Advancements in Bladder Cancer Management: A Comprehensive Review of Artificial Intelligence and Machine Learning Applications

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Abstract

Artificial intelligence (AI) and machine learning (ML) have emerged as powerful tools in the diagnosis and treatment of bladder cancer, offering significant advancements in accuracy and speed. AI algorithms have enabled precise segmentation of the bladder wall and accurate detection of bladder tumors using non-invasive 3D image-based features from CT and MRI scans. Decision support systems based on AI have improved the assessment of treatment efficacy for muscle-invasive bladder cancer. AI-assisted cystoscopy has demonstrated higher sensitivity and specificity in identifying and categorizing bladder lesions, potentially outperforming human urologists. ML algorithms, including artificial neural networks, have shown superior predictive capabilities in prognosis and outcome prediction compared to conventional models. Radiomics and ML techniques have enhanced bladder cancer staging and treatment response assessment through accurate analysis of imaging data. AI-driven biomarker discovery, including metabolomics, has the potential to revolutionize non-invasive bladder cancer diagnosis and monitoring. Automated histologic grading and molecular typing facilitated by AI have led to faster and more precise diagnoses, enabling personalized treatment plans.

The integration of AI and ML in bladder cancer diagnosis has the potential to improve patient outcomes significantly. By providing faster and more precise diagnoses, AI-driven approaches can enhance treatment planning and response evaluation. Additionally, AI-assisted cystoscopy and improved biomarkers can lead to less invasive and more effective diagnostic techniques.
Furthermore, AI-driven prognostic models offer a more accurate prediction of patient outcomes, enabling personalized treatment strategies. These contributions collectively indicate a promising future for AI and ML in bladder cancer management, enhancing diagnostic accuracy, treatment efficacy, and patient care.

*Keywords*: Artificial Intelligence; Machine Learning; Bladder Cancer; Deep Learning; Neural Networks; Medical imaging;

1. Introduction

Bladder cancer is a significant global health concern, with approximately “573,278 new cases and 212,536 new deaths reported worldwide” (1) Prevalence and death rates are highest in industrialized countries such as the United States, Germany, and Taiwan [1,2]. Bladder cancer is more common in males than women and has a death rate four times greater in men than women worldwide [1]. The current gold standard for non-invasively identifying bladder cancer is urinary cytology, which has a high degree of specificity but low sensitivity [2]. The diagnostic procedure of choice for bladder cancer is cystoscopy [2]. Although cystectomy is a common part of standard treatment for bladder cancer, it is associated with severe morbidity and a drop in quality of life [1, 2]. As a result, the strategy of preserving the bladder has gained popularity. However, there is an urgent need to enhance patient outcomes through the creation of accurate predictive models with high sensitivity and specificity for the efficacy of a given medicine.
“The use of AI has the potential to dramatically improve the detection and treatment of bladder cancer. AI makes use of computational methods that imitate the underlying mechanisms of human intelligence, such as cognition, deep learning, adaptation, engagement, and sensory comprehension” [3]. “In recent years, AI algorithms have been used to perform a variety of clinical tasks associated with the diagnosis and prognosis of bladder cancer, including bladder wall segmentation, automatic tumour detection, staging, and grading, and the prediction of recurrence, treatment response, and overall survival” [4,5].

In order to accurately detect the distribution of heterogeneous tumours [6], “AI can be combined with the 3D image-based features of non-invasive computed tomography and magnetic resonance imaging. In addition, AI based decision support systems have been created to assess therapeutic response in muscle-invasive bladder cancer” [6]. In addition, AI has improved cystoscopy, leading to more precise diagnoses by highlighting anomalies that could otherwise go undetected by a human's unaided eye [5,6]. “Predictions of recurrence and survival rates for bladder cancer patients can also be made with the help of ML algorithms” [7].

As a result of these shortcomings, accurate predictive models with high sensitivity and specificity are needed to determine whether or not a certain medicine would be effective in treating bladder cancer (BCa). “Automatic tumour detection, staging, grading, recurrence, treatment response, and overall survival prediction are just few examples of the many supervised learning difficulties that modern ML applications in Bladder cancer diagnosis and outcome prediction address. In this scenario, CT urograms from two groups of controls and patients with Bladder cancer are employed as input, and the presence or absence of malignant lesions in each
The advent of deep learning (DL) has additionally accelerated up AI progress in recent years. Artificial neural networks (ANN) and deep convolutional neural networks (DCNN), two types of ANN with a lot of popularity due to their accuracy, are trained as part of DL. DCNN can be used to classify and anticipate cystoscopic findings. To aid urologists in the course of cystoscopic examinations, a DL model such as this one could be incorporated into an AI-assisted image diagnostic tool. As the big data era gets underway, more complicated healthcare data will become available. These data frequently contain redundant information, are noisy, and exhibit high fluctuation. AI, with ML algorithms and ANN processes, can provide an accurate and comprehensive view of a clinical scenario. Thus, this review aims to examine the research and application potential of AI, ML, and DL in BCa.

2. Search Strategy and Keywords

To systematically gather relevant literature for this review, a comprehensive search strategy was employed across multiple electronic databases. The search aimed to identify studies and articles related to the application of AI and ML in bladder cancer diagnosis and treatment. The following databases were explored:

PubMed
Scopus
The search for relevant publications was carried out comprehensively, encompassing articles from the inception of each database up to [mention your specific end date or year]. To ensure a thorough exploration of the literature, a combination of pertinent keywords and Medical Subject Headings (MeSH terms) was employed in various Boolean combinations. These keywords and terms included "Bladder cancer," "Bladder carcinoma," "Artificial intelligence," "Machine learning," "Deep learning," "Neural networks," "Histopathological grading," "Molecular typing," "Diagnosis," "Prognosis," "Treatment," "Radiomics," "Image analysis," "Gene expression analysis," "Biomarkers," "Treatment response," "Personalized medicine," "Clinical data," and "Electronic health records." This comprehensive approach allowed for the identification of a wide range of relevant studies and publications across various databases.

The search was limited to articles published in English and focused on human subjects. The reference lists of selected articles were also reviewed for additional relevant publications.

The initial search yielded a substantial number of articles, which were then screened for relevance. Abstracts and full texts were assessed, and studies that met the inclusion criteria were included in this review. The search strategy aimed to encompass a wide range of studies to provide
a comprehensive overview of the topic.

Table 1 summarises the articles reviewed

<table>
<thead>
<tr>
<th>Author</th>
<th>Objective</th>
<th>Dataset</th>
<th>Input</th>
<th>Output</th>
<th>Training Features</th>
<th>Algorithms</th>
<th>Performance Index</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atsushi Ikeda et al. (2020)</td>
<td>Support System of Cystoscopic Diagnosis for Bladder Cancer Based on AI</td>
<td>ImageNet18 dataset (1000-class classification)</td>
<td>Cystoscopic images</td>
<td>Classification of bladder cancer lesions vs normal tissue</td>
<td>NA</td>
<td>CNN based on GoogLeNet17 with transfer learning</td>
<td>Area under the ROC curve=0.98, Youden index=0.837, Sensitivity =89.7%, Specificity =94.0%</td>
<td>AI system capable of classifying tumors-lesions and normality with high accuracy</td>
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<tr>
<td>Negasisi et al. (2020)</td>
<td>ML/DL/CNN applications in cystoscopic image recognition</td>
<td>177 images of histologically confirmed bladder tumors, Cystoscopic images</td>
<td>N/A</td>
<td>ImageNet-Convolutional Neural Network</td>
<td>Sensitivity=93.0%, Specificity=83.7%</td>
<td>Differentiate between tumor and healthy urothelium</td>
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<tr>
<td>Authors</td>
<td>Methodology</td>
<td>Images Description</td>
<td>Model Description</td>
<td>Results</td>
<td>Conclusion</td>
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<tr>
<td>Ikeda et al. (2020)</td>
<td>Cystoscopic diagnosis of bladder cancer using AI</td>
<td>133 images of healthy urothelium, 431 images of tumors, 1671 normal images</td>
<td>GoogleNet architecture and fine-tuned with Adam algorithm</td>
<td>Sensitivity: 89.7%, Specificity: 94.0%, Area under the ROC curve: 0.98</td>
<td>Classify cystoscopic images, including tumor lesions and normality</td>
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<tr>
<td>Ikeda et al. (2021)</td>
<td>Improve bladder tumor detection using transfer learning</td>
<td>1-1.2 million general images, 8,728 gastroscopic images, 2,102 cystoscopic images</td>
<td>Convolutional neural network (CNN)</td>
<td>Sensitivity: 95.4%, Specificity: 97.6%</td>
<td>Value of transfer learning in limited datasets for bladder tumor detection</td>
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<tr>
<td>Shkolyar et al. (2019)</td>
<td>Augmented bladder tumor detection using deep learning</td>
<td>Develop dataset: 95 patients for training and 5 videos from 100 patients who underwent TURBT</td>
<td>CystoNet (CNN-based image analysis platform)</td>
<td>Per-frame sensitivity: 90.9%, Per-frame specificity: 98.6%, Per-tumor sensitivity:</td>
<td>Improve ment in cystoscopy quality and availability using CystoNet</td>
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<tr>
<td>Research work</td>
<td>Goal</td>
<td>Data used</td>
<td>Methodology</td>
<td>Sensitivity</td>
<td>Specificity</td>
<td>Impact</td>
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<tr>
<td>Ikeda et al (2020) [16]</td>
<td>Support system of cystoscopic diagnosis for bladder cancer</td>
<td>2,102 cystoscopic images: 1,671 normal tissue, 431 tumor lesions</td>
<td>TIFF files of 1350×1080 pixels by white light</td>
<td>90.9%</td>
<td>CNN model based on GoogLeNet with transfer learning</td>
<td>for bladder tumor detection</td>
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</table>

**Imaging**

<table>
<thead>
<tr>
<th>Research work</th>
<th>Goal</th>
<th>Data used</th>
<th>Methodology</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Impact</th>
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<tbody>
<tr>
<td>Soheil a Borhani et al (2022) [17]</td>
<td>Bladder cancer diagnosis and outcome prediction</td>
<td>Pelvic CT images with and without bladder malignancies</td>
<td>Automated bladder tumor detection using CNN-based model named CystoNe</td>
<td>N/A</td>
<td>Non-linear supervised classification CNN-based model</td>
<td>Sensitivity =0.91, Specificity =0.99</td>
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<tr>
<td>Sebastian Marsc</td>
<td>Organ segmentation</td>
<td>Thoracic CT images</td>
<td>Automatic contouring of organs</td>
<td>N/A</td>
<td>DI2IN based on a</td>
<td>A deep image-to-image</td>
</tr>
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</table>

AI based BCa diagnostics and prognostics has the potential to improve patients' quality of life and reduce the financial burden.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Methodology/Algorithm</th>
<th>Data Description</th>
<th>Application/Result</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ge et al. (2019) [19]</td>
<td>Progress of radiomics with ML in bladder cancer management</td>
<td>Convolutional Encoder-Decoder architecture with a multi-level feature concatenation auto-segmentation algorithm</td>
<td>84 bladder cancer lesions from 76 CT urography (CTU) cases</td>
<td>LDA, NN, SVM, RAF</td>
<td>Accuracy: 82.9%, Sensitivity: 78.4%, Specificity: 87.1%, AUC: 86.1%</td>
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</tbody>
</table>

Here et al. (2022) [18] | Algorithm for radiation treatment planning | (n=237) Pelvic CT images (n=102) at risk in radiation treatment planning | Convolutional Encoder-Decoder architecture with a multi-level feature concatenation auto-segmentation algorithm | Network (DI2IN) algorithm for automatic contouring of organs at risk in radiation treatment planning. | |
<table>
<thead>
<tr>
<th>Method</th>
<th>Endourology and Robotic Surgery</th>
<th>Endourology and Robotic Surgery</th>
<th>Deep Learning Systems and Robotic Video/Image-Based Data</th>
<th>Deep Learning Systems Including RP-Net Based on InceptionV3</th>
<th>&gt; 95% Accuracy for Classification; Potential for Improved Patient Outcomes</th>
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<td><strong>Histopathology</strong></td>
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<tr>
<td>Harm on et al. (2020)</td>
<td>Predict positive lymph nodes from primary tumors in bladder cancer using digital pathology</td>
<td>Training and Validation: 219 patients, Testing: 89 patients</td>
<td>307 patients were identified TCGA (n = 294) in-house (n = 13)</td>
<td>Multivariable Logistic Regression Models</td>
<td>AUC of clinicopathological model 0.755, AUC of AI score 0.866</td>
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<tr>
<td>Harm</td>
<td>Prediction</td>
<td>Training</td>
<td>Clinicopathology</td>
<td>Multivariate</td>
<td>AUC:</td>
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<tr>
<td>on et al (2020) [23]</td>
<td>of positive lymph nodes in bladder cancer</td>
<td>: Digitized cystectomy specimens (TCGA), Validation: In-house cohort</td>
<td>hologic features, AI score</td>
<td>iable Logistic Regression</td>
<td>0.866 (cross-validation), AUC: 0.755 (training and validation)</td>
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<td>Woerl et al (2020) [24]</td>
<td>Predicting molecular subtype of MIBC samples from histomorphology using deep learning</td>
<td>Two cohorts: (1) The Cancer Genome Atlas Urothelial Bladder Carcinoma dataset (407 patients) and (2) cohort with 16 treatment-naïve patients</td>
<td>Image tiles generated from annotations</td>
<td>Molecular subtype prediction from hematoxylin and eosin (HE) slides</td>
<td>ResNet (CNN)</td>
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</tbody>
</table>

**Biomarkers, Molecular and Genetics**

| Loeffler et al. | Predict mutations of the | Digitized slides stained | FGF R3 mutant | Deep Learning Network | Detect genetic alteration |
Fibroblast Growth Factor Receptor (FGFR) gene with hematoxylin and eosin from the Cancer Genome Atlas (TCGA) cohort ions detected with an AUR OC of 0.701 (p < 0.0001) in the TCGA cohort and 0.725 (p < 0.0001) in the “Aachen” cohort.

<table>
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<tr>
<th>Treatment and prognostication</th>
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<tbody>
<tr>
<td>Okyaz Emina et al. (2022) [26]</td>
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<tr>
<td>AI-Based Prognostic Model for Urologic Cancers: A SEER-Based Study</td>
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<td>N/A</td>
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<tr>
<td>Survival probabilities</td>
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<td>Risk stabilization based on the risk velocity</td>
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<tr>
<td>N/A</td>
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<tr>
<td>Harrell’s Concordance Index</td>
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<tr>
<td>Feasible data-driven AI solution for cancer-specific survival estimation and potential</td>
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<tr>
<td>Study</td>
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<tr>
<td>Kong et al. (2022)</td>
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<td>Lee et al (2021)</td>
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<td>Zaki</td>
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<td>Hasna in et al. (2019) [28]</td>
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<td>Nicolás Brieu et al. (2019) [30]</td>
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3. AI aided Cystoscopy

Bladder cancer (BC) is a malignancy that is common around the world, with a high rate of recurrence, considerable morbidity, and mortality. Cystoscopy (BC) is currently the gold standard for identifying and keeping track of bladder cancer. However, there are drawbacks to manual cystoscopy, such as subjectivity and inter-observer variability. Therefore, a precise and consistent method for diagnosing bladder cancer is urgently needed. This need may be met by AI, which makes it possible to create precise predictive models with high sensitivity and specificity.

AI-assisted cystoscopy is one of the most exciting uses of AI in bladder cancer treatment. The viability and promise of AI-aided cystoscopy in identifying and categorising bladder lesions have been established in a number of studies. A deep learning algorithm called CystoNet, created by Shkolyar et al. [15], can recognise bladder tumours in white light imaging (WLI) cystoscopic recordings. A convolutional neural network (CNN) trained using 2335 frames of a healthy or benign bladder and 417 labelled frames of urothelial carcinoma with histological confirmation was used to create CystoNet. When tested on 54 full-length cystoscopy recordings, the system has a sensitivity of 95.5% and a specificity of 98.6%.

Transfer learning was used in a work by Ikeda et al. [25] to create a bladder tumour classifier using a pre-trained CNN (GoogLeNet). The system identified bladder cancer with a sensitivity of 90% and a specificity of 94%, highlighting the promise of transfer learning in AI-assisted cystoscopy. In addition, Lucas et al. [20] used pre-trained CNNs to extract and classify characteristics from 72 movies of Trans urethral resection of bladder tumor (TURBT) taken using
a probe-based confocal laser endomicroscopy (pCLE). The CNN was taught to distinguish between low-grade and high-grade tumors as well as between benign and malignant lesions. The accuracy of the technique was 79% for separating benign from malignant urothelium and 82% for differentiating high-grade from low-grade urothelial tumors.

AI has emerged as a transformative technology in the field of cystoscopy, a widely used procedure for diagnosing bladder cancer. Cystoscopy involves inserting a thin, flexible tube with a camera (cystoscope) into the bladder to visualize its interior and detect abnormalities, including tumors. AI-driven advancements in cystoscopy have significantly improved accuracy by addressing some of the inherent limitations of traditional cystoscopy, such as subjectivity, inter-observer variability, and the potential for missed lesions. Let's delve deeper into the use of AI in cystoscopy and its role in improving accuracy:

AI algorithms, trained on extensive datasets of cystoscopy images, demonstrate the potential to automatically identify and classify bladder lesions. CNNs prove particularly effective in this realm, exhibiting high sensitivity and specificity in detecting bladder tumors. By highlighting suspicious regions in real-time, the AI system can alert urologists to potential lesions that might have been overlooked during traditional cystoscopy, addressing a critical challenge. False negatives, often an issue due to human visual perception limitations, can be mitigated through AI-enhanced cystoscopy, augmenting the urologist's ability to detect subtle lesions and thereby improving early cancer detection. Furthermore, AI algorithms can function as computer-aided diagnostic tools, offering immediate feedback during cystoscopy and assisting urologists in making more accurate assessments. AI's role extends to objective documentation by recording and
analyzing the entire cystoscopy procedure, generating comprehensive reports that include crucial
details for follow-up and treatment planning. Integration with enhanced imaging techniques, such
as narrow-band imaging (NBI) and fluorescence cystoscopy, further amplifies AI's impact. AI's
continuous learning and improvement through model refinement based on new data is pivotal,
enabling enhanced accuracy and performance over time. By acting as a clinical decision support
tool, AI-driven cystoscopy collaborates with urologists, providing evidence-based
recommendations and second opinions, fostering confident and informed decision-making. As AI-
assisted cystoscopy continues to advance, ensuring its robustness and generalizability across
diverse datasets through external validation is imperative. To enhance patient outcomes, future
research should emphasize the verification of these algorithms on larger and more varied datasets,
as well as their practical implementation in clinical settings.

4. Radiomics for staging and treatment response assessment

Radiomics and ML have demonstrated potential for bladder cancer staging and grading that
is correct, which is essential for choosing the most effective treatment plan and follow-up therapy.
Preoperative bladder cancer tumour grading has been devised using multiparametric MRI-based
radiomic analysis models. “With an AUC of 0.9233 for the training cohort and 0.9276 for the
validation cohort, Wang et al.'s study found that a joint model combining T2-weighted imaging,
DWI, ADC, and Max-out performed better than the other four single-modality models in terms of
accuracy, sensitivity, and specificity “[34]. A radiology department implemented AI-driven
radiomics analysis for bladder cancer staging based on multiparametric MRI scans. The AI
algorithm extracted and analyzed a wide range of quantitative imaging features, such as texture,
shape, and intensity, from the MRI images to create a radiomic signature for each patient. This shows promise for reducing subjectivity and encouraging increased use in the future for grading bladder cancers prior to surgery. For the assessment of the efficacy of muscle-invasive bladder cancer treatments, computerised decision-support systems (CDSS) incorporating deep learning convolutional neural network and radiomic features have been established. “With mean AUCs of 0.80 for CDSS-T alone, 0.74 for clinicians who did not use CDSS-T, and 0.77 for clinicians who did use CDSS-T, Cha et al.’s study found that CDSS-T enhanced the performance of attending abdominal radiologists, diagnostic radiology residents, attending oncologists, and attending urologists in assessing pathologic T0 disease” [35].

The validity of a "concurrent approach," in which AI predictions may be displayed from the outset and it is up to the clinician to use them in their decision-making process, must be further investigated. The FDA currently permits physicians to utilise computer-aided detection (CAD) tools as "second readers," revisiting their initial diagnosis with the computer's prediction as additional data [36]. Predicting disease-specific survival and overall survival in bladder cancer treatment is essential for choosing the most effective course of action. In a comparison of ANN and multivariable CPH models, Bhambhvani et al. found that their ANN model predicted overall survival more accurately (AUC 0.81 vs 0.70 vs CPH models) and disease-specific survival with comparable accuracy (AUC 0.80 vs 0.81) in bladder cancer patients [31]. In order to create a predictive model with clinicopathological variables from a primary bladder cancer dataset of 3503 BC patients, Hasnain et al. combined a variety of ML techniques [29]; the model predicted patient recurrence and survival with better than 70% sensitivity and specificity 1, 3, and 5 years after
radical cystectomy. These studies show the capability of radiomics and ML to predict bladder cancer patient prognosis and treatment response with accuracy.

5. Improving biomarkers

With a high specificity of 99%, urinary cytology has long been regarded as a desirable non-invasive screening test for bladder cancer, although its sensitivity for high-grade malignancies is only 0-50% and lower for low-grade cancers. This can be improved upon by using additional urine markers, such as Fluorescent in Situ Hybridization (FISH), Immunocyte, Nuclear Matrix Protein (NMP)-22, and Bladder Tumour Antigen (BTA stat). These markers all have higher sensitivity than urinary cytology, but they have not yet completely replaced it [37].

“Using ML techniques is one promising way to increase the precision of biomarkers for BC diagnosis. In a recent study, the ability to predict 5-year disease-specific survival (DSS) and overall survival (OS) in BC patients using multivariable CPH models and artificial neural networks (ANN) was assessed [38]. In comparison to the CPH models, which had an AUC of 0.70 for OS and 0.81 for DSS, the ANN models demonstrated more accuracy, with an area under the curve (AUC) of 0.81 for OS and 0.80 for DSS. The ANN OS model's calibration slope and intercept were 1.03 and 0.04, respectively, whereas the ANN DSS model's values were 0.99 and 0.04, respectively. These findings imply that ANN models might be more useful in predicting BC patients' survival outcomes.”

By using metabolomics, BC biomarkers can be improved yet another way. A recent study [39], using urine metabolomics, identified promising indicators for the diagnosis of BC. The expression of 19 metabolites from different metabolic pathways was observed to differ between BC patients
and healthy controls. A logistic regression model was used to further filter a subset of 11 of these metabolites, producing a ROC curve with an AUC value of 0.983, a sensitivity of 95.3%, and a specificity of 100%. These findings highlight the need for additional study into the discovery of biomarkers for different diseases and show the promise of metabolomics as a non-invasive tool for diagnosing BC.

Finally, non-invasive biomarkers for BC detection and monitoring are being investigated and developed constantly. The improvement of the precision and dependability of BC biomarkers has shown encouraging outcomes when using ML approaches like metabolomics and artificial neural networks.

**Automated histologic grading and molecular typing**

Algorithms are now able to recognise and categorise tumours based on their histological characteristics and molecular markers because of advancements in AI and ML. For instance, datasets generated from PSA, MRI-guided biopsies, genetic biomarkers, and Gleason grading are frequently employed in the diagnosis of prostate cancer for patient risk assessment, follow-up, and treatment planning[^40]. Similar to this, radiomics and AI from multiparametric magnetic resonance imaging (MRI) have been employed for the evaluation of molecular subtypes in breast cancer using multi-layer perceptron feed-forward artificial neural networks (MLP-ANN) for pairwise comparisons[^41]. Additionally, several experimental setups and post-experiment analytical methods for tumour classification have been compared using AI-based systems. For instance, a study compared three PCA-based classification methods—linear discriminant analysis (LDA), support
vector machine (SVM), and artificial neural network (ANN)—under various experimental circumstances and found that SVM had the highest classification accuracy \[^{42}\]. “APTw) MRI has been employed in the diagnosis of bladder cancer to establish the stage and histologic grade of the disease. Combining APTw and ADC improved diagnostic performance for differentiating between low- and high-grade bladder cancer, according to the study \[^{43,44}\].

Automated histopathological grading and molecular typing are pivotal in the effective management of bladder cancer. Histopathological grading, a crucial step in gauging cancer aggressiveness, has traditionally relied on manual examination by pathologists, which is time-consuming and subjective due to inter-observer variability. AI, especially employing deep learning techniques like CNNs, has emerged as a powerful tool for analyzing histopathological images. CNNs can extract intricate features from these images, aiding in the identification of subtle cellular and tissue patterns associated with different grades of bladder cancer. Transfer learning, involving fine-tuning pre-trained CNN models on histopathological images, enhances grading accuracy by leveraging learned representations. AI algorithms can further segment Regions of Interest (ROIs) within histopathological slides, focusing on tumor areas and improving grading accuracy by excluding non-cancerous tissues. Integrating clinical data, encompassing patient demographics, medical history, and genetic information, enhances AI models for a comprehensive and personalized assessment of cancer aggressiveness.

6. Prognostic algorithms
“In a study by Bhambhvani et al. [31] using traditional clinicopathological data from 161,227 bladder cancer patients in The National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) 18 database, they compared the performance of multivariable CPH models and artificial neural networks (ANN) in predicting 5-year disease-specific survival (DSS) and overall survival (OS) in bladder cancer patients. When compared to the CPH model's AUC of 0.70, the ANN model more accurately predicted OS with an AUC of 0.81, while the AUCs for the DSS were comparable (0.80 and 0.81, respectively). From a substantial perspective primary bladder cancer dataset of 3503 BC patients, Hasnain et al. [29] integrated a number of ML approaches to produce a predictive model including clinicopathological characteristics. After a radical cystectomy (RC), the patient's recurrence and survival were predicted with greater than 70% sensitivity and specificity at 1, 3, and 5 years. These findings imply that AI and ML algorithms can assist prognostic models for bladder cancer to be more accurate and precise, which would enhance treatment planning and patient outcomes.”
Fig. 1 Workflow in management of Bladder cancer with AI integration.

Table 2 Comparison between AI enhanced diagnosis and traditional diagnosis

<table>
<thead>
<tr>
<th>AI enhanced diagnosis</th>
<th>Traditional diagnosis</th>
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<tr>
<td>Leverages multi-omics data, clinical records, and medical imaging.</td>
<td>Relies on fragmented data sources</td>
</tr>
<tr>
<td>Automated histopathological grading and molecular typing</td>
<td>Manual grading and typing by pathologist</td>
</tr>
<tr>
<td>High precision due to advanced algorithms and ML</td>
<td>Subject to inter-observer variability</td>
</tr>
<tr>
<td>Tailored treatment plans based on individual patient data</td>
<td>Limited personalization of treatment</td>
</tr>
<tr>
<td>Early detection through data analysis</td>
<td>May result in late stage diagnosis</td>
</tr>
</tbody>
</table>
Table 3 Advantages and limitations of AI in bladder cancer management.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Improved diagnostic accuracy</td>
<td>1. Data Dependence and Quality: AI models heavily rely on high-quality and diverse datasets for accurate predictions. Limited or biased data may lead to suboptimal results</td>
</tr>
<tr>
<td>2. Early detection and prognosis</td>
<td>2. Ethical Considerations: The use of AI in healthcare raises ethical concerns related to data privacy, patient consent, and potential biases in algorithmic decision-making.</td>
</tr>
<tr>
<td>3. Personalized treatment strategies</td>
<td>3. Interpretability and Transparency: Some AI models, particularly deep learning algorithms, are often considered &quot;black boxes,&quot; making it challenging to interpret their decision-making process.</td>
</tr>
<tr>
<td>4. Enhanced treatment planning</td>
<td>4. Integration into Clinical Workflow: Incorporating AI into existing clinical workflows requires careful implementation and acceptance by healthcare professionals.</td>
</tr>
<tr>
<td>5. Reduced Healthcare costs</td>
<td>5. Expertise and Training: AI implementation demands skilled personnel with expertise in both medical and AI fields. Training healthcare professionals to use AI effectively can be time-consuming.</td>
</tr>
<tr>
<td>7. Advancement in Research</td>
<td>7. Regulatory and Legal Challenges: Regulatory</td>
</tr>
</tbody>
</table>
approval and compliance with legal requirements can be complex and time-consuming for AI applications in healthcare.

8. Data Security and Privacy: Storing and processing sensitive patient data requires robust security measures to prevent data breaches.

Challenges and Solutions

The integration of AI in bladder cancer care presents both opportunities and challenges. One of the significant challenges is the need for robust and diverse datasets that encompass various patient demographics, disease stages, and treatment responses. Limited or biased data can result in AI models that do not generalize well across different populations. Addressing this challenge involves collaboration among healthcare institutions and researchers to compile comprehensive and representative datasets, ensuring the inclusivity of diverse patient profiles. Additionally, advancements in federated learning, a technique that allows models to be trained across multiple decentralized sources of data, offer a potential solution to data privacy concerns while promoting data sharing and model improvement.

Another obstacle is the interpretability and transparency of AI algorithms, particularly in complex medical decision-making processes. Building AI models that provide clear explanations for their predictions is crucial for gaining trust from clinicians and ensuring the safe integration of AI into
clinical workflows. Research in explainable AI methods and model interpretability is essential to make AI more understandable and acceptable to healthcare professionals.

Moreover, ensuring regulatory compliance and adherence to healthcare standards is a critical challenge. AI algorithms need to meet stringent regulatory requirements to ensure patient safety and data security. Collaborative efforts between AI developers, healthcare institutions, and regulatory bodies are vital to establish guidelines and standards for AI implementation, validation, and monitoring within the healthcare sector.

Lastly, the integration of AI into routine clinical practice requires education and training of healthcare professionals. Understanding the capabilities and limitations of AI models is necessary for optimal utilization and interpretation of AI-generated insights. Continuous training programs, workshops, and educational initiatives can bridge the knowledge gap and facilitate seamless adoption of AI technologies in bladder cancer care.

Addressing these challenges collectively will pave the way for the effective implementation of AI in bladder cancer care, ultimately improving patient outcomes and revolutionizing the landscape of cancer diagnosis, treatment, and management.

7. Conclusion

The application of AI and ML in bladder cancer care has shown remarkable potential,
revolutionizing various aspects of diagnosis and treatment. The key findings presented in this review demonstrate how AI-driven algorithms have enhanced diagnostic precision, treatment planning, and patient outcomes. As we look to the future, further developments in AI and ML hold the promise of even greater impact on bladder cancer care.

**Future Directions:**

AI and ML have revolutionized the field of healthcare, particularly in the realm of bladder cancer care. These technologies can analyze extensive patient data, encompassing genetic profiles, imaging results, and treatment responses, to craft personalized treatment plans tailored to each individual. This approach has the potential to yield more effective therapies while mitigating side effects. Moreover, AI algorithms can detect subtle patterns in patient data, enabling early identification of bladder cancer and accurate prognosis. Timely intervention based on these insights significantly improves survival rates and reduces the necessity for aggressive treatments. Additionally, AI-assisted tumor boards, utilizing multidisciplinary teams of experts, can be pivotal in discussing individual patient cases. AI algorithms provide valuable insights and recommendations rooted in the latest research and patient data, enhancing informed decision-making. However, for AI to be seamlessly integrated into routine clinical practice, the development of user-friendly tools that seamlessly integrate with existing healthcare systems is imperative. Addressing ethical considerations, such as data privacy, bias, and transparency, is crucial to ensure fair and equitable healthcare delivery as AI and ML continue to play a prominent role in bladder cancer care.
Potential Impact:

The integration of AI and ML in bladder cancer care holds significant promise, offering a transformative impact on both patients and healthcare providers. AI-powered algorithms have the potential to significantly enhance diagnostic accuracy by aiding clinicians in identifying bladder lesions more precisely during cystoscopy and analyzing imaging data for accurate tumor staging. Moreover, AI can predict patient responses to specific treatments, enabling personalized treatment planning tailored to individual patient characteristics, thereby improving treatment outcomes. This tailored approach not only enhances patient care but also has the potential to reduce healthcare costs by optimizing resource utilization through early detection and personalized treatment strategies, mitigating expenses associated with aggressive treatments and disease management. Furthermore, AI-driven diagnostic tools can empower patients by providing them with access to comprehensive information, facilitating informed discussions with healthcare providers regarding treatment options and potential outcomes. Additionally, AI and ML can accelerate research efforts through large-scale analysis of patient data, potentially leading to the discovery of novel biomarkers and therapeutic targets. In conclusion, responsible and ethical integration of AI and ML in bladder cancer care holds the key to realizing their full potential, ultimately revolutionizing bladder cancer management, improving diagnostic precision, treatment efficacy, and overall patient well-being.

Conflict of interest

There are no conflicts to declare.
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