Journal of Al-Qadisiyah for Computer Science and Mathematics Vol.18.(2) 2026,pp.Comp 212–219

Available online at www.qu.edu.iq/journalcm
JOURNAL OF AL-QADISIYAH FOR COMPUTER SCIENCE AND MATHEMATICS
ISSN:2521-3504(online) ISSN:2074-0204(print)

A Survey of Machine Learning for Bladder Tumor Detection in Medical Imaging

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ARTICLE INFO

Article history:
Received: 02 /03/2026
Rrevised form: 23 /03/2026
Accepted : 24 /03/2026
Available online: 30/06/2026

Keywords:

Bladder Cancer ,

deep learning,

machine Learning,

CNN,

MRI.

ABSTRACT

bladder cancer at an early stage and treating it successfully is extremely difficult due to its recurrence and spread. With the use of artificial intelligence and medical imaging tools to identify the disease, modern systems face many difficulties in applying them to different data sets; thus, they lack classification accuracy. Other problems with these models include a lack of spatial information and high computational complexity. On the other hand, although VIT models have shown promising results in medical image analysis, their performance still depends heavily on the quality of hyperparameter tuning, making them less efficient. This supports the early detection of bladder cancer, emphasizing the need to create a complete VIT-based system that is then enhanced in a meta-heuristic manner to increase detection accuracy while reducing computational complexity. In the Radiomics study, machine learning (ML) methods were systematically applied to identify sophisticated features and create analytical patterns for cancer classification and medical outcome prediction. Deep learning (DL) has significantly improved cancer detection, segmentation, and classification with convolutional neural networks and U-Net. Recently, vision transformer models have become well known for their ability to detect long-range connections in medical images. This proves that histological examination and magnetic resonance imaging allow for a new approach to bladder cancer treatment. Even if these different ideas have evolved, there are not enough routine tests to prove how well they work together. Based on bladder tumor detection techniques, This survey provides a systematic classification and diagnostic evaluation of current artificial intelligence, thereby emphasizing its methods, benefits, limitations, and potential directions for further investigation.

https://doi.org/ 10.29304/jqcsm.2026.18.22702

1. Introduction

Tumor Bladder begins approximately loss of life 200,000 worldwide every time. [1]. and around 10-15% of cases diagnosed with bladder cancer have spread to other organs by the time symptoms appear. [2][1]. the United Kingdom. tumor Bladder begins approximately 5,000 loss of life .each year .[3]. Reduce clusters socioeconomic are changed extremely, by an general 5-year existence 46% rate of compared to the upper socioeconomic 56% in group [4]. This indicates that tumor Bladder is a disease of populations with low socioeconomic status. A model disease study based on continuous development was developed using hematoxylin and eosin (H&E) stained histological images and was adopted. [5]. The authors in [6]. used medical imaging data to validate and evaluate a novel machine

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learning-based method for improving the detection and analysis of bladder cancer. In [7]. a multi-machine radiomics model was designed and tested based on contrast-enhanced CT images. accurately predicting the overall survival rate of patients with muscle-invasive bladder cancer . In [32]. authors projected the technique (RDA U-Net) for computerizing segmentation bladder malignant tumor, succeeding a factor parallel accuracy Dice of 0.8872. The authors presented in[22]. the "CystoNet" system based on deep learning to improve bladder cancer prediction and achieved an accuracy of approximately 90.9%, and they acknowledged the limitations related to the exclusive focus on papilloma's. The authors proposed in[36]. hybrid models for detecting bladder cancer and its spread to lymph nodes. Their model achieved an accuracy of AUC 0.871. a limited size sample and a retrospective nature.

In [8]. using a database containing data from 3,499 patients recommended models were created using machine learning to improve prediction after radical cystectomy, including demographic, pathological, clinical, and surgical factors. The bladder is a complex organ with high elasticity that performs two essential functions: storing urine for long periods and repeatedly eliminating it through urination. The urine reservoir maintains urine pressure at safe levels and prevents reflux to protect the kidneys from continuous damage leading to organ failure. Urination is characterized by remarkable flexibility and storage, making the urinary bladder noteworthy. Distinctive vital characteristics are associated with the structural features and biomechanical properties of its wall tissues.[9]. In [31]. The authors organization developing a model hybrid based on deep learning ResNet50 to guess lymphatic vascular attack by scan CT.

In.[10]. showed that early detection of bladder cancer has improved thanks to machine learning models. The review indicated that deep learning and radiology methodologies have improved the assessment of bladder segmentation, muscle invasion, and tumor segmentation compared to older methods. In [33] large case studies. large-scale learning on CT scan images revealed HER2 detection in bladder cancer. In [34]. researchers combined various loss functions with the U-Net bladder segmentation model, achieving an accuracy of 0.94. However, they faced limitations due to the small sample size.

In.[11]. The authors introduce technique provided an objective and reproducible alternative to established risk assessment methods. In cases of bladder cancer, artificial intelligence generally improved the ability to personalize monitoring and treatment options after therapy. This improvement marked a milestone on the path to data-driven precision medicine for bladder cancer. In [35] .The authors presented a deep learning model for a team investigating bladder infections, cancer, and inflammation, using electronic interfaces with a focus on data from a single hospital.

In patients with urothelial bladder cancer, researchers studied the medical significance of soluble immune checkpoint molecules sB7-H3 and sB7-H4.[12] . Studies have shown that serum levels of these markers in cancer patients are significantly elevated compared to healthy individuals and patients with non-serious conditions. [13]. The results indicated a positive correlation between elevated levels of these markers and cancer stage, progression, severity, and muscle invasion. In addition, statistical studies revealed that these biomarkers are highly sensitive and accurate, suggesting their potential for use in non-invasive diagnosis. Ultimately, the results demonstrated that elevated levels of these markers are associated with poor prognosis and lower overall survival rates .[14]. this survey aims to detecting bladder tumor using AI and organized as follows: section 1 covers bladder cancer and the need for rapid diagnosis. section 2 presents the identification of bladder cancer using DL models. section 3 examines ML models, while section 4 ,Discussion. section 5 limitations, while section 6, concludes with a summary.

3.Related Works

Artificial intelligence has played a vital role in the development of bladder cancer detection technologies by providing intelligent systems that can analyze medical images accurately and efficiently. Research has shown that deep learning techniques and vision-based approaches have contributed to improving early diagnosis, reducing human error, and helping doctors make reliable decisions[15]. Machine learning has also contributed to enhancing the detection of urinary tract infections by accurately analyzing clinical data and providing early diagnosis.[16].

3.1. Detection Bladder Cancer Using deep learning

Using deep machine learning techniques, scientists have developed a computer-based imaging system to diagnose bladder cancer in its early stages. Specifically, they used convolutional neural networks (CNNs) such as VGG16 and VGG19 architectures to analyze images taken from endoscopy videos. The researchers used preprocessing methods including mid-range filtering to remove interference before analysis and ensure data quality. To improve data the management of this, the system used technology transfer learning, which enabled model to extract features complex automatically and without intervention human. They have showed that technique was intelligent to identify images with accuracy important. [17].

Authors highlighted the important shift from computer traditional methods imaging to provided deep learning models and advance a detailed overview of method classification for bladder tumor. They emphasized that accurate risk assessment and treatment selection still depend on accurately determining the extent of cancer spread in the body's muscles. Although multiparametric magnetic resonance imaging (mp-MRI) has become a crucial tool, the research indicated that it still suffers from problems, including motion artifacts in radiologist readings. Based on this, the authors examined the success of deep machine learning techniques—particularly convolutional neural networks (CNNs)—in achieving significant success in automating the delineation of bladder tumors. However, research indicated that other medical fields have made significant progress in classifying the bladder into multiple regions, compared to other fields such as this one. Furthermore, the review indicated that current methods often follow older studies without addressing the difficulties specific to accurate bladder imaging. The researchers offered important considerations regarding the limitations of currently used methods, including reliance on image quality and manual input, to assist in this regard. Accuracy [18].

The team used cross-sectional images to create an automatic deep learning framework aimed at developing kidney stone detection technology . The study used advanced data augmentation techniques to avoid overfitting by applying the XResNet-50 network architecture to examine a set of non-contrast cross-sectional images. The study authors used the Grad-CAM approach, which allows the model to visually highlight areas of particular interest where kidney stones are located, ensuring interpretability. Studies have shown that this method has an accuracy rate of up to 96.82% and is characterized by a high degree of sensitivity and specificity, which is very good. In addition, the results showed that the system can reliably function as a backup for radiologists in clinical diagnostic imaging, as it can find very small stones that may not be detectable to the naked eye[19].

Researchers in [20] created and validated a new deep learning model designed to automatically detect bladder cancer in people with severe hematuria. This study examined images taken from renal tomography using a convolutional neural network based on 3D-Unet architecture, thereby integrating convolutional and convolutional layers. The authors used the results obtained from cystoscopy as a reference standard, trained the system on a training set, and then tested it on 400 people in a separate set to verify the results. The results showed that the sensitivity of the AI model reached 0.83 and the negative predictive value reached 0.97, successfully detecting most tumors. In addition, the study showed that in nine cases missed by radiologists in the original report, the model was able to accurately identify the presence of these tumors.

The authors [21] focus on their shift from traditional methods to more advanced deep learning methods, and they conducted an in-depth study of the current state of ordering for urological tumors. They emphasized that determining the stage of the disease and choosing the appropriate treatment depends on accurately identifying the bladder wall and tumors. The studies concluded that, contrary to the apparent usefulness of artificial intelligence, many of the models used today face problems due to the difficulty of ultrasound imaging of the bladder.

Using images taken from a traditional ureteroscope, the team presented an integrated AI-powered system that not only diagnoses bladder cancer, but also differentiates between malignant tumors and analyzes their different types. They created a powerful classifier based on the EFFICIENTNET-B0 network, which shows high accuracy even in difficult cases by focusing on the most important visual features. The study used an improved UNet++ model to accurately define cancer boundaries in order to precisely locate the tumor. It is worth noting that the scientists also explored a new approach to non-invasive diagnosis by predicting hidden molecular characteristics, including tumor aggressiveness indicators, through deep learning, opening up new horizons. They have combined all of this into an easy-to-use web platform so that doctors can get quick diagnostic feedback to ensure that these devices are truly useful in hospitals [22].

Table1. represents a deep learning method.

Author	Dataset	Data Type	Method	Results	Limitation
Shkolyar, E.et al[18]. (2021).	patients95	Video clips from urological endoscopy (WLC) with standard white light.	model Deep learning based on CNN ,convolutional neural networks.	Sensitivity: 90.9% Specificity: 98.6% Sensitivity: 95.5%	image quality and manual input, to assist in this regard. Accuracy.
Sun, R.et al .[19]. (2024).	patients239	(Cortical and medullary stages, urinary imaging, and excretion).	M RMR and LASSO schemes.	AUC (external test): 0.834 (95% CI: 0.659-1.000).	Data size.
Subramanya, S. et al.[20]. (2021).	histological images. 277	images Histological.	VGG16, ResNet18, Squeeze Net, and MobileNetV2.	Arithmetic mean of the average dice coefficient: 0.82; arithmetic mean of the Jaccard index: 0.74.	Small data.
Hwang, W. K.et al.[21]. (2025).	images Cystoscope.	(Normal, Halimi, Flat, Shared).	VGG19 model with an additional fully connected layer, using sparse categorical cross-entropy loss.	Accuracy score of 0.912.	difficulty of ultrasound imaging of the bladder.

3.2. Detection Bladder Cancer Using machine learning

Artificial intelligence has changed the way urinary tract cancer is detected early by enabling the automatic diagnosis of large medical images and clinical data. Recent studies have shown that machine learning and deep learning models have significantly improved the accuracy of tumor identification, segmentation, classification, and staging. These smart systems have contributed to improving diagnostic speed and reducing reliance on human interpretation. Furthermore, AI-based methods have aided clinical decision-making and contributed to improving the diagnostic workflow across multiple imaging modalities. Overall, artificial intelligence shows great potential to bring about significant change in the diagnosis of urological cancer and has paved the way for future medical integration [23].

This study[24] was based on magnetic resonance imaging (MRI) data of the urinary bladder with the aim of developing an automated diagnostic framework based on machine learning and deep learning techniques. The method proposed in this study combined image preprocessing, feature selection, and classification models to accurately distinguish between diseased cases. The results indicated that the classification system achieved a high degree of diagnostic performance at 86.7%. However, the authors acknowledged limitations related to the relatively small size of the dataset, the imbalance between patient groups, and limited generalizability to different clinical settings. These results undoubtedly confirm that the proposed methodology supports early diagnosis and assists in making appropriate treatment choices.

In [25]. They have relied on a medical imaging database containing magnetic resonance images of patients' bladders taken during medical examinations to develop an automated diagnostic framework. The proposed methodology included preliminary image processing, feature selection, and automated classification to accurately distinguish between various pathological conditions. Test evaluations indicated that the developed model achieved

96.8% diagnostic accuracy, along with high sensitivity and specificity, demonstrating reliable medical performance. Overall, the results indicated that this system enhances early detection and supports medical decision-making in the diagnosis of bladder diseases.

in[26]. The study relied on a centralized database of 207 contrast-enhanced computed tomography (CT) images of patients with bladder cancer to develop an interpretable framework for radiation-based machine learning. The experimental evaluation showed that the random forest model achieved the highest diagnostic performance, reaching an AUC of 0.815 and an accuracy of 75.5% in the independent test set. However, the researchers acknowledged limitations related to the retrospective design, relatively small sample size, and potential selection bias across centers. Overall, the results confirmed that the proposed approach effectively enabled non-invasive and reliable prediction of HER2 status in bladder cancer, supporting clinical decision-making.

in[27]. This study developed an integrated machine learning and deep learning framework to predict ureteral cancer diagnosis and evaluate the tumor microenvironment using whole slide images and genetic data. The study used multi-source datasets from the TCGA database (406 samples), GEO database (458 samples), and IMvigor210 (348 samples), which included gene expression profiles, clinical information, and histopathological images. The authors used ten machine learning models and created an immune-related machine learning signature (IRMLS), followed by a deep learning model to directly classify immune subtypes from histopathological images. Despite its strong predictive performance, the model faces limitations, including reliance on public data sources, lack of clinical validation, and experimental biological verification. The presented framework achieved high predictive accuracy, with a maximum AUC of 0.833 and a C-index of 0.727, demonstrating its efficiency in predicting survival and immune response outcomes.

In.[28]. Supporters structure efficiently improve a platform AI applying of 59 MIBC patients the TCGA dataset to chemotherapy predict response analysis through deep learning of H&E-stained histopathology specimens. They have applied this expertise to abstract detailed nuclear and three-dimensional features, detecting that improved matter heterogeneity is strongly associated with worse specific - cancer survival. they have established a predictive ability with a concordance index of 0.70 and a significant hazard ratio of 0.265, effectively separating responders robust from non-responders. Although should to clarify some cohort appearances as a limitation, this innovative methodology has showed its possible to assistance doctor distinguish which patient role are most likely to benefit from cisplatin-based chemotherapy.

In.[29]. Academics have effectively establish an advanced heterogeneity intratumor ITH sign to expect outcomes clinical advantages in cancer bladder patient. They have utilize across-the-board data transcriptomic beginning the TCGA-BLCA cohort 406 patients as their dataset basic, accompanied by respective GEO datasets GSE13507, GSE31684, GSE32894, for authentication. By using innovative algorithms machine learning, the players maintains clinical integrated signs with ITH scores to identify patients most likely to respond to immune checkpoint inhibitors. provided a multigene robust model for medication individualized.

In [30]. Authors established an machine learning- novel established ocular approach to recognize among urinary poisoning ,urinary tract infections, , and cancer bladder. They use a single dataset containing of spectra urine gathered about measurements spectral from patient role clinical. By checking 27 models several, the examine group identified the most effective models for providing reliable diagnostic classifications. Although the study responded some restrictions recounted to the require for restricted verification clinical through different group patient.

Table 2 represents the machine learning.

Author	Dataset	Data Type	Method	Results	Limitation
Tokuyama, N,et al.[24]. (2022).	125 patients	MRI	develop an automated diagnostic framework.	Performance 86.7%.	limited generalizability to different clinical settings.
Yin, P, et al.[25]. (2020).	imaging dataset.	MRI	proposed approach has integrated image preprocessing.	accuracy of 96.8%.	preliminary image.
Wei, Z ,et al.[26]. (2024).	Cambria (Headings)	CT scans	The extracted radiomic features have been processed using LASSO feature selection and classified through multiple ML models.	AUC of 0.815.	limitations related to the retrospective design.
Nie, W,et al.[27]. (2024).	TCGA (406 samples).	whole slide images.	developed an integrated machine learning and deep learning framework to predict bladder cancer.	maximum AUC of 0.833.	limitations, including reliance on public data sources.
Causio, F, et al.[28]. (2024).	59 MIBC patients.	TCGA dataset.	successfully developed an AI platform using the TCGA dataset of 59 MIBC patients to predict chemotherapy response through deep learning analysis.	ratio of 0.265.	clarify some cohort appearances.
Chen, C, et al.[29]. (2024).	406 patients.	TCGA-BLCA cohort	established an innovative intratumor heterogeneity (ITH) signature to predict clinical outcomes and immunotherapy benefits in bladder cancer patients.	higher sensitivity to immunotherapy compared to high-score groups.	Small data.
Sokołowski, P, et al.[30]. (2024).	clinical patients.	urine spectra collected.	developed an innovative optical method supported by machine learning.	accuracy of up to 95%	restricted verification clinical through different group patient.

4. Discussion

Deep learning methods used with conventional imaging techniques have resulted in a significant change in the diagnosis and treatment of bladder cancer through the analysis of study results. Whether in light cystoscopy (WLC) or computed tomography (CT), the results repeatedly show that relying on human visual examination alone often leads to small tumors being overlooked. In response, scientists have created powerful models such as the CystoNet system and advanced CNN systems that show an amazing ability to detect lesions that were previously overlooked by doctors or radiologists.

5. Limits and Challenges :

• Restrictions on medical data: Maintaining patient privacy and the small number of participants present ethical and medical difficulties in obtaining images of patients' bladders classified according to all stages of the disease. Some studies either contain few or uneven data samples, which may compromise the application of the results and make the model more prone to bias.

• methods CNN are difficult and many include variable quantity, so they need a deal of power calculation.

6. Conclusion

General, mixing algorithms AI artificial intelligence into tumor bladder analysis has develop extra of a essential than a comfort in the pasture of study. By provide unbiased and a reliable second opinion, these technologies have helped reduce human error during real-time cystoscopy and diagnostic or histological image analysis. But they have emphasized that the diversity of patient information require more comprehensive model.

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