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Original Article

Diagnostic Accuracy of Multiparametric MRI in Differentiating Non-Muscle-Invasive from Muscle-Invasive Urinary Bladder Cancer Using Histopathology as the Gold Standard

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Abstract

Background: Accurate preoperative staging of urinary bladder cancer is essential for appropriate treatment planning and improved patient outcomes. While cystoscopy with biopsy remains the gold standard, it is invasive and has limitations in assessing tumor depth and extravesical extension. Magnetic resonance imaging (MRI), particularly multiparametric MRI, offers superior soft tissue contrast and the ability to differentiate bladder wall layers, making it a promising non-invasive alternative.

Objective: To determine the diagnostic accuracy of MRI in differentiating non-muscle-invasive bladder cancer (NMIBC) from muscle-invasive bladder cancer (MIBC), using histopathology as the gold standard.

Methodology: This cross-sectional validation study included 160 patients aged 25–65 years with suspected bladder cancer. MRI was performed using a 1.5-T system, and findings were interpreted by an experienced radiologist. Histopathological examination following transurethral resection of bladder tumor (TURBT) served as the reference standard. Diagnostic parameters including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated.

Results: MRI demonstrated a sensitivity of 92.13%, specificity of 90.14%, PPV of 92.13%, NPV of 90.14%, and an overall diagnostic accuracy of 91.25% in differentiating NMIBC from MIBC.

Conclusion: Multiparametric MRI shows high diagnostic accuracy and can serve as a reliable non-invasive modality for differentiating muscle-invasive from non-muscle-invasive bladder cancer, thereby aiding in clinical decision-making and treatment planning.

Keywords: Bladder cancer, Diagnostic accuracy, Magnetic resonance imaging, Sensitivity, Specificity.

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Introduction

Over the past three decades, urinary bladder cancer has undergone notable epidemiological and pathological transitions, with urothelial carcinoma emerging as the predominant histological subtype [1]. It is the second most common malignancy of the genitourinary tract and represents a significant global health burden due to its high incidence, recurrence rate, and associated healthcare costs. Accurate staging of bladder cancer is essential, as treatment strategies and prognosis are primarily determined by the depth of tumor invasion and extent of disease spread [2].

Cystoscopy with biopsy remains the gold standard for diagnosis and staging of bladder cancer because of its high sensitivity and ability to provide direct visualization and histological confirmation of tumors [3]. However, this approach is invasive and associated with several limitations, including reduced sensitivity for flat lesions, operator dependency, and inability to reliably assess tumor invasion beyond the bladder wall [4]. These limitations necessitate the development and validation of advanced, non-invasive imaging modalities capable of providing accurate local and regional staging.

Several imaging techniques have been explored to improve staging accuracy, including computed tomography (CT) and positron emission tomography/computed tomography (PET/CT), particularly for detecting metastatic disease [5,6]. Despite these advances, precise evaluation of local tumor invasion—especially differentiation between non-muscle-invasive (≤T1) and muscle-invasive (≥T2) bladder cancer—remains a major clinical challenge. This distinction is critical, as non-muscle-invasive tumors are typically managed with transurethral resection with or without intravesical therapy, whereas muscle-invasive tumors require more aggressive treatments such as radical cystectomy, systemic chemotherapy, radiotherapy, or multimodal approaches [1,3,4].

Magnetic resonance imaging (MRI), particularly multiparametric MRI (mpMRI), has emerged as a promising modality for local staging of bladder cancer. MRI offers superior soft tissue contrast, absence of ionizing radiation, and the ability to differentiate various layers of the bladder wall, enabling accurate assessment of tumor depth and extravesical extension [6]. Advanced functional imaging techniques, including diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) imaging, further enhance diagnostic accuracy by providing information on tumor cellularity and vascularity.

Previous studies have reported variable diagnostic performance of MRI in staging bladder cancer. One study demonstrated a sensitivity of 67% and specificity of 88% for detecting muscle invasion [7], while another reported lower diagnostic accuracy, with sensitivity and specificity of 50.0% and 55.6%, respectively [8]. In contrast, a meta-analysis by Cornelissen et al., involving 1724 patients and 1778 lesions, reported pooled sensitivity and specificity of 92% and 88%, respectively, for differentiating ≤T1 from ≥T2 disease [9]. These inconsistencies highlight the need for further validation of MRI across diverse clinical settings and populations.

Given the limited availability of local data and the variability in previously reported outcomes, the present study was designed to evaluate the diagnostic accuracy of MRI in differentiating non-muscle-invasive from muscle-invasive bladder cancer in a local population, using histopathology as the gold standard. The findings of this study are expected to enhance preoperative staging accuracy, support evidence-based clinical decision-making, and contribute to improved patient outcomes.

Methodology

Study design

This study was conducted as a cross-sectional diagnostic validation study aimed at evaluating the diagnostic accuracy of magnetic resonance imaging (MRI) in differentiating non-muscle invasive bladder cancer (NMIBC) from muscle invasive bladder cancer (MIBC), using histopathology as the gold standard.

Ethics

Ethical approval for the study was obtained from the institutional review boards of the participating hospitals prior to commencement. All procedures were performed in accordance with ethical standards of human research. Written informed consent was obtained from all participants after explaining the study objectives, procedures, risks, and benefits, ensuring voluntary participation and confidentiality of patient data.

Setting

The study was conducted at the Department of Urology, Shahida Islam Teaching Hospital, Lodhran, and Bahawal Victoria Hospital/Quaid-e-Azam Medical College, Bahawalpur, Pakistan. Data collection was carried out over a period of six months, from June 2024 to December 2024, in a tertiary care clinical setting equipped with MRI and histopathological diagnostic facilities.

Participants

A total of 160 patients of either gender, aged between 25 and 65 years, presenting with suspected bladder cancer were enrolled. Suspicion was based on ultrasonographic findings indicating an irregular soft tissue mass projecting into the bladder lumen from a fixed mural site. Patients were selected using a non-probability consecutive sampling technique. Exclusion criteria included patients with prior radiation therapy, renal impairment, biopsy-proven muscle invasive bladder cancer, recurrent bladder tumors, benign histology, and contraindications to MRI such as claustrophobia, cardiac pacemakers, or pregnancy. Previously diagnosed MIBC cases were excluded to avoid interpretation bias and ensure accurate assessment of MRI's diagnostic performance in initial staging.

Variables

The primary outcome variable was the diagnostic accuracy of MRI in differentiating NMIBC from MIBC. Independent variables included MRI findings (VI-RADS score classification), while the dependent variable was histopathological confirmation of tumor invasion. Additional variables included demographic characteristics (age, gender) and tumor characteristics (size, invasion status).

Data sources/measurement

MRI examinations were performed using a 1.5-T Philips MRI system with a body phased-array coil, with patients in the supine position. Imaging protocols included T2-weighted imaging, diffusion-weighted imaging (DWI), and dynamic contrast-enhanced (DCE) sequences. Standard parameters such as TR (3000–4000 ms), TE (70–90 ms), slice thickness (5 mm), and field of view were maintained. The VI-RADS scoring system was used by expert radiologists, blinded to histopathology, to assess the likelihood of muscle invasion, with a score ≥3 considered indicative of possible muscle invasion. Following MRI, all patients underwent transurethral resection of bladder tumor (TURBT), and specimens were analyzed by experienced histopathologists blinded to MRI findings. The presence of detrusor muscle in specimens was confirmed to ensure accurate staging. Data were recorded using a structured proforma.

Bias

Several measures were taken to minimize bias. Radiologists interpreting MRI images were blinded to histopathological findings, and histopathologists were blinded to MRI results to reduce observer and confirmation bias. Exclusion of previously diagnosed MIBC cases minimized selection and verification bias. Standardized imaging protocols and use of the VI-RADS system improved inter-observer reliability and diagnostic consistency.

Study size

The sample size of 160 patients was calculated using a 95% confidence level, 12% margin of error, and an expected prevalence of muscle invasive bladder cancer of 41.9%. Previously reported sensitivity (50.0%) and specificity (55.0%) values of MRI were used to estimate the required sample size, ensuring adequate power for diagnostic accuracy evaluation.

Quantitative variables

Quantitative variables included age and tumor size, which were expressed as mean ± standard deviation. Diagnostic parameters such as sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), likelihood ratios, and overall diagnostic accuracy were calculated as percentages with corresponding confidence intervals.

Statistical methods

Data analysis was performed using SPSS version 25.0. Descriptive statistics were used to summarize demographic and clinical characteristics. Qualitative variables were presented as frequencies and percentages, while quantitative variables were expressed as mean ± standard deviation. Diagnostic performance of MRI was evaluated using a 2×2 contingency table, comparing MRI findings with histopathology (gold standard). Sensitivity, specificity, PPV, NPV, likelihood ratios, and overall diagnostic accuracy were calculated to assess the effectiveness of MRI in differentiating NMIBC from MIBC.

Results

Participants

A total of 160 patients fulfilling the inclusion criteria were enrolled in this study and completed all stages of imaging and histopathological evaluation. The age of participants ranged from 25 to 65 years, with a mean age of 44.98 ± 9.10 years. The majority of patients, 90 (56.25%), were within the age group of 46–65 years, indicating a higher burden of disease in middle-aged to older adults. Gender distribution showed a slight male predominance, with 92 (57.50%) males and 68 (42.50%) females, resulting in a male-to-female ratio of approximately 1.4:1.

Descriptive data

Tumor characteristics revealed that the mean tumor size was 6.44 ± 1.96 cm, reflecting relatively advanced lesion presentation at diagnosis. MRI evaluation categorized patients into muscle-invasive and non-muscle-invasive

groups based on imaging criteria. Histopathological examination confirmed the final diagnosis and served as the reference standard. The distribution of true and false diagnostic outcomes demonstrated that MRI correctly identified 82 true-positive and 64 true-negative cases, while 7 false-positive and 7 false-negative cases were observed (Table I).

Outcome data

Using histopathology as the gold standard, MRI demonstrated high diagnostic performance. The sensitivity of MRI in detecting muscle invasion was 92.13% (95% CI: 86.5–97.7%), while specificity was 90.14% (95% CI: 83.2–97.1%). The positive predictive value (PPV) was 92.13%, and the negative predictive value (NPV) was 90.14%. Additionally, likelihood ratio analysis showed a positive likelihood ratio (LR+) of 9.34 and a negative likelihood ratio (LR−) of 0.08, indicating strong discriminatory ability of MRI in differentiating NMIBC from MIBC (Table I).

Main results

MRI achieved a diagnostic accuracy of 91.25% in distinguishing between muscle-invasive and non-muscle-invasive bladder cancer. The high sensitivity indicates that MRI is highly effective in correctly identifying patients with muscle invasion, while the high specificity reflects its reliability in ruling out invasion in non-muscle-invasive cases. The balanced performance across PPV and NPV further supports MRI as a robust non-invasive diagnostic modality. These findings, as summarized in Table I, demonstrate that MRI can serve as a reliable tool for preoperative staging and clinical decision-making in patients with suspected bladder cancer.

Table 1: 2x2 contingency table of MRI's diagnostic precision and gold standard

	Positive Histopathology	Negative Histopathology	P-value
Positive MRI	82 (True Positive)	07 (False Positive)	
Negative MRI	07 (False Negative)	64 (True Negative)	0.0001

Sensitivity: 92.13% (95% CI: 86.5–97.7%)
Specificity: 90.14% (95% CI: 83.2–97.1%)
Positive Predictive Value (PPV): 92.13% (95% CI: 86.5–97.7%)
Negative Predictive Value (NPV): 90.14% (95% CI: 83.2–97.1%)
LR+ = 9.34
LR- = 0.08
Diagnostic Accuracy: 91.25%

Discussion

Magnetic resonance imaging (MRI) has emerged as a valuable non-invasive modality for the local staging of urinary bladder cancer due to its superior soft tissue contrast and ability to delineate the bladder wall, perivesical tissues, and adjacent structures [10,11]. In the present study, MRI demonstrated high diagnostic performance, with sensitivity (92.13%), specificity (90.14%), and overall accuracy (91.25%) in differentiating muscle-invasive bladder cancer (MIBC) from non-muscle-invasive bladder cancer (NMIBC). These findings support the growing evidence that multiparametric MRI (mpMRI) is an effective tool for preoperative staging.

The diagnostic accuracy observed in this study is consistent with previous literature. Studies have shown that advanced MRI sequences, particularly diffusion-weighted imaging (DWI), significantly improve staging accuracy compared to conventional T2-weighted imaging alone [12,13]. The integration of DWI with anatomical imaging enhances tumor detection and improves differentiation between superficial and invasive lesions. Similarly, Thoeny et al. reported high specificity (90–99%) and accuracy (83–96%) for MRI in detecting malignant lymph nodes, further highlighting its diagnostic utility [16].

However, variability in MRI performance has been reported across studies. For instance, earlier studies documented sensitivity and specificity values of 67% and 88%, respectively [7,14,15], while another study reported relatively lower diagnostic accuracy with sensitivity of 50.0% and specificity of 55.6% [8]. These discrepancies may be attributed to differences in imaging protocols, magnet strength, observer experience, and patient selection. In contrast, a meta-analysis of 20 studies demonstrated pooled sensitivity and specificity of 0.90 and 0.86, respectively, supporting the reliability of MRI in distinguishing NMIBC from MIBC [17,18].

The use of multiparametric MRI protocols, including T2-weighted imaging, DWI, and dynamic contrast-enhanced (DCE) sequences, has been shown to significantly enhance diagnostic performance [19]. The Vesical Imaging-Reporting and Data System (VI-RADS) provides a standardized framework for assessing the likelihood of muscle invasion, improving inter-observer agreement and reproducibility. Studies have demonstrated that VI-RADS scores ≥4 are highly predictive of muscle-invasive disease, further supporting its clinical applicability [19].

Additionally, diffusion-weighted MRI has demonstrated superior accuracy in detecting tumor invasion and perivesical extension compared to conventional imaging. Studies have reported higher diagnostic accuracy with DWI (83.0%) compared to non-DWI MRI (66.7%) for identifying muscle invasion, along with significant correlations between apparent diffusion coefficient (ADC) values and tumor characteristics such as size, grade, and stage [20-22]. The use of gadolinium-based contrast agents in DCE imaging further improves diagnostic performance, particularly in assessing tumor vascularity and distinguishing organ-confined from non-organ-confined disease [23-25].

The findings of the present study are in agreement with existing evidence and reinforce the role of MRI as a reliable imaging modality for bladder cancer staging. The high sensitivity and specificity observed indicate that MRI can effectively guide clinical decision-making by accurately identifying patients requiring aggressive treatment while avoiding overtreatment in those with non-invasive disease.

Conclusion

Multiparametric MRI demonstrates high diagnostic accuracy in differentiating muscle-invasive from non-muscle-invasive bladder cancer, with excellent sensitivity and specificity when compared to histopathology. Its non-invasive nature, combined with superior soft tissue characterization, makes it a valuable tool for preoperative staging and treatment planning.

Authors' Contributions:

All authors meet the ICMJE criteria for authorship.

Author 1: Substantial contribution to conception and design, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 2: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 3: Analysis and interpretation of data, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 4: Analysis and interpretation of data, critical revision, final approval, agreed to be accountable for all the work.
Author 5: Substantial contribution to conception and design, drafting the manuscript, final approval, agreed to be accountable for all the work.
Author 6: Substantial contribution to conception and design, data acquisition, drafting the manuscript, final approval, agreed to be accountable for all the work.

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