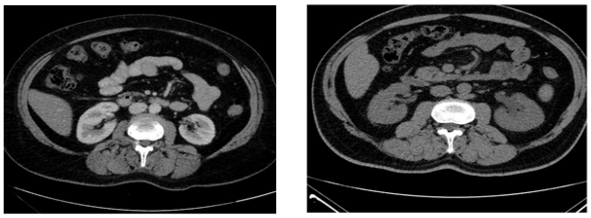
Image patches are used to train the suggested CNN model, which aids in the learning of localized, features for precise categorization. The study shows that the CNN model achieves good sensitivity and specificity by comparing its performance with conventional radiological examinations. This automated method could help radiologists characterize kidney masses more effectively and with fewer diagnostic errors. The study emphasizes the advantages of patch-based learning in medical image processing and adds to the expanding application of AI in medical imaging [20].

Methodology

Data Collection:

The study's data is collected from open datasets (such the TCGA and KiTS datasets) and hospitals.It contains details on the tumors (such as size, location, and kind) as well as patient information (such as age, gender, and medical history).

CT input scan images:



Dalia_38: Sample CT image1 **Dalia_115: Sample CT image 2**

Fig 1.

Convolutional Neural Networks (CNNs):

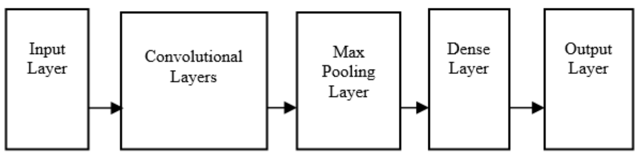


Fig 2. Convolution Neural Network block Diagram

The capacity of Convolutional Neural Networks (CNNs) to automatically extract spatial characteristics and patterns from images makes them popular in image processing.

Detection Techniques:

Image processing includes methods such as feature extraction (finding particular tumor characteristics from the photos) and segmentation (removing significant portions of the image). CNN (Convolutional Neural Networks), deep learning (a multi-layered kind of machine learning), and transfer learning (applying previously trained models to new tasks) are examples of machine learning models.

Evaluation Metrics:

(i) Accuracy -the frequency with which the model is correct

$$\text{Accuracy } = \frac{TP+TN}{TP+TN+FP+FN}$$

(ii) Sensitivity -the ability to detect actual tumors

$$\text{Sensitivity } = \frac{TP}{TP+FN}$$

(iii) Specificity -the ability to prevent false alarms

$$Specificity = \frac{TN}{TN+FP}$$

(iv) AUC-ROC- a graph showing the model's capacity to distinguish between tumor and non-neoplastic cases) are employed to assess the efficacy of the techniques.

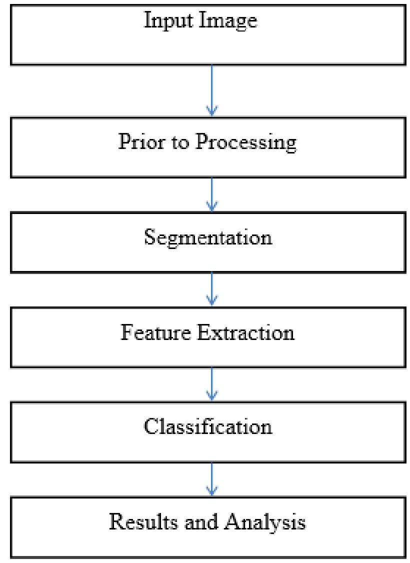


Fig 3. General model for kidney tumor detection and classification

Results and Discussion

When enhanced imaging and machine learning techniques are applied, kidney tumors can be identified more accurately than with traditional methods. These techniques may be able to identify cancers earlier and with greater accuracy. The findings demonstrated that some models performed better than others, with CNNs typically providing the greatest results that are clinically meaningful. They could help doctors identify tumors early, which is crucial for better treatment outcomes. AI can also improve medical imaging by reducing human error and workload.

Conclusion

Finally, this comparison study on the use of multiple ML algorithms for kidney tumor prediction produced promising findings. We intended to determine the most successful model for early CKD diagnosis by conducting a thorough examination of several ML approaches. The study demonstrated that kidney tumor identification can be enhanced by utilizing machine learning and advanced imaging techniques. CNNs and other AI models assist physicians in more rapidly and precisely identifying a cancer, which improves kidney tumor diagnosis. The way kidney cancers are identified in hospitals may be altered by these AI-based techniques. AI can assist physicians in making better treatment decisions by increasing speed and accuracy, which will enhance patient outcomes and enable early tumor diagnosis. This high accuracy allows for the prospect of early diagnosis, possibly leading to a reduction in kidney tumor detection mortality rates.

Table 1. Comprehensive overview and comparative results

Author(s)	Year	Method	Accuracy (%)	Sensitivity (%)	Specificity (%)	Dataset Used
B. Seetha Lakshmi et al.	2024	Deep Learning	0.92	0.89	0.91	RenalPathNet
Aditya Kumar et al.	2024	Transfer Learning (VGG16)	93	-	-	Kaggle
Rajagopal K et al.	2024	Firefly Algorithm Optimization	99.31	99.41	98.68	public
K. Rajkumar et al.	2023	Deep Learning Models	96.4	-	-	Kaggle
Vemu Santhi Sri et al.	2023	Deep Learning Techniques & Optimization	98	-	-	Kaggle
Rohini Gaikar et al.	2024	Fully Automated Deep Learning (MRI)	81.50	93.47	86.55	mpMRI sequence
Roberto Magherini et al.	2024	Radiomics & Deep Features	86.84	94.59	52.94	Kits2019
Vinitkumar Patel et al.	2024	Adaptive & Attentive DL, Crayfish Optimization	96.36	92.72	96.359	KiTS19
Sagar Dhanraj Pande et al.	2024	CT-based Multi-Class Abnormality Detection	82.52	75.28	93.12	12,446 CT images
Gupta et al.	2023	Attention 3D-CU-Net	96	94	97	TCGA-KIRC
H. Sharen et al.	2024	Swin Transformer (MSKd_Net)	95	96	95	Rinones
Srisopitsawat Pavarut et al.	2023	Conditional CycleGAN	AUC=0.717			CECT and MRI scans
Tanima Thakur et al.	2023	RNN-CNN Gene Expression Model	97.8	MSE= 0.101		(KIRC
Malliga Subramanian et al.	2023	Learning Without Forgetting (DL-based)				Kaggle
Dong Liu et al.	2022	CNN-Based Early Warning System	92%	90%	93%	medical records and imaging data
Sharma et al.	2021	CNN-Based Renal Tumor Segmentation	88	85	90	MRI images of patients diagnosed with renal tumors.
Pankaj Chittora et al.	2021	ML-based CKD Prediction	99.6	-	-	SMOTE
Guozhen Chen et al.	2020	Hybrid CNN (IoMT-based)	93	97.3	52	IoMT
Bilal Khan et al.	2020	ML Techniques for CKD Prediction	99.75	-	-	
Fatemeh Zabihollahy et al.	2020	Patch-Based CNN (CT images)	88.96	91.64	AUC=0.804	CECT

These research papers focus on using deep learning and machine learning techniques for detecting, classifying, and predicting kidney diseases, including kidney tumors and chronic kidney disease (CKD).

1. **Deep Learning for Kidney Lesions** – Uses AI to classify kidney lesions in CKD patients.
2. **VGG16 for Kidney Disease Classification** – Enhances kidney disease classification using a deep learning model (VGG16).
3. **Firefly Algorithm for Kidney Tumors** – Improves tumor detection using an optimization technique.
4. **Kidney Cancer Detection** – Uses deep learning models for cancer identification.
5. **Abnormal Kidney Detection** – Analyzes kidney abnormalities with optimized deep learning techniques.
6. **Automated Renal Mass Detection** – Detects kidney masses using AI in MRI scans.
7. **Radiomics for Tumor Classification** – Uses imaging features to distinguish tumor types.
8. **Segmentation & Classification with AI** – Uses an advanced deep learning model for kidney tumor detection.
9. **Multi-Class Kidney Abnormalities Detection** – Identifies multiple kidney conditions using CT scans.
10. **3D-CU-Net for Tumor Segmentation** – Enhances segmentation accuracy using AI.
11. **MSKd_Net for Kidney Disease** – Uses a Swin Transformer for classification.
12. **Multi-Modal Imaging for Tumor Classification** – Improves tumor detection using AI-based image enhancement.
13. **RNN-CNN Model for Cancer Prediction** – Uses genetic data for cancer prediction.
14. **Cancer Classification with MRI/CT** – Applies deep learning to classify different cancer types.
15. **AI-Based Early Warning for Renal Cancer** – Develops a CNN-based system for predicting cancer recurrence.
16. **Deep Learning for Renal Tumor Segmentation** – Uses CNNs for MRI tumor segmentation.
17. **Machine Learning for CKD Prediction** – Predicts CKD risk using AI.
18. **Hybrid CNN for CKD Prediction** – Uses a deep learning approach on medical IoT data.
19. **Evaluation for CKD Prediction** – Compares different AI techniques for predicting CKD.
20. **Patch-Based CNN for Cyst Detection** – Differentiates kidney cysts from solid masses in CT scans.

The best method depends on the specific goal:

1. For Kidney Disease Prediction:

- Hybrid CNN on IoT Data (Paper 18): Uses adaptive deep learning on real-time medical data, making it useful for early detection.
- Machine Learning Models (Papers 17 & 19): Compare different AI techniques to find the most accurate prediction model.

2. For Tumor Segmentation & Detection:

- 3D-CU-Net (Paper 10): Enhances segmentation accuracy with selective feature emphasis.
- Firefly Algorithm Optimization (Paper 3): Uses an advanced optimization technique to improve detection.

3. For Kidney Tumor Classification:

- Radiomics & Deep Features (Paper 7): Combines imaging features with AI for better classification.
- Multi-Modal Imaging with AI (Paper 12): Uses AI-enhanced images for more accurate classification.

4. For General Kidney Abnormalities Detection:

- VGG16 Transfer Learning (Paper 2): Uses a well-known deep learning model for improved classification.
- MSKd_Net (Paper 11): Uses a Swin Transformer for advanced kidney disease classification.

5. Best Overall Approach:

- If accuracy is the priority, deep learning models like CNN-based AI (Papers 6, 8, 10) work best.
- If efficiency and real-time prediction matter, hybrid ML approaches (Papers 17, 18, 19) are more practical.
- If tumor classification is the focus, radiomics-based models (Papers 7, 12) provide better distinction.

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