Clinical utility of the Vesical Imaging-Reporting and Data System for muscle-invasive bladder cancer between radiologists and urologists based on multiparametric MRI including 3D FSE T2-weighted acquisitions

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Clinical utility of the Vesical Imaging-Reporting and Data System for muscle-invasive bladder cancer between radiologists and urologists based on multiparametric MRI including 3D FSE T2-weighted acquisitions

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Abstract

Objectives To investigate the clinical utility of the Vesical Imaging-Reporting and Data System (VI-RADS) by comparing its diagnostic performance for muscle-invasive bladder cancer (MIBC) between radiologists and urologists based on multiparametric MRI, including three-dimensional (3D) fast spin-echo (FSE) T2-weighted acquisitions.

Methods This study included 66 treatment-naïve patients (60 men, 6 women; mean age 74.0 years) with pathologically proven bladder cancer who underwent multiparametric MRI, including 3D FSE T2-weighted imaging, before transurethral bladder tumour resection between January 2010 and November 2018. The MRI scans were categorised according to the five-point VI-RADS score by four independent readers (two board-certified radiologists and board-certified urologists each), blinded to the histopathological findings. The VI-RADS scores were compared with the postoperative histopathological diagnosis. Interobserver agreement was assessed using weighted kappa coefficients. ROC analysis and generalised estimating equations were used to evaluate the diagnostic performance.

Results Forty-nine (74.2%) and 17 (25.8%) tumours were confirmed to be non-MIBC and MIBC, respectively, based on pathological examination. The interobserver agreement was good-to-excellent between all pairs of readers (range, 0.73–0.91). The urologists' sensitivity/specificity values for DCE-MRI VI-RADS scores were significantly lower than those of radiologists. No significant differences were observed for the overall VI-RADS score. The AUC for the overall VI-RADS score was 0.94, 0.92, 0.89, and 0.87 for radiologists 1 and 2 and urologists 1 and 2, respectively.

Conclusions The VI-RADS score, based on multiparametric MRI including 3D FSE T2-weighted acquisitions, can be useful for radiologists and urologists to determine the bladder cancer muscle invasion status preoperatively.

Key Points

- *VI-RADS (using multiparametric MRI including 3D FSE T2-weighted acquisitions) achieves good to excellent interobserver agreement and has similar diagnostic performance for detecting muscle invasion by both radiologists and urologists.*
- *The diagnostic performance of the overall VI-RADS score is high for both radiologists and urologists, particularly due to the dominant effect of diffusion-weighted imaging on the overall VI-RADS score.*

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- *The sensitivity and specificity values of the T2WI VI-RADS scores for four readers in our study (using 3D FSE T2-weighted acquisitions) were similar (with slightly higher specificity values) to previously published results (using 2D FSE T2-weighted acquisitions).*

Keywords Contrast media · Diffusion · Magnetic resonance imaging · Neoplasm staging · Urinary bladder neoplasms

Abbreviations

BCa	Bladder cancer
EAU	European Association of Urology
FSE	Fast spin echo
MIBC	Muscle-invasive bladder cancer
Mp-MRI	Multiparametric MRI
NMIBC	Non-muscle-invasive bladder cancer
SI	Signal intensity
T2WI	T2-weighted imaging
TURBT	Transurethral resection of bladder tumour
VI-RADS	Vesical Imaging-Reporting and Data System

Introduction

Bladder cancer (BCa) is the seventh most commonly diagnosed cancer worldwide [1]. Most BCas are urothelial cell carcinomas, which are histologically stratified into low- and high-grade cancers. Tumour depth infiltration is subdivided according to the absence or presence of muscle invasion by the tumour. Non-muscle-invasive bladder cancer (NMIBC), which recurs often, is treated using either intravesical chemotherapy or Bacillus Calmette–Guerin therapy [2]. Muscle-invasive bladder cancer (MIBC) is an aggressive tumour with a poor prognosis [3]. An accurate discrimination between NMIBC and MIBC is crucial, owing to the stark differences in treatment options and prognoses.

The diagnostic algorithm for BCa involves the acquisition of histopathological samples via transurethral resection of the bladder tumour (TURBT) [2]. However, the quality of the first TURBT often varies depending on the urologists, and pathologists may consequently disagree on the BCa grading (10–29% discordance) and T staging (15–56% discordance) [4, 5]. Therefore, a second TURBT is often conducted to obtain a more accurate diagnosis given the potential of missing a muscle-invasive tumour, according to the European Association of Urology (EAU) Guidelines [2].

Recent advances in magnetic resonance imaging (MRI), such as multiparametric MRI (mp-MRI), are useful for determining the muscle invasion status of BCas [6–10].The Vesical Imaging-Reporting and Data System (VI-RADS) was released in May 2018 as a standard imaging and diagnostic method for determining the muscle invasion status of BCas [11]. The VI-RADS classifies the probability of muscle invasion, as indicated by mp-MRI findings, into five scores and is expected to improve the diagnostic accuracy compared to TURBT, and reduce staging errors through better anatomical visualisation, without radiation exposure [12, 13]. However, it remains unknown whether a urologist's interpretation of the VI-RADS score provides similar diagnostic value compared to when a radiologist performs the reading.

According to the VI-RADS guidelines, at least two planes of multi-planar (axial, coronal, and sagittal) T2-weighted images (T2WI) with two-dimensional (2D) fast spin-echo (FSE) sequences are recommended, while 3D FSE T2 acquisitions may be used as an adjunct to the 2D acquisitions [11]. Although an arbitrary plane perpendicular to the tumour base can help to detect muscle invasion more accurately [9], 2D T2WI does not allow for retrospective post-processing if the coverage or imaging planes have been prescribed incorrectly. 3D FSE acquisitions enable reformatting of an arbitrary plane perpendicular to the tumour base [14], which may help to improve the examination efficiency and diagnostic performance for determining the muscle invasive status in patients with BCa.

This study investigated the clinical utility of VI-RADS for determining the muscle invasion status by comparing the preoperative diagnostic performance for MIBC between radiologists and urologists based on mp-MRI with 3D T2 acquisitions.

Materials and methods

The study protocol was approved by our Institutional Medical Ethics Committee (approval number: 20180298). The requirement for written informed patient consent was waived due to the retrospective nature of the study.

Patients

Data were collected retrospectively (Y.A., with 6 years of experience in radiology) from our institutional imaging server system.

All bladder treatment-naïve patients who were clinically suspected of having a bladder tumour based on haematuria, diagnostic cystoscopy, and/or computed tomography (CT) urography, and who also subsequently underwent mp-MRI of the bladder, including T2WI with a 3D acquisition, diffusion-weighted imaging (DWI) with both axial and sagittal plane acquisitions, and dynamic contrast-enhanced (DCE)-MRI using a 3D T1-weighted gradient echo sequence with fat

suppression acquisition before undergoing the first TURBT at our institution between January 2010 and November 2018 were considered for inclusion in this study. Patients without a pathological diagnosis of BCa (i.e. patients with no bladder tumour on cystoscopy or patients with no urothelial carcinoma on pathological examination) and patients with an incomplete mp-MRI examination were excluded.

Histopathologic evaluation

After collecting data of all patients who met the inclusion criteria, the board-certified chief genitourinary pathologist (S.M., with 22 years of experience in uropathology) in our institution carefully reviewed all the resected tumour specimens for the purpose of the present study. Tumour grades were assessed according to the 2004 World Health Organization/International Society of Urologic Pathology consensus classification. Tumours were staged according to the American Joint Committee on Cancer/Union for International Cancer Control tumour-node-metastasis classification [15]. According to the EAU Guidelines [2], 4 weeks after the first TURBT, 10 high-risk patients underwent re-TURBT at the known tumour site to eliminate any suspicious residual areas and to confirm disease staging. The re-TURBT and radical cystectomy staging were used as the reference standard. In patients with multiple tumours, only the lesion with the highest pathological T stage or largest size (for equal T stage lesions) was further analysed.

Mp-MRI examination

Mp-MRI of the bladder was performed in the supine position. Patients were required to urinate 2 h pre-MRI and to refrain from drinking liquid or urinating thereafter until the MRI examination was completed. Imaging was performed with a 1.5-T system (Signa HDxt/Discovery MR450w, GE Healthcare) using an eight-channel body-array coil or a 32-channel small anterior-array coil. The entire pelvis was imaged from the aortic bifurcation to the inferior margin of the pubic symphysis. A 3D fast spin echo with variable flip angle (CUBE) was used for high-spatial-resolution T2WI, and an arbitrary plane perpendicular to the tumour base was reformatted. DWI was performed during free breathing with a water-excited single-shot spin-echo echo-planar sequence in both the axial and sagittal planes. ADC maps were calculated based on a standard monoexponential fit model on the operating console of the MRI system, using b values of 0 and 1000 s/mm^2. DCE-MRI was acquired with an axial or sagittal fat-suppressed 3D volumetric spoiled gradient-echo sequence (i.e. LAVA) before and after intravenous injection of 0.1 mmol/kg of gadobutrol (Gadovist, Bayer Schering Pharma) at 2.0 mL/s. The early DCE-MRI phase was obtained 40 s post-contrast material injection. The scanning parameters are summarised in Table 1.

Image analysis

A study coordinator (M.J., with 31 years of experience in radiology) chose the target lesions according to pathological examination as follows: tumours with the greatest invasion depth were selected first; in cases with an equal degree of invasion, the largest lesion was selected, in line with the previous report by Ueno et al [12]. For each patient, three image sequences (T2WI, DWI, and DCE-MRI) were scored using the five-point scoring system, strictly according to the VI-RADS criteria [11], on a picture archiving and communication system workstation (Centricity™ Universal Viewer, PACS, GE Healthcare). In brief, on T2WI, we evaluated whether a continuous low signal intensity line was present in the bladder wall (representing an intact muscularis propria). On DWI, a tumour has high signal intensity (SI), while the tumour stalk and inner layer have low SI; the presence of the latter two features were evaluated (ADC maps were also used for interpretation). On DCE-MRI, the tumour and inner layer show early enhancement, often to the same degree, while the muscularis propria has a low SI in the early phase; we evaluated disruption of the low muscularis propria SI by tumour invasion. A VI-RADS score between 1 and 5 was assigned to suggest the probability of muscle invasion (where 1 denotes muscle invasion to be highly unlikely and 5 indicates muscle invasion to be highly likely) [11].

The three sequences were evaluated separately and scoring was performed independently by a board-certified uroradiologist (H.A., with 18 years of experience in radiology; radiologist reader 1), a board-certified body-radiologist (T.S., with 12 years of experience in radiology; Radiologist reader

Table 1 Multiparametric MRI protocol at 1.5 T

Parameter setting	T2WI	DWI	DCE-MRI
TR (ms)	2000	4000	6.6
TE (ms)	80	85	3.2
Flip angle (degree)			12
FOV (cm)	28	36	26
Matrix	288 × 224	128 × 160	256 × 256
Slice thickness (mm)	2	5	2
Slice gap (mm)	0	0.5	0
Number of excitations	1	6	1
B value (s/mm^2)		0–1000	
Echo train length (ms)	80		

TR = repetition time, *TE* = echo time, *FOV* = field of view, *T2WI* = T2-weighted imaging, *DWI* = diffusion-weighted imaging, *DCE* = dynamic contrast enhanced, *MRI* = magnetic resonance imaging

2), and two board-certified urologists (K.S. and R.K., with 10 and 7 years of experience in urology, respectively; urologist reader 1 and 2, respectively). All images were interpreted with the readers blinded TO the surgical and histological findings.

Final overall VI-RADS scoring

The five-point overall VI-RADS score was compiled using the individual T2WI, DWI, and DCE-MRI scores, as shown in Fig. 1. The dominant sequences for estimation of muscle invasion were DWI followed by DCE-MRI; T2WI provided an overview of the tumour and basic anatomic structures [11].

Statistical analysis

The interobserver agreement was assessed with a consistency test and by calculating the weighted kappa value. The Cochran–Armitage trend test was used to evaluate the association between the overall VI-RADS score, as well as its T2WI, DWI, and DCE-MRI components, with the muscle invasion status. A two-tailed p value < 0.05 was considered significant. Areas under the receiver operating characteristic curves (AUCs) were used to assess the utility of the VI-RADS score for predicting muscle invasion. The optimal cut-off score for maximum accuracy was determined using the Youden index. The diagnostic performance of the overall and component VI-RADS scores for muscle invasion was evaluated by calculating the sensitivity and specificity, using cut-off scores $\geqq 3$ or 4. The Cochran–Armitage test and generalised estimating equations were performed in SAS software (version 9.4; SAS Institute); other statistical analyses were performed using SPSS software (version 25; IBM).

Results

Patient and tumour characteristics

Of the 112 treatment-naïve patients who were considered for inclusion in the study, 43 patients without pathological diagnosis of BCa and 3 with incomplete mp-MRI examinations were excluded. Thus, 66 patients were selected for the current study. All mp-MRI scans were performed prior to the first TURBT (median 2 weeks, range 1–6 weeks). The patient selection process is shown in Fig. 2.

Among these patients, 50/66 (75.8%) had only one tumour and 16/66 (24.2%) had multiple tumours. The final pathologic stages of the 66 analysed patients were as follows: Ta, 26/66 (39.4%); T1, 23/66 (34.8%); T2, 14/66 (21.2%); and T3, 3/66 (4.6%). Of the 66 tumours, 14/66 (21.2%) were grade 1, 25/66 (37.9%) were grade 2, and 27/66 (40.9%) were grade 3. Tumours occurred most frequently in the lateral posterior wall (14/66 [21.2%] in the right posterior and 9/66 [13.6%] in the left posterior wall) of the bladder. Ten of the 66 patients who were considered high-risk NMIBC patients based on the first TURBT results underwent re-TURBT according to the EAU Guidelines [2]. Of them, three patients were upstaged by re-TURBT. Thirteen patients underwent radical cystectomy. The patients' and tumours' characteristics are presented in Table 2.

Interobserver agreement for VI-RADS scores

The weighted kappa value ranges for the four readers were 0.91–0.73, 0.83–0.70, 0.89–0.77, and 0.94–0.62 for the overall, T2WI, DWI, and DCE-MRI VI-RADS scores, respectively (Table 3). Thus, the consistency among the four readers for VI-RADS scoring was good to excellent.

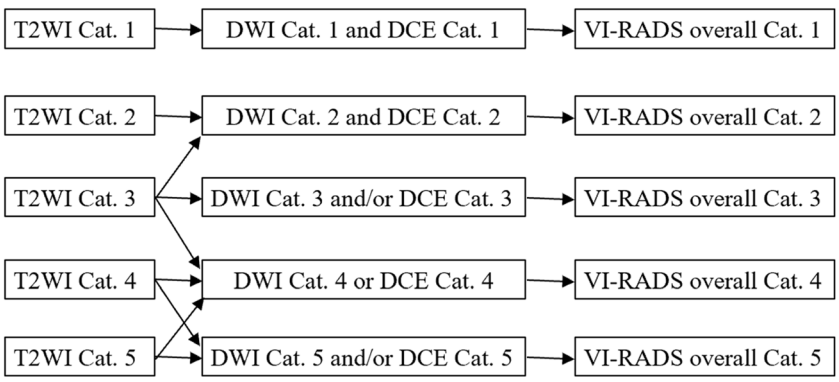

Fig. 1 Summary schematic representation of VI-RADS overall scoring. T2WI = T2-weighted imaging; DCE = dynamic contrast-enhancement; DWI = diffusion-weighted imaging; Cat = category. In addition to the VI-RADS overall scoring flow chart, the overall VI-RADS score was confirmed as 2 when (1) T2WI score was 2, DCE-MRI score was 3, and DWI score was 2; (2) T2WI score was 2, DCE-MRI score was 4, and DWI score was 2; or (3) T2WI score was 4, DCE-MRI score was 3, and DWI score was 2. The overall VI-RADS score was confirmed as 3 when (1) T2WI score was 3, DCE-MRI score was 2, and DWI score was 3, according to the VI-RADS criteria

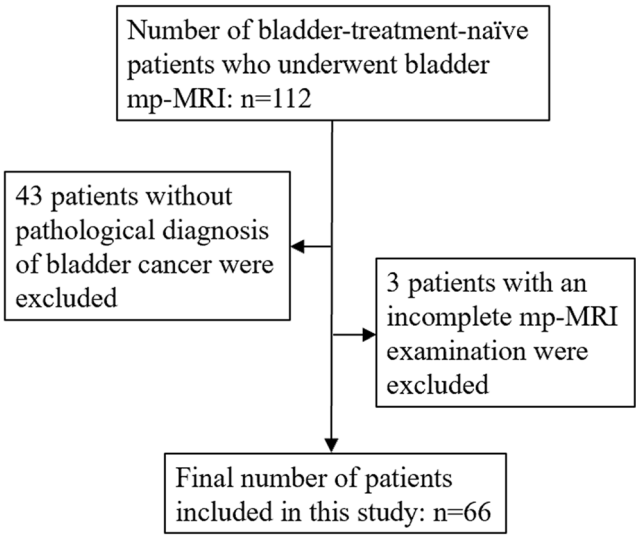

Fig. 2 Flowchart of patient inclusion. mp-MRI = multiparametric MRI

Performance of T2WI, DWI, DCE-MRI, and overall VI-RADS scores for diagnosing muscle invasion

The T2WI, DWI, DCE-MRI, and the overall VI-RADS scores for MIBC detection are shown in Supplementary Table 1 (Table S1). Among the 66 patients, 49/66 (74.2%) had NMIBC (T1 or lower) and 17/66 (25.8%) had MIBC (T2 or higher), based on the pathological findings. The Cochran–Armitage test showed that T2WI alone, DWI alone, DCE-MRI alone, and the VI-RADS overall score were significantly associated with muscle invasion, for all four readers ($p < 0.001$) for all parameters. The AUC values for the overall VI-RADS scores for predicting MIBC were as follows: 0.94, 0.92, 0.89, and 0.87, with an optimal cut-off value ≧ 3, for the four readers. Dichotomised VI-RADS scores yielded sensitivity/specificity values of 94.1/89.8, 88.2/87.8, 82.4/85.7, and 82.4/83.7%, with a cut-off score ≧ 3, and 76.5/91.8, 76.5/91.8, 70.6/91.8, and 70.6/89.8%, with a cut-off score ≧ 4 for detecting MIBC for the four different readers (Table 4). Figure 3 shows a representative correctly estimated patient with NMIBC (VI-RADS category 2 for both urologist and radiologist readers), and Fig. 4 shows a representative patient with overestimated NMIBC (VI-RADS category 4 for the urologist readers and 3 for the radiologist readers).

Table 2 Patients' (n = 66) clinical and pathological characteristics

Characteristics	Value (%)
Age, year	
Median	74
Range	32–91
Sex	
Male	60 (90.9)
Female	6 (9.1)
No. of lesions	
Single	50 (75.8)
Multiple	16 (24.2)
Diameter of lesion, mm	
Median	17.4
Range	2.4–65.2
Pathologic T stage	
Ta	26 (39.4)
T1	23 (34.8)
T2	14 (21.2)
T3	3 (4.6)
Pathologic muscle invasion status	
Muscle invasion	17 (25.8)
No muscle invasion	49 (74.2)
Tumour grade	
G1	14 (21.2)
G2	25 (37.9)
G3	27 (40.9)

Data are presented as numbers or (percentages)

Diagnostic performance comparison among radiologists and urologists

The results of the generalised estimating equation analysis are shown in Table 4. The sensitivity/specificity values of the dichotomised DCE-MRI score (using a cut-off score ≧ 3) for urologists were significantly lower than those for radiologists ($p = 0.04/0.002$, respectively), and the sensitivity value of the dichotomised DCE-MRI score (using a cut-off score ≧ 4) for urologists was significantly lower than that for radiologists

Table 3 Interobserver agreement scores for VI-RADS among the four readers

	R_R2	U_R1	U_R2
Overall score			
R_R1	0.91	0.88	0.81
R_R2		0.86	0.73
U_R1			0.87
T2WI			
R_R1	0.83	0.80	0.74
R_R2		0.81	0.70
U_R1			0.71
DWI			
R_R1	0.88	0.88	0.83
R_R2		0.82	0.77
U_R1			0.89
DCE-MRI			
R_R1	0.94	0.70	0.62
R_R2		0.71	0.63
U_R1			0.87

T2WI = T2-weighted imaging, *DWI* = diffusion-weighted imaging, *DCE* = dynamic contrast enhanced, *MRI* = magnetic resonance imaging, *R_R1* = radiologist_reader 1, *R_R2* = radiologist_reader 2, *U_R1* = urologist_reader 1, *U_R2* = urologist_reader 2

Table 4 Diagnostic performance of T2WI, DWI, and DCE-MRI, and overall VI-RADS scores for detecting muscle invasion for the four readers

Score	R_R1		R_R2		U_R1		U_R2		R vs U	
	Sens (%)	Spec (%)	Sens (%)	Spec (%)	Sens (%)	Spec (%)	Sens (%)	Spec (%)	P (Sens)	P (Spec)
T2WI ≧ 3	88.2	73.5	82.4	83.7	82.4	85.7	94.1	81.6	0.33	0.18
DWI ≧ 3	94.1	89.8	88.2	87.8	82.4	85.7	82.4	83.7	0.13	0.18
DCE-MRI ≧ 3	88.2	89.8	88.2	87.8	76.5	75.5	76.5	73.5	0.04*	0.002*
VI-RADS overall score ≧ 3	94.1	89.8	88.2	87.8	82.4	85.7	82.4	83.7	0.13	0.18
T2WI ≧ 4	58.8	91.8	58.8	91.8	58.8	93.9	52.9	95.9	0.56	0.46
DWI ≧ 4	70.6	91.8	76.5	93.9	64.7	91.8	70.6	91.8	0.10	0.34
DCE-MRI ≧ 4	64.7	93.9	76.5	91.8	52.9	87.8	52.9	85.7	0.03*	0.07
VI-RADS overall score ≧ 4	76.5	91.8	76.5	91.8	70.6	91.8	70.6	89.8	0.10	0.58

T2WI = T2-weighted imaging, *DWI* = diffusion-weighted imaging, *DCE* = dynamic contrast enhanced, *MRI* = magnetic resonance imaging, *R_R1* = radiologist_reader 1, *R_R2* = radiologist_reader 2, *U_R1* = urologist_reader 1, *U_R2* = urologist_reader 2, *R* = radiologists, *U* = urologists, *VI-RADS* = Vesical Imaging-Reporting and Data System, *Sens* = sensitivity, *Spec* = specificity

*$p < 0.05$, statistically significant

($p = 0.03$). The sensitivity/specificity values for the dichotomised overall VI-RADS scores and the remaining mp-MRI component scores were not significantly different between urologists and radiologists.

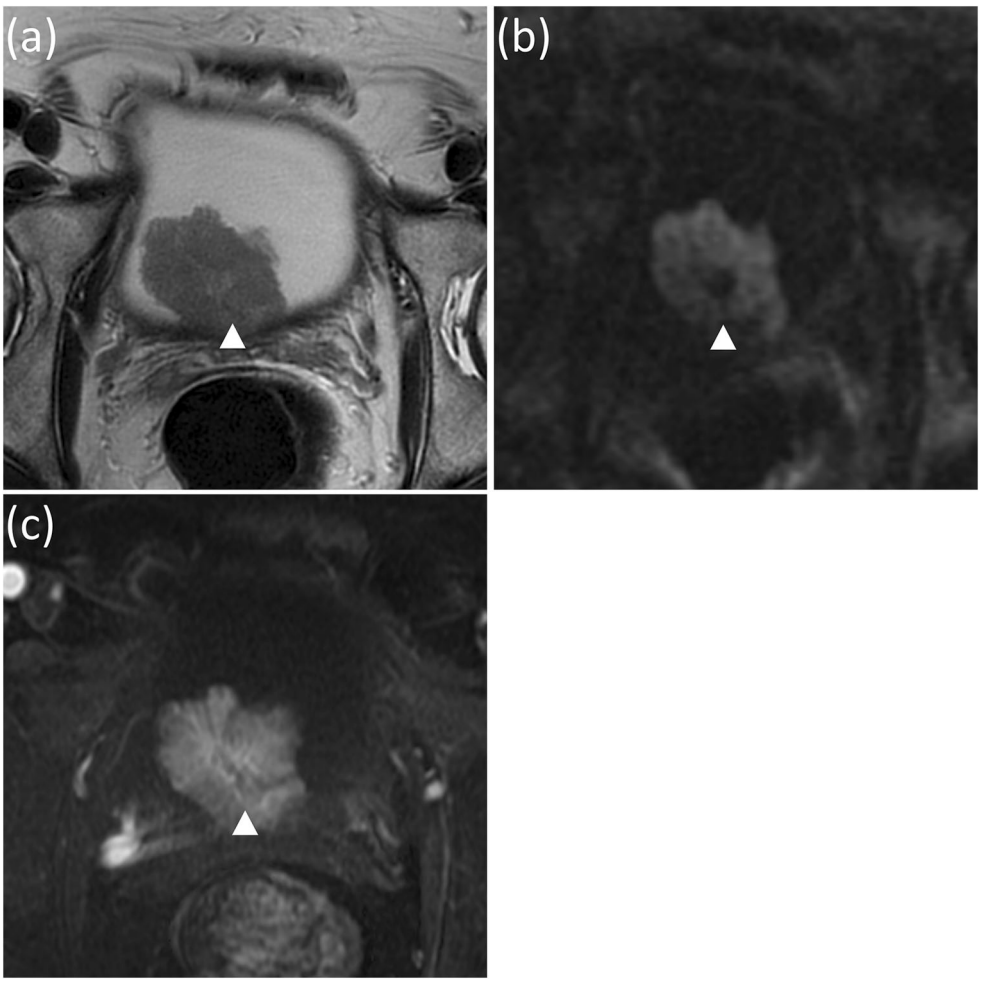

Fig. 3 Representative correctly estimated case of a 41-mm exophytic tumour located in the posterior wall in a 77-year-old man with non-muscle-invasive bladder cancer. **a** Axial T2-weighted image shows an exophytic tumour with a stalk (arrowhead). **b** Diffusion-weighted image shows a high signal intensity tumour with a low signal intensity stalk (arrowhead). **c** Dynamic contrast-enhanced image shows early enhancement of the inner layer, but no early enhancement of the muscularis propria (arrowhead). Pathological specimens obtained by TURBT showed that there was no urothelial carcinoma cell infiltration in the detrusor muscle

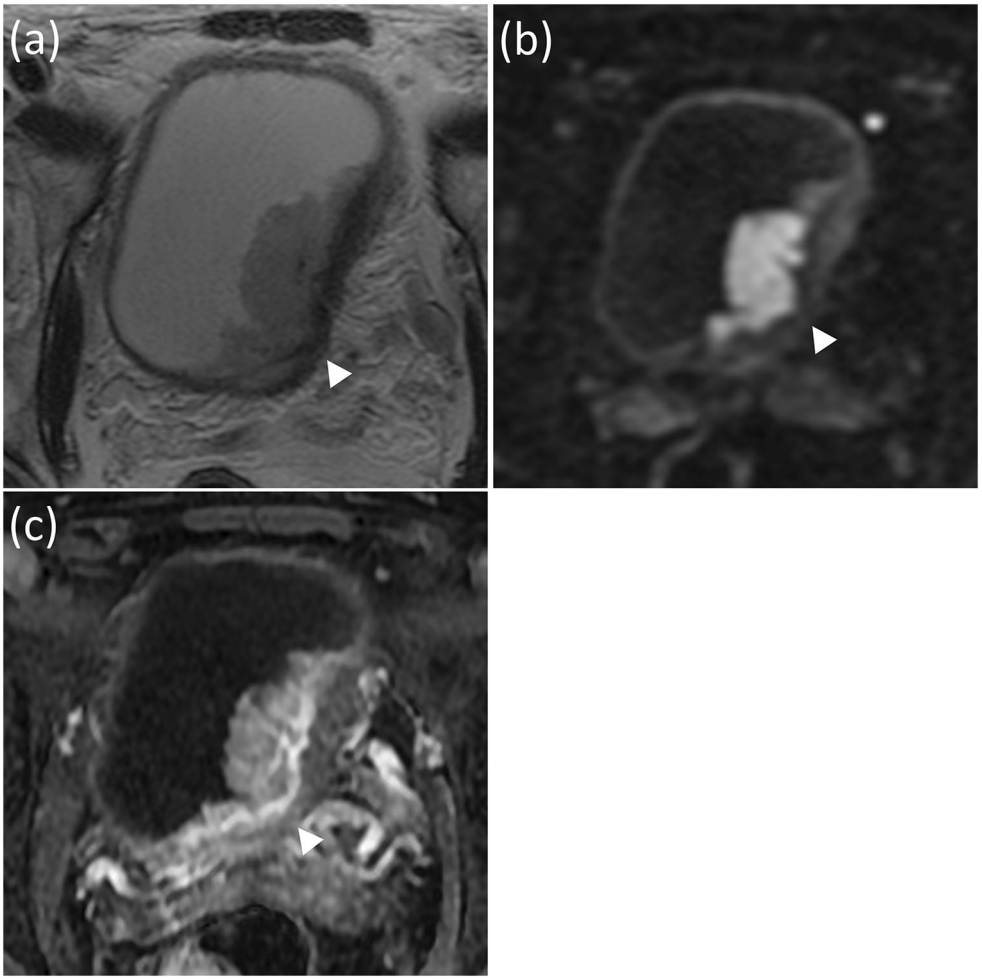

Fig. 4 Representative overestimated case by urologist readers of a 62-mm broad-based exophytic tumour located in the left lateral wall in a 77-year-old man with non-muscle invasive bladder cancer. **a** Interruption of low signal intensity muscularis propria is suspected (arrowhead). **b** On the diffusion-weighted image, interruption of the low signal intensity muscularis propria was suspected (arrowhead). **c** On the dynamic contrast-enhanced image, early tumour enhancement, extending focally to the muscularis propria, was suspected (arrowhead). Pathological specimens obtained by TURBT showed that there was no urothelial carcinoma cell infiltration in the detrusor muscle

Discussion

Our study demonstrated that VI-RADS achieves good to excellent interobserver agreement and has good diagnostic performance for detecting muscle invasion by radiologists as well as urologists. Therefore, VI-RADS, which was found to be suitable for tumour staging in patients with BCa by radiologists [12, 16], can also be considered an additional tool for urologists. No previous study has validated the utility of VI-RADS across both radiologists and urologists.

According to a recent VI-RADS validation study with a cohort of 340 patients, the sensitivity and specificity values of the dichotomised overall VI-RADS score (with a cut-off score ≧ 3) were 87.1% (95% confidence interval [CI] 78%, 93%) and 96.5% (95% CI 93%, 98%), respectively. The study reported an AUC of 0.94 (95% CI 0.90, 0.98) [17], which is similar to our findings. Moreover, the AUC in our study was similar to a recently reported diagnostic meta-analysis of studies on the VI-RADS [18].

In the present study, the sensitivity and specificity values of the DCE-MRI score (with a cut-off score ≧ 3) and the sensitivity values of the DCE-MRI score (with a cut-off score ≧ 4) for urologists were significantly lower than those for radiologists. This may have resulted from over- or underestimating the inflammatory changes or fibrosis and oedema surrounding the tumour, which can mimic BCa invasion [19]. This may be due to unfamiliarity with window-width/window-level and multi-planar reconstruction adjustments. Although over- or understaging occurred more often in the VI-RADS DCE-MRI scores of urologists than those of radiologists, the diagnostic performance of the overall VI-RADS scores was maintained between urologists and radiologists. This indicates the dominant effect of DWI on the overall VI-RADS score, described as the key component in the overall VI-RADS scoring flow chart (Fig. 1) [11]. While T2WI can provide a clear image of the basic anatomic structure of the bladder, and DCE-MRI can depict lesions < 0.5 mm [17], DWI can reduce the over- and understaging ratio [7, 8, 19–25]. Nevertheless, DWI with echo planar imaging may sometimes be degraded by artefacts or inadequate signal-to-noise ratio, depending on the MR settings and patient-related factors such as the presence of a hip prosthesis or bowel movement. Therefore, each sequence that contributes to the VI-

RADS score (i.e. T2WI, DWI, and DCE-MRI) is essential for making the appropriate diagnosis.

According to recent reports, either diffusion kurtosis imaging or the combination of DWI radiomics features with transurethral resection could improve the diagnosis of MIBC [26, 27]. Radiogenomic signatures including contrast-enhanced CT, transcriptomics, and clinical features have been reported to be able to predict progression-free interval [28]. Furthermore, the inchworm sign (which is found on MRI in BCa and provides information regarding the degree of microinvasion into the muscularis propria) on DWI may be used to determine the progression of pT1 BCa [29]. Therefore, the addition of clinical and imaging findings derived from other modalities, including gene expression data, has the potential to increase the diagnostic performance of VI-RADS.

The 3D FSE T2-weighted acquisition (i.e. CUBE) allows interactive reconstruction in any orientation in a single scan, but the sequence may suffer from decreased image quality due to motion sensitivity [14]. However, the sensitivity and specificity values of the T2WI VI-RADS scores in our study (sensitivity between 82.4 and 94.1% and specificity between 73.5 and 85.7%) were at least similar (with slightly higher specificity values) to previously published results by Wang et al [17] who used a 2D FSE T2-weighted acquisition (sensitivity of 89.4% [95% CI 80%, 95%] and specificity of 71.4% [95% CI 65%, 77%] with a cut-off score ≧ 3). Thanks to 3D acquisitions, an arbitrary plane perpendicular to the tumour base can be reformatted [14]; this might have improved the specificity of the T2WI VI-RADS score in our study.

Although it is not common for urologists to read mp-MRI, urologists and radiologists discuss the most appropriate treatment plan for each BCa patient in multidisciplinary meetings, and we believe an excellent agreement between radiologists and urologists in diagnostic interpretation to be indispensable for providing accurate surgical outcomes. Our results suggest that VI-RADS could become a novel diagnostic tool to fill the gap in urologists' and radiologists' knowledge and can, therefore, be used to optimise preparation before TURBT. However, further investigations are warranted to confirm the clinical value of VI-RADS for planning the surgical strategy.

Our study had several limitations. First, the study was retrospective, and our data were based on reinterpretation by four readers. Second, the sample size was small and from a single institution. Further multicentred validation studies with larger study groups are warranted. Third, only the tumour with the highest pathological T stage or size was analysed in patients with multiple tumours, which might have caused a selection bias.

In conclusion, VI-RADS (using multiparametric MRI including 3D FSE T2-weighted acquisitions) is a useful tool for preoperative muscle invasion assessment in BCa, and can be used for communication and preoperative planning by both radiologists and urologists.

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Compliance with ethical standards

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Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

Statistics and biometry Mr. Ryota Ishii, who is one of the authors, has significant statistical expertise.

Informed consent Written informed consent was waved by the Institutional Review Board due to the retrospective nature of this study.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- diagnostic study
- performed at one institution

References

1. Antoni S, Ferlay J, Soerjomataram I, Znaor A, Jemal A, Bray F (2017) Bladder cancer incidence and mortality: a global overview and recent trends. Eur Urol 71:96–108
2. Babjuk M, Böhle A, Burger M et al (2017) EAU guidelines on non-muscle-invasive urothelial carcinoma of the bladder: update 2016. Eur Urol 71:447–461
3. Alfred Witjes J, Lebret T, Compérat EM et al (2017) Updated 2016 EAU guidelines on muscle-invasive and metastatic bladder cancer. Eur Urol 71:462–475
4. Paner GP, Montironi R, Amin MB (2017) Challenges in pathologic staging of bladder cancer: proposals for fresh approaches of assessing pathologic stage in light of recent studies and observations pertaining to bladder histoanatomic variances. Adv Anat Pathol 24:113–127
5. Tritschler S, Mosler C, Straub J et al (2012) Staging of muscle-invasive bladder cancer: can computerized tomography help us to decide on local treatment? World J Urol 30:827–831
6. Tekes A, Kamel I, Imam K et al (2005) Dynamic MRI of bladder cancer: evaluation of staging accuracy. AJR Am J Roentgenol 184: 121–127
7. Takeuchi M, Sasaki S, Ito M et al (2009) Urinary bladder cancer: diffusion-weighted MR imaging–accuracy for diagnosing T stage and estimating histologic grade. Radiology 251:112–121
8. Panebianco V, De Berardinis E, Barchetti G et al (2017) An evaluation of morphological and functional multi-parametric MRI sequences in classifying non-muscle and muscle invasive bladder cancer. Eur Radiol 27:3759–3766
9. Panebianco V, Barchetti F, de Haas RJ et al (2016) Improving staging in bladder cancer: the increasing role of multiparametric magnetic resonance imaging. Eur Urol Focus 2:113–121

10. Huang L, Kong Q, Liu Z, Wang J, Kang Z, Zhu Y (2018) The diagnostic value of MR imaging in differentiating T staging of bladder cancer: a meta-analysis. Radiology 286:502–511
11. Panebianco V, Narumi Y, Altun E et al (2018) Multiparametric magnetic resonance imaging for bladder cancer: development of VI-RADS (Vesical Imaging-Reporting and Data System). Eur Urol 74:294–306
12. Ueno Y, Takeuchi M, Tamada T et al (2019) Diagnostic accuracy and interobserver agreement for the vesical imaging-reporting and data system for muscle-invasive bladder cancer: a multireader validation study. Eur Urol 76:54–56
13. Del Giudice F, Barchetti G, De Berardinis E et al (2020) Prospective assessment of Vesical Imaging Reporting and Data System (VI-RADS) and its clinical impact on the management of high-risk non-muscle-invasive bladder cancer patients candidate for repeated transurethral resection. Eur Urol 77:101–109
14. Lim KK, Noe G, Hornsey E et al (2014) Clinical applications of 3D T2-weighted MRI in pelvic imaging. Abdom Imaging 39:1052–1062
15. Soukup V, Čapoun O, Cohen D et al (2017) Prognostic performance and reproducibility of the 1973 and 2004/2016 World Health Organization grading classification systems in non-muscle-invasive bladder cancer: a European Association of Urology Non-muscle Invasive Bladder Cancer guidelines panel systematic review. Eur Urol 72:801–813
16. Barchetti G, Simone G, Ceravolo I et al (2019) Multiparametric MRI of the bladder: inter-observer agreement and accuracy with the Vesical Imaging-Reporting and Data System (VI-RADS) at a single reference center. Eur Radiol 29:5498–5506
17. Wang H, Luo C, Zhang F et al (2019) Multiparametric MRI for bladder cancer: validation of VI-RADS for the detection of detrusor muscle invasion. Radiology 291:668–674
18. Luo C, Huang B, Wu Y, Chen J, Chen L (2020) Use of Vesical Imaging-Reporting and Data System (VI-RADS) for detecting the muscle invasion of bladder cancer: a diagnostic meta-analysis. Eur Radiol. https://doi.org/10.1007/s00330-020-06802-z
19. Watanabe H, Kanematsu M, Kondo H et al (2009) Preoperative T staging of urinary bladder cancer: does diffusion-weighted MRI have supplementary value? AJR Am J Roentgenol 192:1361–1366
20. Wang HJ, Pui MH, Guo Y et al (2015) Multiparametric 3-T MRI for differentiating low versus high-grade and category T1 versus T2 bladder urothelial carcinoma. AJR Am J Roentgenol 204:330–334
21. El-Assmy A, Abou-El-Ghar ME, Mosbah A et al (2009) Bladder tumour staging: comparison of diffusion- and T2-weighted MR imaging. Eur Radiol 19:1575–1581
22. Yamada Y, Kobayashi S, Isoshima S, Arima K, Sakuma H, Sugimura Y (2014) The usefulness of diffusion-weighted magnetic resonance imaging in bladder cancer staging and functional analysis. J Cancer Res Ther 10:878–882
23. Ohgiya Y, Suyama J, Sai S et al (2014) Preoperative T staging of urinary bladder cancer: efficacy of stalk detection and diagnostic performance of diffusion-weighted imaging at 3T. Magn Reson Med Sci 13:175–181
24. Gupta N, Sureka B, Kumar MM, Malik A, Bhushan TB, Mohanty NK (2015) Comparison of dynamic contrast-enhanced and diffusion weighted magnetic resonance image in staging and grading of carcinoma bladder with histopathological correlation. Urol Ann 7:199–204
25. Lee M, Shin SJ, Oh YT et al (2017) Non-contrast magnetic resonance imaging for bladder cancer: fused high b value diffusion-weighted imaging and T2-weighted imaging helps evaluate depth of invasion. Eur Radiol 27:3752–3758
26. Wang F, Chen HG, Zhang RY et al (2019) Diffusion kurtosis imaging to assess correlations with clinicopathologic factors for bladder cancer: a comparison between the multi-b value method and the tensor method. Eur Radiol 29:4447–4455
27. Xu S, Yao Q, Liu G et al (2020) Combining DWI radiomics features with transurethral resection promotes the differentiation between muscle-invasive bladder cancer and non-muscle-invasive bladder cancer. Eur Radiol 30:1804–1812
28. Lin P, Wen DY, Chen L et al (2020) A radiogenomics signature for predicting the clinical outcome of bladder urothelial carcinoma. Eur Radiol 30:547–557
29. Yajima S, Yoshida S, Takahara T et al (2019) Usefulness of the inchworm sign on DWI for predicting pT1 bladder cancer progression. Eur Radiol 29:3881–3888