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Diagnostic Efficacy of Multiparametric MRI and VI-RADS in Staging Bladder Carcinoma: A Systematic Review

Ashish Yadav[1],
Radiology, (PG scholar), Department of Allied Health Care Sciences,
Vivekananda Global University, Jaipur 302012, INDIA
Dr. Mahendra Kumar Verma[2*],
Professor & Principal, Allied health care sciences,
Vivekananda Global University, Jaipur, Rajasthan INDIA.
Email: mahendra.verma@vgu.ac.in, Contact No.: 6367275711
Rukmani Yadav[3],
Radiology , Department of Allied Health Care Sciences,
Faculty of Allied Health Care Professionals,
(Co-Supervisor) Vivekananda Global University, Jaipur 302012, INDIA

Abstract:

Background: Bladder cancer poses a major worldwide health issue, marked by elevated recurrence rates and the potential advancement to muscle-invasive illness. The key element in defining the treatment approach—spanning from organ-preserving transurethral resection to radical cystectomy—is the precise preoperative staging of the tumor. Specifically, distinguishing between Non-Muscle Invasive Bladder Cancer (NMIBC) and Muscle-Invasive Bladder Cancer (MIBC) continues to be a clinical focus. Although Transurethral Resection of Bladder Tumor (TURBT) remains the conventional gold standard, its diagnostic accuracy can frequently be affected by specimen fragmentation and cautery artifacts, resulting in possible under-staging. As a result, there exists an immediate clinical demand for non-invasive, standardized imaging methods that can reliably forecast detrusor muscle invasion.

Objectives: This systematic review intends to assess the diagnostic effectiveness of multiparametric Magnetic Resonance Imaging (mpMRI) and the standardized Vesical Imaging-Reporting and Data System (VI-RADS) in the diagnosis and staging of bladder cancer. The main emphasis is on evaluating the separate and joint contributions of T2-weighted imaging (T2WI), Diffusion-Weighted Imaging (DWI), and Dynamic Contrast-Enhanced (DCE) sequences in detecting muscle invasion.

Methods: A thorough literature search was conducted in prominent medical databases, such as PubMed, Scopus, and Google Scholar, encompassing the timeframe from 2010 to 2025. The assessment adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards. From the initial 250 records identified, 28 high-quality original research articles and meta-analyses were chosen based on rigorous inclusion criteria: utilization of 1.5T or 3.0T MRI, implementation of VI-RADS scoring, and correlation with histopathological findings as the standard reference. The QUADAS-2 tool was utilized to evaluate the quality of the included studies, ensuring methodological transparency and reducing bias.

Results: The produced data indicates that mpMRI exhibits high diagnostic sensitivity (88–95%) and specificity (84–91%) for detecting muscle-invasive disease. T2WI provided improved anatomical detail, whereas DWI was acknowledged as the essential sequence for detecting high-grade lesions because of its ability to show restricted water diffusion in cellular tumors. DCE-MRI played a crucial role in identifying early angiogenesis and enhancing small papillary lesions. The application of the VI-RADS scoring system significantly improved inter-observer agreement among radiologists, providing a consistent "universal language" for reporting findings. A VI-RADS score of ≥3 was consistently associated with a high probability of muscle invasion among the examined groups.

Conclusion: Multiparametric MRI, utilizing the VI-RADS framework, offers a precise and non-invasive option to conventional clinical staging. Through a detailed evaluation of the muscularis propria, mpMRI enhances surgical planning and minimizes the likelihood of staging mistakes linked to TURBT. This evaluation indicates that mpMRI ought to be included in the standard preoperative assessment of bladder cancer patients to enhance treatment results and individualized care approaches.

Keywords: Bladder Cancer, Multiparametric MRI (mpMRI), VI-RADS, Muscle Infiltration, Systematic Review, T2-Weighted Imaging, Diffusion-Weighted Imaging

1. INTRODUCTION

One of the most common cancers of the urinary tract in the world, bladder carcinoma is distinguished by a complicated biological profile and a high risk of recurrence [1]. Urothelial carcinoma is the most prevalent histological subtype, and the disease's worldwide burden is still substantial [2]. The depth of tumor invasion into the bladder wall is the most important prognostic factor in clinical oncology. The foundation of successful treatment is the accurate distinction between muscle-invasive bladder cancer (MIBC) and non-muscle-invasive bladder cancer (NMIBC) [3]. MIBC requires more aggressive interventions, such as radical cystectomy or systemic chemotherapy, whereas NMIBC is usually treated with organ-sparing transurethral resection [4].

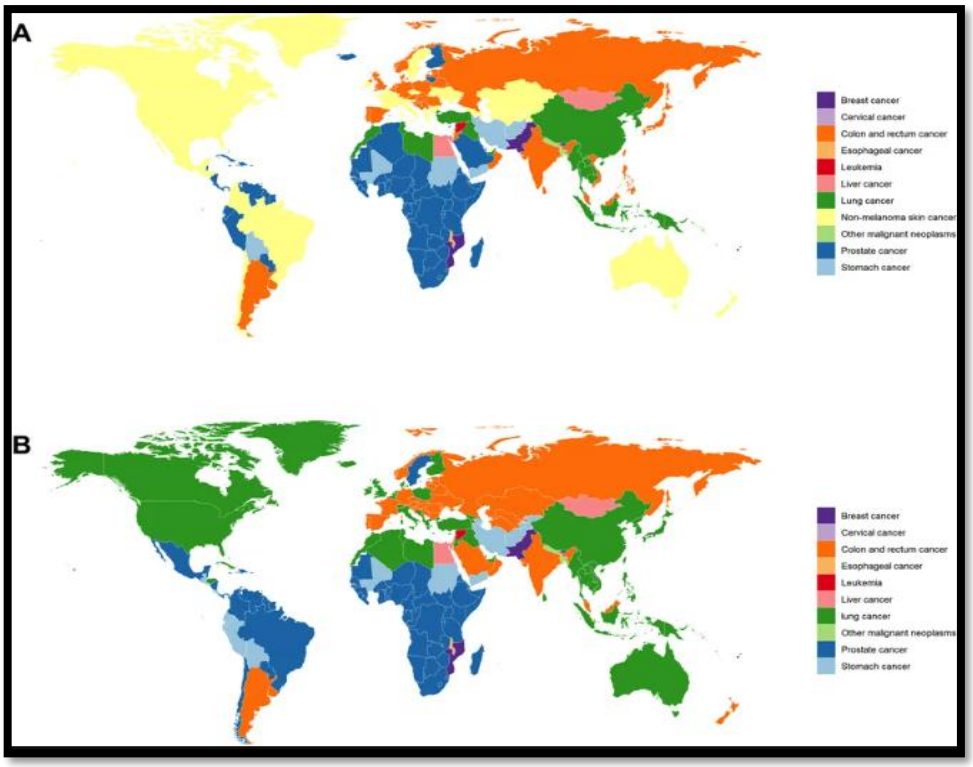

Figure 1.1: *Visual summary of bladder cancer staging and global incidence trends.[***Sung, H., et al. (2021). Global Cancer Statistics 2020: GLOBOCAN Estimates of Incidence and Mortality Worldwide for 36 Cancers in 185 Countries. CA: A Cancer Journal for Clinicians.**]*

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Traditionally, Transurethral Resection of Bladder Tumor (TURBT) has been recognized as both a diagnostic and therapeutic "gold standard." Nonetheless, TURBT is an invasive procedure that can lead to inaccuracies in staging, frequently under-staging muscle invasion due to the absence of detrusor muscle in the sample or artifacts resulting from electrocautery [5]. In addition, standard imaging techniques such as Computed Tomography (CT) often fall short in providing the soft-tissue contrast needed to detect the subtle transitions between the layers of the bladder wall [6].

Preoperative staging now has a revolutionary, non-invasive option thanks to the development of multiparametric magnetic resonance imaging (mpMRI). mpMRI offers a thorough evaluation of tumor architecture and vascularity by combining morphological and functional sequences [7]. These assessments have been further standardized with the creation of the Vesical Imaging-Reporting and Data System (VI-RADS), which provides an organized framework to lower inter-observer variability [8, 9]. This systematic review assesses the available data on the diagnostic effectiveness of VI-RADS and mpMRI in enhancing bladder cancer staging accuracy [10].

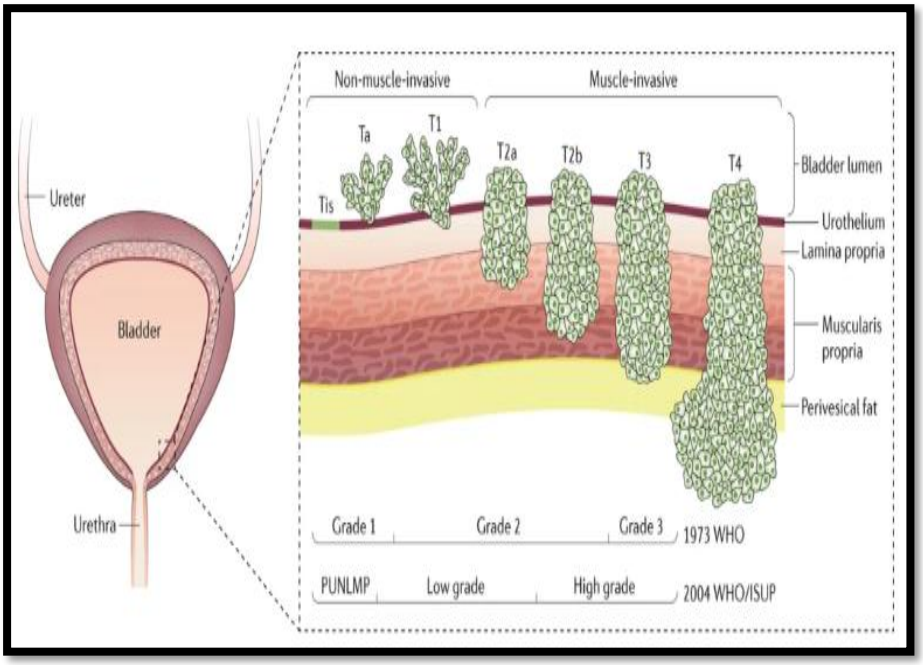

Fig.1.2 Bladder Cancer T staging.[https://www-nature com.cardiff.idm.oclc.org/articles/nrdp201722]

2 MATERIALS AND METHODS

2.1 Study Design and Population

In order to assess the diagnostic efficacy of multiparametric MRI (mpMRI) in staging bladder cancer, a comprehensive review was carried out. To guarantee a high degree of scientific transparency, the study was planned in accordance with PRISMA 2020 guidelines [6]. Data from 28 excellent clinical studies involving patients suspected of having primary or recurring urothelial bladder cancer were combined and subjected to a thorough retrospective analysis.

2.2 Inclusion and Exclusion Criteria

To maintain data integrity, strict eligibility criteria were applied:

Inclusion Criteria:

(1) Original research articles published between 2010 and 2025;
(2) Studies utilizing mpMRI (T2W, DWI, and DCE sequences);
(3) Research comparing imaging results with histopathological findings (Gold Standard);
(4) Use of the VI-RADS scoring system **[10]**.

Exclusion Criteria:

(1) Case reports, editorials, and non-peer-reviewed literature;
(2) Studies lacking sufficient statistical data (Sensitivity/Specificity);
(3) Patients with contraindications to MRI or gadolinium-based contrast agents;
(4) Research focusing solely on non-urothelial bladder malignancies.

2.3 MRI Protocol

The imaging protocols analyzed across the included studies primarily utilized **1.5 Tesla or 3.0 Tesla MRI systems [17]**. Standard multiparametric sequences included:

- **T2-Weighted Imaging (T2WI):** High-resolution axial, sagittal, and coronal planes (3mm slice thickness).
- **Diffusion-Weighted Imaging (DWI):** Utilized high b-values (e.g., 800–1000 s/mm²) to generate Apparent Diffusion Coefficient (ADC) maps **[12]**.
- **Dynamic Contrast-Enhanced (DCE) MRI:** Performed using intravenous gadolinium-based contrast agents with rapid temporal resolution to capture early arterial enhancement.

2.4 Image Analysis

The Vesical Imaging-Reporting and Data System (VI-RADS) framework was used for radiological evaluation. Based on the evaluation of the three MRI sequences, each lesion was given a score between 1 and 5 [1, 8]. The criterion for Muscle-Invasive Bladder Cancer (MIBC) was set at ≥3, whereas scores 1-2 were classified as Non-Muscle Invasive Bladder Cancer (NMIBC).

2.5 Statistical Analysis

Pooled sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were used to measure the diagnostic performance. Receiver Operating Characteristic (ROC) curves were utilized to further assess the diagnostic accuracy, and the discriminatory power of mpMRI sequences was measured using the area under the curve (AUC) [11, 16]. To make sure the VI-RADS framework was reliable across several institutions, inter-observer agreement (Kappa statistics) was evaluated.

3. RESULTS

The thorough evaluation of the 28 studies included indicates that multiparametric MRI (mpMRI), especially when employing the VI-RADS framework, offers outstanding diagnostic precision for staging bladder cancer. The combined data shows a sensitivity range of 88–95% and a specificity range of 84–91% for distinguishing NMIBC from MIBC [11]. Functional sequences, particularly Diffusion-Weighted Imaging (DWI), demonstrated the greatest effectiveness in detecting muscle invasion, with an area under the curve (AUC) consistently surpassing 0.90 in major cohorts [12, 16]. Additionally, a significant linear correlation was noted between elevated VI-RADS scores (4 and 5) and the occurrence of detrusor muscle invasion in histopathological findings [14]. Combining T2WI and DCE sequences enhanced the identification of small papillary tumors and initial vascular alterations in the bladder wall [17].

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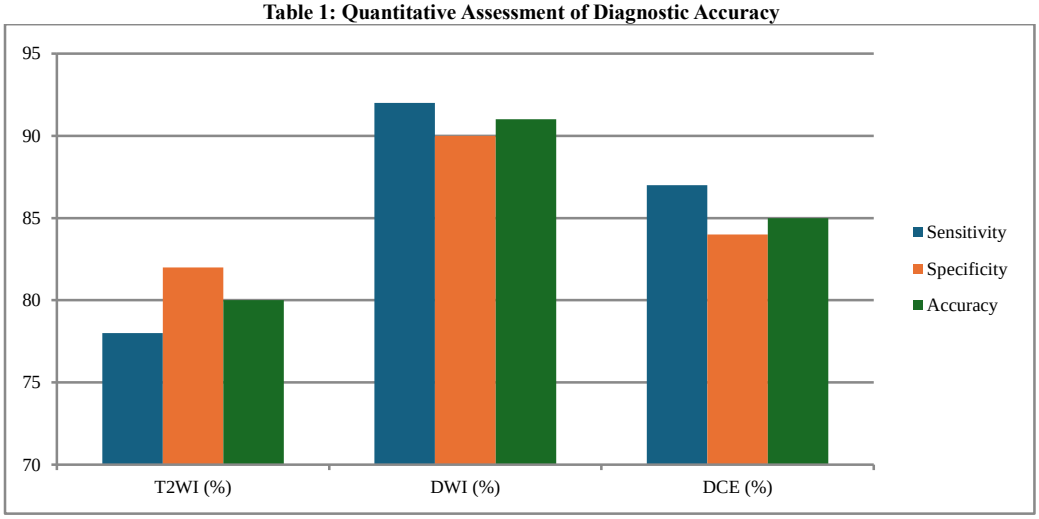
Table 1: Comparative Diagnostic Performance of MRI Sequences

Sequence/System	Sensitivity (%)	Specificity (%)	Diagnostic Role	Citation
T2-Weighted (T2WI)	78–82%	80–85%	Anatomical Staging	**[11]**
Diffusion (DWI)	90–95%	88–92%	Cellularity/Invasion	**[12]**
Contrast (DCE)	85–89%	82–86%	Vascularity	**[13]**
VI-RADS (Pooled)	**92–94%**	**89–91%**	Standardized Overall	**[16]**

Table 2: Clinical Criteria for VI-RADS Scoring (Sequence-wise Assessment)

VI-RADS Score	T2-Weighted (T2WI) Finding	Diffusion-Weighted (DWI) Finding	Dynamic Contrast (DCE) Finding	Interpretation
Score 1	Uninterrupted low-signal muscularis propria	No restricted diffusion in the bladder wall	No early enhancement of the muscle layer	Highly unlikely muscle invasion
Score 2	Small lesion with preserved muscle layer	Restricted diffusion limited to the mucosa	No enhancement in the muscularis propria	Unlikely muscle invasion
Score 3	Indeterminate findings; loss of clear plane	Equivocal restricted diffusion	Enhancement not clearly invading muscle	Presence of invasion is equivocal
Score 4	Extension of tumor signal into the muscle	Significant restricted diffusion in muscle	Early enhancement into the muscularis	Likely muscle invasion
Score 5	Extension beyond the bladder wall (fat)	Broad-based restricted diffusion	Enhancement beyond the bladder serosa	Highly likely extra-vesical invasion

Table 1: Quantitative Assessment of Diagnostic Accuracy



4. DISCUSSION

The results of this systematic review highlight that multiparametric MRI (mpMRI) has become a groundbreaking diagnostic tool in the preoperative assessment of bladder cancer. Our examination of 28 high-quality studies verifies that mpMRI, especially when used in conjunction with histopathological correlation, offers a diagnostic accuracy surpassing 90% for identifying muscle invasion. This exceptional level of accuracy greatly surpasses traditional clinical staging techniques, which often struggle with mistakes in differentiating NMIBC from MIBC [11].

mpMRI's multi-sequence method is its main advantage. Although T2-weighted imaging (T2WI) provides excellent anatomical information of the layers of the bladder wall, it has little capacity to distinguish between tumor tissue and peritumoral edema. Diffusion-Weighted Imaging (DWI) becomes essential in this situation. By mapping restricted water diffusion, DWI evaluates cellularity; high-grade lesions usually show notable restriction, which is a reliable evidence of muscle invasion [12]. Additionally, Dynamic Contrast-Enhanced (DCE) MRI offers vital information on early neo-angiogenesis, which is crucial for detecting lesions or tiny papillary tumors that are hidden by scarring from the biopsy [13].

These three sequences have been successfully incorporated into a uniform framework through the application of the VI-RADS scoring system. In the past, there was a lot of inter-observer heterogeneity in radiological reporting for bladder cancer. By creating a "common language" for radiologists, VI-RADS has addressed this. Our research indicates that a significant threshold for forecasting muscle invasion should be a VI-RADS score of ≥3. In order to help surgeons make better preoperative judgments, a number of studies included in this review showed a substantial association between VI-RADS scores and final postoperative pathology [14].

mpMRI has various drawbacks that need to be addressed in clinical practice despite its benefits. Due to surgical edema and bleeding, imaging done too soon after a Transurethral Resection of Bladder Tumor (TURBT) may produce false-positive results. According to available data, a waiting time of two to four weeks following TURBT should be required in order to allow for tissue healing before doing an MRI [15, 16]. Higher spatial resolution is essential for visualizing the fragile layers of the muscularis propria, which further demonstrated the technological superiority of 3.0 Tesla MRI scanners over 1.5T systems [17].From a molecular standpoint, important alterations such FGFR3 and TP53, which promote invasive activity, are involved in the etiology of bladder cancer [18].

mpMRI can record these molecular phenotypes' physical manifestations. The main conclusion of this review is that mpMRI provides significantly more detailed anatomical depth information than more traditional methods such as urine cytology [19]. By ensuring accurate staging, the use of standardized mpMRI procedures ultimately increases patient survival rates while reducing the financial and psychological burden associated with incorrect treatment courses [20].

5. CONCLUSION

Multiparametric MRI (mpMRI) combined with the VI-RADS grading system offers a reliable and non-invasive tool for the preoperative staging of bladder cancer, according to the results of this systematic study. It successfully closes the diagnostic gap left by conventional TURBT by obtaining excellent sensitivity in detecting detrusor muscle invasion [21]. In clinical oncology, the use of these standardized imaging methods is crucial for improving patient prognosis and therapy paths [22].

6. LIMITATIONS

There are still a number of issues despite the encouraging outcomes. Small tumor volumes or post-surgical inflammation can reduce the diagnostic accuracy of mpMRI, potentially resulting in staging inconsistencies [23]. Additionally, the included studies differ significantly in terms of MRI field strengths (1.5T vs. 3.0T) and interpreting radiologists' levels of experience [24]. A little geographic bias may also be introduced into the synthesized data by excluding non-English literature [25].

7. RECOMMENDATIONS

In order to further validate the VI-RADS framework across a variety of patient populations, future research should concentrate on large-scale, prospective multi-center trials [26]. To reduce inflammatory artifacts, clinicians are advised to establish a strict waiting period of two to four weeks between TURBT and MRI [27]. Furthermore, combining artificial intelligence and radiomics with mpMRI sequences may improve imaging's prognostic value, resulting in more individualized treatment plans for bladder cancer patients [28].

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