Cureus
Part of SPRINGER NATURE

Open Access Original Article

Diagnostic Performance of the Vesical Imaging-Reporting and Data System for Predicting Muscle Invasion in Bladder Cancer

Review began 10/28/2026
Review ended 11/07/2026
Published 11/14/2026

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DOI: 10.7759/cureus.119650

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Abstract

Background and aim

Accurate assessment of muscle invasion in bladder cancer is essential for appropriate treatment planning. The Vesical Imaging-Reporting and Data System (VI-RADS) was developed to standardize magnetic resonance imaging (MRI) interpretation and improve the prediction of muscle-invasive bladder cancer. This study aimed to retrospectively evaluate the diagnostic performance of 1.5-T multiparametric MRI using a predefined VI-RADS threshold of ⩾4 for predicting muscularis propria invasion (⩾T2) in patients with primary or recurrent urothelial bladder carcinoma who underwent MRI within one month before transurethral resection of bladder tumor (TURBT), using histopathological findings as the reference standard.

Methods

This retrospective, single-center observational study was conducted at the Department of Urology, Mohammed V Military Hospital, between January 2020 and December 2025. A total of 135 patients with primary or recurrent bladder tumors who underwent bladder MRI before transurethral resection of bladder tumor (TURBT) were included. MRI examinations were interpreted by senior radiologists, and VI-RADS scores were compared with histopathological findings. Diagnostic performance was evaluated by calculating sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy.

Results

The study included 135 patients with a mean age of 60±7.46 years, including 117 men (86.7%). A history of smoking was reported in 124 patients (91.9%). Among 81 patients with VI-RADS scores ⩾4, muscle invasion was confirmed histopathologically in 75 (92.6%) patients. Among 54 patients with VI-RADS scores ⩽3, 51 (94.4%) had non-muscle-invasive disease. Using a VI-RADS cutoff of ⩾4, sensitivity was 96.2%, specificity was 89.5%, positive predictive value was 92.6%, negative predictive value was 94.4%, and overall diagnostic accuracy was 93.3%.

Conclusions

Using a predefined threshold of ⩾4, VI-RADS demonstrated high diagnostic accuracy for predicting muscularis propria invasion in this selected retrospective cohort. These findings suggest that VI-RADS may serve as a complementary non-invasive tool for preoperative assessment, without replacing histopathological confirmation. Further prospective studies are needed to validate its clinical utility.

Categories: Urology, Oncology
Keywords: bladder cancer, diagnostic accuracy, magnetic resonance imaging, muscle-invasive bladder cancer, transurethral resection, vi-rads

Introduction

Bladder cancer is a major global health concern and one of the most common malignancies of the urinary tract. According to Global Cancer Observatory (GLOBOCAN) 2024 estimates, approximately 635,264 new cases and 227,626 deaths were attributed to bladder cancer worldwide, making it the eighth most frequently diagnosed cancer and the 13th leading cause of cancer-related mortality globally [1]. The burden of bladder cancer varies considerably across geographical regions and between sexes, reflecting differences in exposure to established risk factors, particularly tobacco smoking, and occupational carcinogens [2].

In Morocco, bladder cancer represents an important oncological burden, particularly among men. According to GLOBOCAN 2022 estimates, bladder cancer was the fourth most frequently diagnosed malignancy among

Moroccan men, with approximately 1,911 new cases, accounting for 6.2% of all newly diagnosed cancers in the male population [3]. These findings highlight the importance of improving diagnostic assessment and optimizing therapeutic management in the Moroccan healthcare setting.

Urothelial carcinoma is the predominant histological type of bladder cancer. Accurate local staging is essential for determining prognosis and selecting appropriate treatment. In particular, distinguishing non-muscle-invasive bladder cancer (NMIBC) from muscle-invasive bladder cancer (MIBC) is a critical step in clinical decision-making, as these two disease categories require substantially different therapeutic approaches. Transurethral resection of bladder tumor (TURBT), followed by histopathological examination, remains fundamental for diagnosis and pathological staging. However, incomplete resection, inadequate sampling, or the absence of muscularis propria in the specimen may lead to understaging and necessitate repeat resection [4].

Multiparametric magnetic resonance imaging (mpMRI) has emerged as a promising noninvasive technique for the local staging of bladder cancer. Its superior soft-tissue contrast allows detailed assessment of the bladder wall and potential muscularis propria invasion. In 2018, Panebianco et al. introduced the Vesical Imaging-Reporting and Data System (VI-RADS), a standardized five-point scoring system designed to estimate the likelihood of muscle invasion using T2-weighted imaging, diffusion-weighted imaging, and dynamic contrast-enhanced sequences [5]. Subsequent studies have demonstrated encouraging diagnostic performance, supporting the potential role of VI-RADS in differentiating NMIBC from MIBC. Nevertheless, its optimal integration into routine clinical decision-making remains under investigation [6].

Although VI-RADS has been extensively evaluated in previous studies, additional evidence from different clinical settings and patient populations remains valuable, particularly in cohorts including both primary and recurrent bladder cancer. The present retrospective, single-center study aimed to evaluate the diagnostic performance of VI-RADS using 1.5-T multiparametric MRI for predicting muscularis propria invasion (⩾T2) in a North African cohort of patients with histologically confirmed urothelial bladder carcinoma. All patients underwent MRI within one month before TURBT, and the primary analysis used a predefined VI-RADS threshold of ⩾4. The reference standard was the highest pathological stage established through TURBT, repeat TURBT, or radical cystectomy, when available.

Secondary objectives were to describe the distribution of VI-RADS scores and to examine the occurrence of false-negative classifications, particularly among patients assigned a VI-RADS 3 score. By including patients with primary and recurrent disease, this study aimed to provide additional evidence regarding the diagnostic performance of VI-RADS in a heterogeneous clinical population undergoing 1.5-T MRI.

Materials And Methods

Study design and patient selection

This retrospective, single-center observational study was conducted at the Department of Urology of Mohammed V Military Hospital, Morocco, between January 2020 and December 2025. All patients who underwent bladder multiparametric magnetic resonance imaging (mpMRI) for suspected primary or recurrent bladder tumors during the study period were retrospectively identified through a comprehensive review of medical records.

A total of 143 patients were initially identified. Five patients were excluded because of technically inadequate or non-interpretable MRI examinations, and three were excluded because histopathological examination did not confirm urothelial carcinoma. The final study population comprised 135 patients with interpretable preoperative mpMRI examinations and histopathologically confirmed urothelial bladder carcinoma.

Patients who had not undergone bladder MRI were not part of the study population. Eligible patients had undergone preoperative mpMRI within one month before transurethral resection of bladder tumor (TURBT). In patients with recurrent bladder cancer, mpMRI was performed at least four weeks after the previous TURBT to minimize potential interference from post-resection inflammatory changes. Given the retrospective nature of the study, no a priori sample size calculation was performed. The sample size was determined by the number of eligible patients identified during the predefined study period.

Patient preparation and MRI acquisition protocol

All MRI examinations were performed using a 1.5-T GE SIGNA HDxt scanner (Chicago, IL: GE Healthcare), following the institutional multiparametric bladder MRI protocol based on the standardized VI-RADS imaging recommendations [5]. Patients were instructed to maintain moderate bladder filling, with a target volume of approximately 200-300 mL, to optimize visualization of the bladder wall. They were advised to refrain from voiding for at least two hours before the examination while maintaining their usual food and fluid intake.

The preparation protocol included premedication with hydroxyzine and intravenous administration of

phloroglucinol (40 mg by slow intravenous injection) as a musculotropic antispasmodic agent, intended to reduce bowel peristalsis-related motion artifacts. T2-weighted turbo spin-echo (TSE) sequences were acquired in three orthogonal planes with a slice thickness of 3 mm, no interslice gap, and a field of view of approximately 200-220 mm. Diffusion-weighted imaging (DWI) was performed in the axial plane with a slice thickness of ⩽4 mm, using low b-values of 0-50 s/mm² and high b-values of 800-1000 s/mm², with corresponding apparent diffusion coefficient (ADC) maps.

Dynamic contrast-enhanced (DCE) imaging was performed using a fat-suppressed three-dimensional T1-weighted gradient-echo sequence with a slice thickness of ⩽3 mm. Dynamic acquisition started at the time of contrast injection, with a temporal resolution of approximately 10-15 s per phase over a total acquisition period of 2-3 min. A gadolinium-based contrast agent was administered at a dose of 0.1 mmol/kg and an injection rate of 2-3 mL/s, followed by a 20-mL saline flush. Serum creatinine measurement was not systematically performed before gadolinium administration.

MRI interpretation

All bladder multiparametric MRI examinations were interpreted in routine clinical practice by experienced senior radiologists using the standardized Vesical Imaging-Reporting and Data System (VI-RADS), based on the combined assessment of T2-weighted imaging (T2WI), diffusion-weighted imaging (DWI), and dynamic contrast-enhanced imaging (DCE).

Multiple senior radiologists participated in MRI interpretation during the study period. Each examination was interpreted by a single radiologist, without double reading or consensus assessment. VI-RADS scores were extracted directly from the original radiological reports, without retrospective reassessment of the images. Radiologists were blinded to cystoscopic findings, and VI-RADS scores were assigned before transurethral resection of bladder tumor and before histopathological findings became available.

The five-point VI-RADS classification was interpreted as follows: VI-RADS 1 indicates that muscle invasion is highly unlikely; VI-RADS 2 indicates that muscle invasion is unlikely; VI-RADS 3 indicates that muscle invasion is equivocal; VI-RADS 4 indicates that muscle invasion is likely; and VI-RADS 5 indicates that muscle invasion is highly likely, with possible extension beyond the bladder wall. In patients with multiple bladder lesions, the highest VI-RADS score was retained for patient-level analysis. For diagnostic accuracy assessment, VI-RADS scores of 1-3 were classified as negative for muscle invasion, whereas scores of 4-5 were classified as positive.

Histopathological assessment

Histopathological findings obtained from TURBT specimens and, when available, subsequent cystectomy specimens were reviewed. All included patients had histopathologically confirmed urothelial bladder carcinoma. Tumor stage and grade were extracted from pathology reports. Muscularis propria was identified in the histopathological specimens of all 135 patients, either from the initial TURBT, repeat TURBT (second-look resection), or subsequent radical cystectomy.

A total of 23 patients (17.0%) underwent repeat TURBT, and 72 patients (53.3%) underwent radical cystectomy. For patients undergoing multiple procedures, the highest pathological tumor stage was retained for the final analysis. Patients were classified into the following two groups according to the presence or absence of muscularis propria invasion: non-muscle-invasive bladder cancer (NMIBC; stages Ta, T1, and carcinoma in situ) and muscle-invasive bladder cancer (MIBC; stage T2 or higher). Histopathological findings served as the reference standard against which preoperative VI-RADS scores were compared.

Data collection

Clinical, radiological, and histopathological data were retrospectively extracted from patient medical records and institutional reports using a standardized data collection form. The collected variables included age, sex, body mass index, smoking history, previous bladder cancer, presenting symptoms, tumor characteristics, VI-RADS scores, histological grade, and pathological tumor stage. Data were collected and verified under the supervision of the principal investigator and subsequently compiled into a structured electronic database for statistical analysis. All required clinical, radiological, and histopathological variables were available for the 135 included patients, with no missing data in the final dataset. Therefore, no missing-data imputation was required.

Statistical analysis

Statistical analyses were performed using jamovi statistical software (version 2.6.44.0) (Sydney, Australia: The jamovi project). Continuous variables were summarized using means and standard deviations, while categorical variables were expressed as frequencies and percentages. For diagnostic accuracy assessment, VI-RADS scores were dichotomized into the following two categories: VI-RADS <4 and VI-RADS ⩾4. Histopathological findings were classified as non-muscle-invasive bladder cancer (NMIBC) or muscle-invasive bladder cancer (MIBC).

A 2×2 contingency table was constructed to compare MRI-based classification with histopathological findings as the reference standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy were calculated, with 95% confidence intervals estimated using the Wilson score method. Receiver operating characteristic (ROC) analysis was performed using the dichotomized VI-RADS classification (≥4 versus <4) to assess its discriminatory ability for detecting muscle invasion.

Results

Patient selection and baseline characteristics

Between January 2020 and December 2025, 143 patients who underwent bladder multiparametric magnetic resonance imaging were retrospectively identified. Eight patients were excluded as follows: five because of technically inadequate or non-interpretable MRI examinations and three because histopathological examination did not confirm urothelial carcinoma. The final study population comprised 135 patients (Figure *1*).

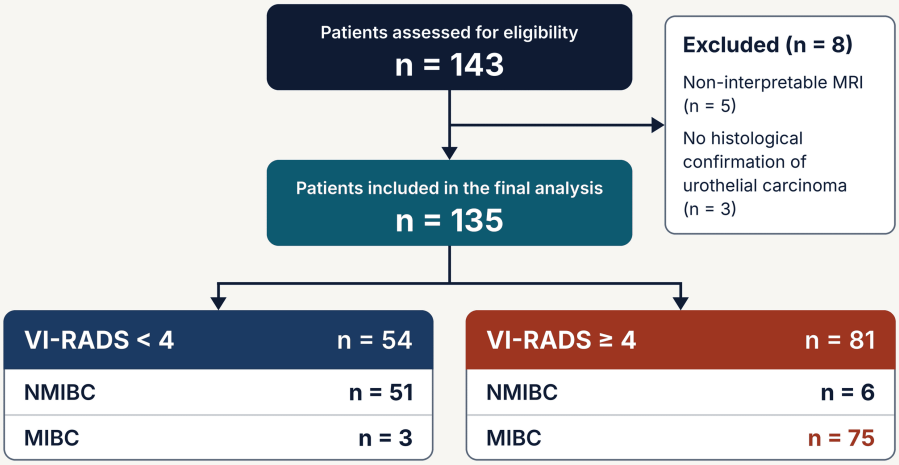


FIGURE 1: Flow diagram of patient selection and diagnostic classification according to VI-RADS and histopathological findings.

NMIBC: non-muscle-invasive bladder cancer; MIBC: muscle-invasive bladder cancer; VI-RADS: Vesical Imaging-Reporting and Data System

The mean age was 60±7.46 years (range: 42-87 years), and the mean body mass index (BMI) was 30.5±4.94 kg/m² (range: 20-40.5 kg/m²). The cohort included 117 men (86.7%) and 18 women (13.3%), corresponding to a male-to-female ratio of 6.5:1. Regarding smoking status, 40 patients (29.6%) were current smokers, 84 (62.2%) were former smokers, and 11 (8.1%) had never smoked. Overall, 124 patients (91.9%) reported a history of smoking.

A total of 72 patients (53.3%) had a previous history of bladder cancer, whereas 63 (46.7%) presented with newly diagnosed disease. Among patients with previous bladder cancer (n=72), 38 (52.8%) had received intravesical bacillus Calmette-Guérin (BCG) therapy, 19 (26.4%) intravesical chemotherapy, and nine (12.5%) both treatments. The remaining six patients (8.3%) had undergone cystoscopic surveillance without prior intravesical therapy.

Hematuria was the most common clinical presentation, reported in 91 patients (67.4%). Bladder tumors were incidentally detected in 33 patients (24.4%), while nine (6.7%) presented with lower urinary tract symptoms and two (1.5%) with pelvic pain. A solitary bladder lesion was identified in 58 patients (43.0%), whereas 77 (57.0%) had multiple lesions. The baseline characteristics of the study population are summarized in Table *1*.

Characteristics	Values (total n=135)
Age (years), mean±SD	60±7.46
Sex, n (%)	
Male	117 (86.7%)
Female	18 (13.3%)
BMI, mean±SD	30.5±4.94 (kg/m²)
Smoking status, n (%)	
Active smoker	40 (29.6%)
Former smoker	84 (62.2%)
Non-smoker	11 (8.1%)
History of bladder cancer, n (%)	
Yes	72 (53%)
No	63 (47%)
Bladder tumor characteristics, n (%)	
Single lesion	58 (43%)
Multiple lesions	77 (57%)
Clinical presentation, n (%)	
Hematuria	91 (67%)
Incidental finding	33 (24%)
Lower urinary tract symptoms	9 (7%)
Pelvic pain	2 (1%)
Prior intravesical therapy, n (%)	
BCG	38 (52.8%)
Intravesical chemotherapy	19 (26.4%)
Both	9 (12.5%)
Cystoscopic surveillance	6 (8.3%)

TABLE 1: General characteristics of the study population at inclusion (n=135).

BCG: bacillus Calmette-Guérin

Distribution of VI-RADS scores

All 135 MRI examinations were evaluated using the Vesical Imaging-Reporting and Data System (VI-RADS), a five-point scoring system developed by Panebianco et al. to standardize MRI assessment of bladder muscle invasion [5]. For patients with multiple bladder lesions, we retained the highest VI-RADS score for patient-level analysis.

The distribution of VI-RADS scores was as follows: VI-RADS 1 in 12 patients (8.9%), VI-RADS 2 in 23 (17.0%), VI-RADS 3 in 19 (14.1%), VI-RADS 4 in 39 (28.9%), and VI-RADS 5 in 42 (31.1%). Using the predefined cutoff of VI-RADS ⩾4, 81 patients (60.0%) were classified as having MRI findings suggestive of muscle invasion, whereas 54 patients (40.0%) had VI-RADS scores below 4. The distribution of VI-RADS scores is illustrated in Figure *2*.

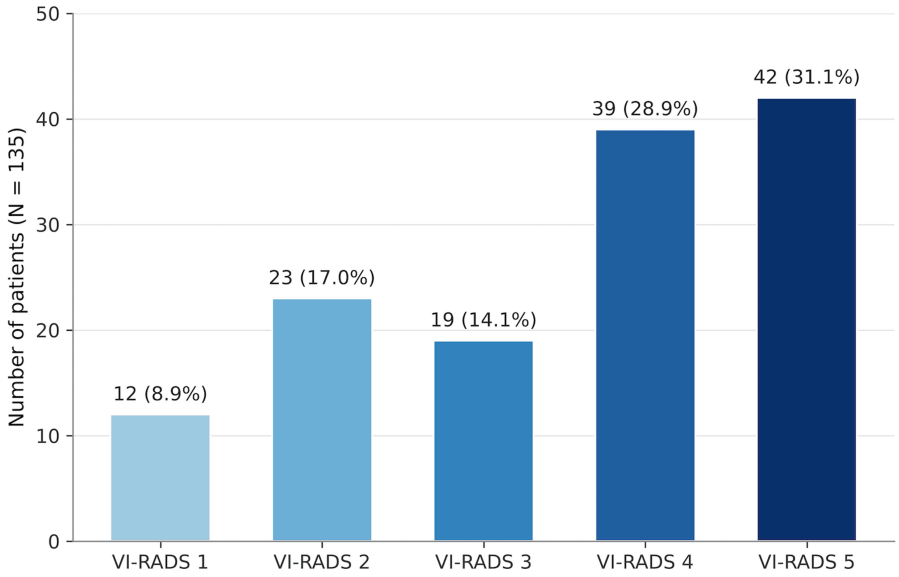


FIGURE 2: Distribution of patients according to VI-RADS score.

VI-RADS: Vesical Imaging-Reporting and Data System

Histopathological findings

Histopathological examination confirmed urothelial carcinoma in all 135 patients. Histopathological findings were obtained from transurethral resection of bladder tumor specimens and, when applicable, subsequent repeat TURBT or radical cystectomy specimens. In patients undergoing multiple procedures, the highest pathological stage was retained for analysis. Muscle-invasive bladder cancer (MIBC) was identified in 78 patients (57.8%), whereas 57 patients (42.2%) had non-muscle-invasive bladder cancer (NMIBC). Histological grade was recorded in all patients. High-grade urothelial carcinoma was identified in 88 patients (65.2%), whereas low-grade urothelial carcinoma was observed in 47 patients (34.8%).

Correlation between VI-RADS classification and histopathological findings

The relationship between VI-RADS classification and histopathological muscle invasion is presented in Table *2*. Among 81 patients with VI-RADS scores ⩾4, 75 (92.6%) had histopathologically confirmed muscle-invasive disease, whereas six (7.4%) had non-muscle-invasive disease. Conversely, among 54 patients with VI-RADS scores below 4, 51 (94.4%) had non-muscle-invasive disease, while three (5.6%) had muscle-invasive disease. The overall agreement between VI-RADS classification and histopathological findings was 93.3% (126/135).

VI-RADS classification	MIBC	NMIBC	Total
VI-RADS <4	3	51	54
VI-RADS ≥4	75	6	81
Total	78	57	135

TABLE 2: Concordance between VI-RADS classification and histopathological muscle invasion.

VI-RADS: Vesical Imaging-Reporting and Data System; MIBC: muscle-invasive bladder cancer; NMIBC: non-muscle-invasive bladder cancer

Diagnostic performance of VI-RADS

At the predefined VI-RADS ⩾4 threshold, sensitivity for detecting muscle invasion was 96.2%, specificity was 89.5%, positive predictive value (PPV) was 92.6%, and negative predictive value (NPV) was 94.4%. Overall diagnostic accuracy was 93.3%. Receiver operating characteristic (ROC) analysis based on the dichotomized

VI-RADS classification yielded an area under the curve (AUC) of 0.928 (Figure 3). The diagnostic performance measures are summarized in Table 3.

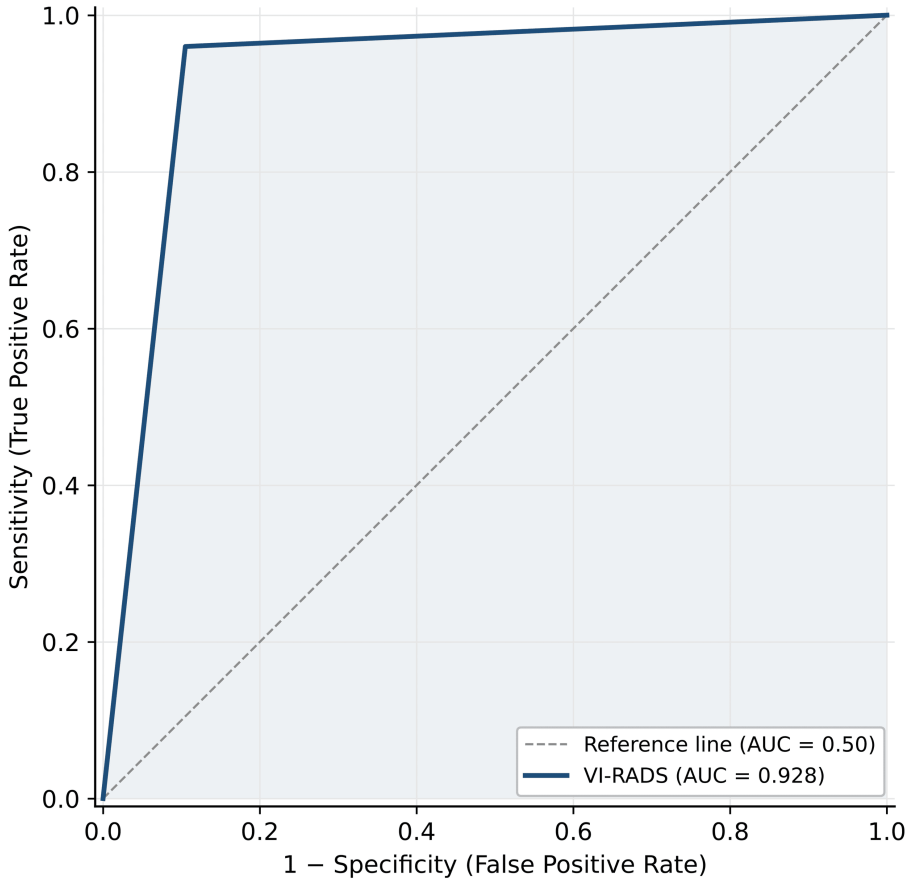


FIGURE 3: Receiver operating characteristic (ROC) curve for VI-RADS dichotomized at a cutoff of ≥4 in predicting muscle-invasive bladder cancer.

AUC=0.928 (95% CI: 0.883-0.974; p<0.001).

AUC: area under the curve; VI-RADS: Vesical Imaging-Reporting and Data System

Diagnostic performance metric	Value	95% CI
Overall diagnostic accuracy	93.3%	87.8-96.5%
Sensitivity	96.2%	89.3-98.7%
Specificity	89.5%	78.9-95.1%
Positive predictive value (PPV)	92.6%	84.8-96.6%
Negative predictive value (NPV)	94.4%	84.9-98.1%
Area under the ROC curve (AUC)	0.928	0.883-0.974

TABLE 3: Diagnostic performance of VI-RADS for predicting muscle invasion.

Diagnostic performance was assessed using a VI-RADS cutoff of ≥4. The ROC analysis was based on the dichotomized VI-RADS classification (≥4 versus <4), with histopathological findings as the reference standard.

VI-RADS: Vesical Imaging-Reporting and Data System; ROC: receiver operating characteristic; AUC: area under the curve

Discussion

Accurate local staging is essential for the appropriate management of bladder cancer, particularly for distinguishing non-muscle-invasive bladder cancer (NMIBC) from muscle-invasive bladder cancer (MIBC). This distinction directly influences therapeutic decision-making, including the need for intravesical treatment, radical surgery, and systemic therapy. Histopathological examination of transurethral resection of bladder tumor (TURBT) specimens remains the reference standard for determining muscle invasion. However, TURBT is an invasive and operator-dependent procedure, and staging accuracy may be affected by incomplete resection, inadequate sampling of the muscularis propria, or the anatomical characteristics of the tumor [6,7].

Multiparametric magnetic resonance imaging (mpMRI) has emerged as a valuable complementary tool for the preoperative assessment of bladder tumors because of its superior soft-tissue contrast and ability to evaluate the bladder wall using morphological and functional sequences [8-10]. The Vesical Imaging-Reporting and Data System (VI-RADS), introduced by Panebianco et al. in 2018, provides a standardized five-point scoring system for estimating the likelihood of muscularis propria invasion [5].

In the present study, VI-RADS demonstrated high diagnostic performance for predicting muscle invasion. Using a predefined threshold of VI-RADS ⩾4, we observed a sensitivity of 96.2%, specificity of 89.5%, positive predictive value of 92.6%, negative predictive value of 94.4%, and overall diagnostic accuracy of 93.3%. These findings suggest that VI-RADS may serve as a potentially useful adjunct to histopathological assessment for distinguishing MIBC from NMIBC in this selected cohort.

An important finding was the occurrence of three false-negative cases in which MRI suggested the absence of muscle invasion, whereas histopathological examination confirmed MIBC. All three cases were assigned a VI-RADS score of 3. This observation highlights the diagnostic uncertainty associated with the intermediate VI-RADS category. In our cohort, these cases represented three of the 19 patients classified as VI-RADS 3. Consequently, lesions assigned a VI-RADS score of 3 should be interpreted cautiously, taking into account the clinical presentation, cystoscopic findings, and tumor characteristics, without relying on MRI findings alone for therapeutic decision-making.

This observation is consistent with the diagnostic challenges investigated by Wang et al., who evaluated the ability of VI-RADS to predict bladder muscle invasion [11]. The intermediate category therefore remains a particular challenge for clinical decision-making and may require multidisciplinary assessment rather than reliance on imaging findings alone.

Our results are broadly consistent with previously published studies evaluating the diagnostic performance of VI-RADS. Barchetti et al. reported high interobserver agreement and diagnostic accuracy in assessing bladder muscle invasion using mpMRI [12]. Similarly, Ueno et al. demonstrated encouraging diagnostic performance and reproducibility in a multireader validation study [13]. These previous studies suggest that standardized VI-RADS assessment may offer reproducible results across different readers, although interobserver agreement was not evaluated in our cohort.

Other studies have reported comparable results, although diagnostic performance varies according to the study population, imaging protocol, reader experience, and VI-RADS threshold used. Wang et al. validated

the diagnostic performance of VI-RADS for detecting detrusor muscle invasion [14], whereas Kim also demonstrated its clinical utility in a retrospective validation study [15]. Del Giudice et al. prospectively evaluated VI-RADS in patients with high-risk NMIBC considered for repeat TURBT, highlighting its potential contribution to risk stratification [16].

Furthermore, published systematic reviews and meta-analyses have demonstrated favorable diagnostic performance of MRI for predicting muscle-invasive bladder cancer [8]. Our findings are consistent with this body of evidence, although the relatively high diagnostic performance observed in our cohort should be interpreted in the context of its retrospective, single-center design.

Beyond diagnostic accuracy, VI-RADS may have important implications for treatment planning. Preoperative identification of patients at high risk of muscle invasion could facilitate multidisciplinary discussions, improve patient counseling, and help clinicians anticipate the need for additional staging investigations or definitive treatment [5,17]. Conversely, a low VI-RADS score may provide useful complementary information when evaluating patients with apparently non-muscle-invasive disease.

The potential role of mpMRI in reducing unnecessary repeat TURBT procedures has also been investigated. Del Giudice et al. assessed whether VI-RADS could improve patient selection for repeat TURBT in high-risk NMIBC [16]. The BladderPath study also explored an imaging-guided diagnostic pathway for patients with suspected muscle-invasive disease [18]. Nevertheless, VI-RADS should not currently be considered a substitute for histopathological confirmation or repeat TURBT when indicated by established clinical guidelines [6,17]. In particular, a high VI-RADS score alone should not justify radical cystectomy or neoadjuvant chemotherapy without appropriate pathological confirmation and multidisciplinary evaluation.

Early identification of muscle-invasive disease could potentially facilitate timely treatment planning, although the impact of VI-RADS on treatment delays was not evaluated in our study. Previous studies have highlighted the potential adverse consequences of prolonged intervals between diagnosis and radical treatment [19,20]. However, whether routine implementation of VI-RADS improves long-term oncological outcomes remains to be established.

Another relevant consideration is the timing of MRI acquisition. Performing mpMRI before TURBT may improve interpretation by avoiding post-resection inflammation, edema, fibrosis, and anatomical distortion, which can mimic or obscure muscle invasion [5,9]. Accordingly, our study primarily evaluated MRI performed before TURBT or sufficiently remote from previous resections in patients with recurrent disease. Although MRI performed after TURBT may still provide useful information in selected circumstances, postprocedural changes can complicate interpretation and should be considered when evaluating VI-RADS scores.

The potential advantages of mpMRI must also be balanced against practical limitations. MRI provides excellent local soft-tissue characterization but does not replace the broader staging information obtained from other imaging modalities [8,9]. Furthermore, the use of gadolinium-based contrast agents requires individual assessment in patients with renal impairment, and MRI should not be considered universally preferable to contrast-enhanced CT solely on the basis of reduced kidney function.

Our study has several limitations. First, its retrospective, single-center design may introduce selection bias and limit the generalizability of our findings. Patients requiring urgent intervention, particularly those with severe hematuria or acute complications, may have been underrepresented. Furthermore, the relatively high prevalence of muscle-invasive bladder cancer (57.8%) suggests a potentially selected population, which may have influenced prevalence-dependent diagnostic measures, particularly positive and negative predictive values.

Second, although MRI examinations were interpreted by experienced radiologists, interobserver agreement was not assessed. Reader experience and familiarity with VI-RADS may influence diagnostic performance, particularly for intermediate lesions [12,13]. Changes in radiologist experience and familiarity with VI-RADS over the study period were not specifically evaluated. Additionally, diagnostic performance was not separately evaluated in patients with primary versus recurrent bladder cancer or according to previous intravesical BCG treatment. The exact interval between the last BCG instillation and MRI was not systematically documented, limiting assessment of potential treatment-related inflammatory changes.

Third, all examinations were performed using a 1.5-T MRI scanner, without comparison with 3-T systems. Moreover, histopathological staging was based on TURBT, repeat TURBT, or radical cystectomy specimens. Although muscularis propria was identified in the histopathological specimens of all patients, the use of different reference specimens may have introduced differential verification bias. Residual understaging following TURBT cannot be entirely excluded, particularly in patients who did not undergo radical cystectomy.

Another limitation concerns the implementation of mpMRI in routine clinical practice. Its use requires coordination between urologists and radiologists, familiarity with the VI-RADS classification, and

consideration of MRI availability and cost, particularly in resource-limited settings.

Finally, our analysis was performed at the patient level, using the highest VI-RADS score in patients with multiple lesions, without assessing lesion-level diagnostic performance. The ROC analysis was based on the predefined binary threshold of VI-RADS ⩾4 rather than the complete five-point ordinal scale. Consequently, the reported AUC reflects the discriminatory performance of this binary classification rather than the full discriminatory ability of the original VI-RADS scale. Histological variants and T1 substaging were not specifically evaluated, as the study focused on the detection of muscularis propria invasion in patients with urothelial bladder carcinoma. The exclusion of patients with uninterpretable MRI examinations and the absence of a dedicated analysis of false-positive cases represent additional limitations.

Further prospective, multicenter studies involving larger populations and radiologists with different levels of experience are needed to validate these results. Future investigations should also evaluate the additional diagnostic value of quantitative imaging parameters, including apparent diffusion coefficient (ADC) measurements and tumor-to-bladder wall size ratios. Particular attention should be given to VI-RADS 3 lesions and to the potential integration of mpMRI into individualized diagnostic and therapeutic pathways.

Overall, our findings suggest that VI-RADS may serve as a useful, noninvasive adjunct for the preoperative assessment of bladder muscle invasion. Its potential contribution to risk stratification and treatment planning should be considered alongside cystoscopic, pathological, and clinical findings, rather than as a substitute for histopathological confirmation.

Conclusions

The VI-RADS scoring system demonstrated high diagnostic accuracy in predicting muscularis propria invasion in our retrospective, single-center cohort of patients with bladder cancer. Among 135 patients, a VI-RADS threshold of ⩾4 achieved a sensitivity of 96.2%, specificity of 89.5%, and overall diagnostic accuracy of 93.3%. Importantly, these findings should be interpreted in the context of our selected study population, characterized by a relatively high prevalence of muscle-invasive bladder cancer and the inclusion of patients with previously treated disease.

These findings suggest that VI-RADS may serve as a complementary noninvasive imaging tool for the preoperative assessment of bladder muscle invasion, although its impact on clinical decision-making was not directly evaluated in this study. However, VI-RADS should not replace histopathological confirmation or independently justify radical treatment decisions. Particular caution is warranted when interpreting VI-RADS 3 lesions, given the risk of underestimating muscle invasion. Further prospective, multicenter studies are needed to validate these findings in broader patient populations and clarify the role of VI-RADS in routine clinical practice.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Larbi Hamedoun, Alaa Sobhi, Tarik Chmitah, Amine Cherraqi, Mohammed Mrabti

Acquisition, analysis, or interpretation of data: Larbi Hamedoun, Tarik Chmitah, Amine Cherraqi, Mohamed Tetou, Abdessamad El Bahri, Mohammed Alami, Ahmed Ameur

Drafting of the manuscript: Larbi Hamedoun, Alaa Sobhi, Tarik Chmitah, Amine Cherraqi, Mohammed Mrabti, Mohamed Tetou

Critical review of the manuscript for important intellectual content: Larbi Hamedoun, Abdessamad El Bahri, Mohammed Alami, Ahmed Ameur

Supervision: Mohammed Alami, Ahmed Ameur

Disclosures

Human subjects: Informed consent for treatment and open access publication was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the

submitted work.

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