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Diagnostic performance of 3-tesla multiparametric MRI for assessment of the bladder cancer T stage and histologic grade

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Abstract

Background: Preoperative staging of urinary bladder carcinomas using TNM system is crucial in the management of bladder cancer which is determined mainly by stage and grade of tumor at diagnosis. We aim to evaluate the diagnostic accuracy of multiparametric MRI (mp-MRI) for assessment of the bladder cancer T stage and histologic grade.

Results: The overall T2-WI diagnostic accuracy for the T stage was 72.3%, increased to be 87.1% for contrast-enhanced images, and 92.6% for DWI, reaching the maximum accuracy 94.5% using the combined multi-parametric MRI technique. Diagnostic accuracies of mp-MRI in differentiating superficial from muscle-invasive (91%) and organ-confined from non-organ confined tumors (92%) were superior to DW-MRI (89% and 87%), DCE-MRI (84% and 83%), and T2W-MRI (74% and 71%), respectively. The agreement between MRI findings and histopathological staging was greater in mp-MRI (k = 0.91; excellent agreement) than in DW-MRI (k = 0.77; moderate agreement), DCE-MRI (k = 0.76; substantial agreement), and T2W-MRI (k = 0.53; fair agreement).

Conclusion: Mp-MRI provides useful information for evaluating the local T stages of bladder cancer and can predict the histological grades of urinary bladder cancers with high diagnostic accuracy.

Keywords: Multiparametric, MRI, Bladder, Cancer, T stage, Histological grades

Background

Clinical management of urinary bladder cancer is determined primarily on the basis of distinguishing superficial tumors (stage T1 or lower) from invasive ones (stage T2 or higher) because the treatment options differ considerably [1]. Superficial tumors are treated with transurethral resection (TUR) with or without adjuvant intravesical chemotherapy or photodynamic therapy [2], whereas invasive tumors are treated with radical cystectomy, radiation therapy, chemotherapy, or a combination [3].

The most important point for the local staging of bladder cancer is the presence or absence of muscle invasion, which has a significant impact on the management strategy as outlined in multiple guidelines including those issued by the European Association of Urology (EAU), the National Comprehensive Cancer Network (NCCN), and the American Urological Association/Society of Urologic Oncology (AUA/SUO) [4, 5].

Multiparametric (mp-MRI) included morphologic imaging technique as high-resolution T2-WI and functional imaging techniques such as dynamic contrast-enhanced MRI (DCE MR) imaging and diffusion-weighted imaging MRI (DWI MRI) [6].

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In high-resolution T2 sequence, urine has high signal intensity, tumors have intermediate signal intensity, and normal detrusor muscle appears as a hypointense line in-between, so in non-muscle-invasive disease, the low signal intensity detrusor lining adjacent to the tumor is preserved, whereas it is interrupted in case of muscle-invasive disease [4, 7, 8].

Diffusion-weighted imaging is a noninvasive functional imaging technique reflecting proton diffusion properties in water. It depends mainly on the Brownian motion through the inhibitory effect of cell membranes to the random motion of water molecules [9]. Changes in ADC are inversely correlated with changes in cellularity; thus, in tissues with high cellularity, decreasing water mobility will be reflected as decreased ADC values. Besides tumor localization and staging, DWI is considered a promising tool in assessment of tumor aggressiveness [10].

Dynamic contrast-enhanced MRI is useful to assess angiogenesis because tumor enhancement is attributed to pathological neovascularization and so malignant neoplasms show earlier enhancement than tissues without neovascularization and this presented as rapid contrast wash-in followed by washout pattern in case of malignant neoplasms [11].

Multiple studies have proved that 3-T MRI shows a better specificity and sensitivity than 1.5-T MRI when used to diagnose and stage bladder cancer. Therefore, the guidelines recommend the use of multi-parametric 3-T MRI to improve the diagnostic accuracy for determining bladder cancer T stage [1].

We hypothesized that mp-MRI can accurately assess the local stage and grade of bladder cancer. So, we conducted this study to prospectively evaluate the usefulness of mp-MRI for determining T stage for bladder cancers and to measure the correlation between mp-MRI and histopathological grade.

Methods

Subjects

This prospective study included 54 consecutive patients with bladder tumors diagnosed either clinically, from urine cytology or by other radiologic investigations including ultrasonography or computed tomography during the period from March 2017 to March 2019. Patients were referred to the Radiology Department (MRI Unit) from the Urology Department of the same center. Exclusion criteria included patients with general contraindications for MR examination (as with pacemaker or metallic prosthesis) or contraindications for cystoscopy (patients unfit for anesthesia or due to urethral stricture), patients with high renal function tests, not suitable for IV-gadolinium injection, and patients refusing consent. Adequate bladder distention is important and can be achieved by instructing the patient not to void for about 1–2 h before imaging or by instructing the patient to start drinking 500–1000 ml of water 30 min before the examination.

MRI technique

MRI was performed in the supine position using a high field system (3-Tesla) MRI scanner (Phillips, ingenia 3 T, the Netherlands) with 18-channel phased external array coil. Each patient was subjected to three main components of mpMRI of the pelvis including high-resolution T2W, diffusion-weighted imaging with ADC map, and DCE MRI. Additional sequences were done including T1W (with and without fat suppression) and axial T2 with fat suppression. Examination protocol was approved by the institutional board of ethics, and informed consents were obtained from all patients.

The applied MRI parameters in the current study were as follows:

- *T2-weighted imaging*: Three planes of multiplanar (axial, coronal, and sagittal) T2W images without fat suppression are obtained with TR (ms) 4690, TE (ms) 119, flip angle (degree) 90, FOV (cm) 23, matrix 400 × 256–302, slice thickness (mm) 3–4, slice gap (mm) 0–0.4, and number of excitations 2–3.
- *Diffusion-weighted imaging*: This was performed during free breathing with axial and coronal plane fat-suppressed water-excited single-shot spin echo with high *b* value (800–1000 s/mm^2) TR (ms) 2500 up to 5300, TE (ms) 61, flip angle (degree) 90, FOV (cm) 32, matrix 128 × 128, slice thickness (mm) 3–4, slice gap (mm) 0.3–0.4, and number of excitations 4–10.
- *DCE-MRI*: Gadopentetate dimeglumine (Magnevist, Bayer Schering Pharma) is administered by mechanical injector at a dose of 0.1 mmol/kg of body weight at a rate of 1.5–2.0 ml/s and followed by saline flush. Imaging started using an axial, sagittal, or coronal fat-suppressed 3D volumetric spoiled gradient echo sequence at 30 s after the beginning of injection and followed by the same sequences four to six times every 30 s. TR (ms) 3.8, TE (ms) 1.2, flip angle (degree) 15, FOV (cm) 27, matrix 192 × 192, slice thickness (mm) 1, slice gap (mm) 0, and number of excitations 1.

Image analysis

All scans were transferred and reviewed on a picture archiving and communication systems (Magic View, GE, Milwaukee, WI, USA). T2-WI, DWI, and DCE-MR images were interpreted referring to T1 and T2-WI image sets, and the tumors were assigned a T stage on a stage-by-stage basis in each sequence. When multiple tumors

were present, the highest T stage represented the T stage of the patient.

In T2-weighted, the signal intensity of bladder cancers is lower than the signal from the urine and perivesical fat and higher than the wall; tumors are staged as follows:

- Stage T1: Preservation of low signal intensity of the bladder wall.
- Stage T2: Interruption of the hypointense bladder wall in tumor site.
- Stage T3: Infiltration of the perivesical fat.
- Stage T4: Tumor extending into the adjacent organs, abdominal or pelvic wall.

In DW-MRI, signal intensity of the lesions is identified at b1000 images; in these images, the tumor is hyperintense and the bladder wall appears slightly hyperintense. While analyzing the DW MRI, the image interpretation was referred to T1 and T2 images and lesions are classified into the following:

- Stage T1: Hyperintense tumor is within the bladder lumen.
- Stage T2: Hyperintense tumor partially seen in bladder wall.
- Stage T3: Hyperintense tumor disrupting the bladder wall.
- Stage T4: Hyperintense tumor extending into the adjacent organs, abdominal or pelvic wall.

In DCE-MRI, bladder tumor, mucosa, and submucosa enhanced early, but the muscle layer maintains its hypointensity and enhanced late. Lesions are classified as follows:

- Stage T1: Intact muscle layer at the base of the tumor showing low signal intensity.
- Stage T2: Disrupted hypointense line and early enhancement without perivesical fat infiltration.
- Stage T3: Disrupted hypointense line and enhancing streaky areas in perivesical fat.
- Stage T4: Lesion extending into adjacent organs or abdominal and pelvic side walls.

The time-intensity curves were constructed from signal intensity values obtained from regions of greatest enhancement selected from the lesions as follows:

- Grade1: Enhancement, followed by a slow increase.
- Grade 2: Enhancement, followed by a plateau.
- Grade 3: Enhancement, followed by washout.

ADC values were calculated from the most hypointense areas of the tumors, corresponding normal bladder walls and urine.

Data were regrouped to evaluate the accuracy of each separate imaging set and mp-MRI in distinguishing non-muscle-invasive from muscle-invasive tumors and organ-confined from non-organ-confined tumors with comparison to the post-operative histopathological data for tumor type, grade, and stage.

Statistical analysis

Qualitative data were described using number and percent. Quantitative data were described using range, mean, standard deviation, and median. The used tests were chi-square test, Fisher's exact test, and Student's *t* test. Kappa statistic was applied to compare the extent of agreement between MRI findings and histopathological results. Receiver operating characteristic curve (ROC) analysis was used to calculate the area under the curve (AUC) for identification of ADC cutoff values differentiating normal values from bladder cancer and differentiating low-grade from high-grade cancers. Diagnostic efficacy was depicted in terms of sensitivity, specificity, negative predictive value, positive predictive value, and diagnostic accuracy. The analysis was performed by SPSS version 25 software. A p value < 0.05 was considered as significant.

Results

This study was conducted on 54 patients, in which 50 (92.6%) were males and 4 patients (7.4%) were females, and their ages ranged between 31 and 82 years (mean age was 62.18 ± 10.3 years). Commonest presenting symptom was hematuria in 47 patients (87%). Histopathological examination showed 47 patients (87%) presented with transitional cell carcinoma, 4 (7.4%) with squamous cell carcinoma, and 3 (5.5%) with adenocarcinoma.

Regarding T staging, 7 patients (12.9%) presented with stage PT1 disease, 17 (31.5%) with PT2 disease, 29 (53.7%) with PT3 disease, and 1 (1.9%) with PT4 disease. Regarding grading, 13 patients (24%) are with low-grade and 41 (76%) with high-grade disease. Histopathological confirmation for local T staging were performed in 28 patients (51.8%) from transurethral resection of bladder tumor (TURBT), 24 patients (44.5%) from radical cystectomy, and 2 patients from diverticulectomy (3.7%) who had localized tumors in bladder diverticulum.

Mp-MRI correctly diagnosed the local T stage in 94.5% patients which is highest diagnostic accuracy compared to T2W-MRI (72.3%), DCE-MRI (87.1%), and DW-MRI (92.6%). Overstaging of local T stage is markedly reduced to 5.9% in MP-MRI if compared to T2 WI (27.7%), DCE-MRI (12.9%), and DW-MRI (7.4%). No understaging occurred in MP-MRI while there was one understaged case in T2WI (1.9%) and one understaged case in DCE-MRI (1.9%) (Table 1).

Table 1 Diagnostic T staging performance of the different sequences and mp-MRI

MRI technique	Correct		Overstaging		Understaging	
	No	%	No	%	No	%
T2WI	39	72.3	15	27.7	1	1.9
DWI	50	92.6	4	7.4	0	0
DCE	47	87.1	7	12.9	1	1.9
Mp-MRI	51	94.5	3	5.9	0	0

The extent of harmony between local T staging of the bladder tumors by different MRI sequences as well as mp-MRI and histopathology (using kappa test) was as follows:

- Mp-MRI: (k = 0.91; excellent agreement).
- DWI: (k = 0.758; moderate agreement).
- DCE-MRI: (k = 0.766; substantial agreement).
- T2 WI: (k = 0.527; fair agreement).

So, the extent of harmony between radiologic and histopathological staging results was greatest when using mp-MRI denoting high diagnostic performance.

Diagnostic accuracy of mp-MRI in differentiating non-muscle-invasive from muscle-invasive tumors (≤ T1 versus ≥ T2 stage) was 94.4% with sensitivity 100%, specificity 85.7%, positive predictive value 97.9%, and negative predictive value 85.7% while the diagnostic accuracy of mp-MRI for differentiating organ-confined versus non-organ-confined disease (≤ T2 versus ≥ T3 stage) was 98.1% with sensitivity 100%, specificity 95.8%, positive predictive value 96.8%, and negative predictive value 100% (Table 2).

As regards the time-signal intensity curve of the DCE-MRI, there were three types of curves identified in our study: type I = ascending pattern, type II = plateau pattern, and type III = descending pattern. There were significant statistical correlations (P < 0.001) between the type of curve and the tumor grade by using the Monte Carlo test.

- Type I curve (ascending) was identified in 2 patients (3.7%) only and both had low-grade tumor.
- Type II curve (plateau) was identified in 11 patients (20.4%) with 8 patients (72.7%) having low-grade tumor and 3 patients (27.3%) having high-grade tumors.
- Type III (descending) curve was identified in 41 patients (75.9%) with 38 patients (92.7%) with high-grade tumors and 3 patients (7.3%) with low-grade tumors.

As regards the mean ± SD of the aberrant diffusion coefficient (ADC) values of the detected bladder tumors in our study, it was 0.813 ± 0.24 × 10^{-3} mm^2/s in urothelial carcinoma (no = 47), 1.02 ± 0.21 × 10^{-3} mm^2/s in SCC, and 0.92 ± 0.24 × 10^{-3} mm^2/s in adenocarcinoma. There is no statistically significant correlation between tumor ADC value and tumor subtypes. There is no statistically significant correlation between the mean ADC value of the tumor subtypes, normal urinary bladder wall ADC, and urine ADC. Also, there was no statistically significant correlation between the ADC value and tumor stage (Table 3 and Fig. 1).

The mean of ADC values of lesions (no = 54) was compared to the grade of tumors. ADC values were significantly lower in high-grade tumors and higher in low-grade tumors (Table 4 and Fig. 2).

A receiver operating characteristic (ROC) curve based on ADC values demonstrated a perfect AUC of 0.959. A cutoff ADC value of 0.941 × 10^{-3} mm^2/s best differentiated high-grade from low-grade carcinomas with a sensitivity of 92.3%, a specificity of 90.2%, PPV of 75%, and NPV of 97.4% (Fig. 3).

Table 2 Diagnostic performance of the different sequences and mp-MRI and their extent of agreement with pathological staging results

	Sensitivity				Specificity				PPV				NPV				Accuracy			
	T2WI	DWI	DCE	Mp-MRI	T2WI	DWI	DCE	Mp-MRI	T2WI	DWI	DCE	Mp-MRI	T2WI	DWI	DCE	Mp-MRI	T2WI	DWI	DCE	Mp-MRI
T1	42.9	85.7	57.1	85.7	100.0	97.9	97.9	100.0	100.0	85.7	80.0	100.0	92.2	97.9	93.9	97.9	92.6	96.3	92.6	98.1
T2	58.8	88.2	88.2	94.1	91.9	94.6	91.9	97.3	76.9	88.2	83.3	94.1	82.9	94.6	94.4	97.3	81.5	92.6	90.7	96.3
T3	86.2	82.8	89.7	96.6	68.0	96	96	96	75.8	96	96.3	96.6	81.0	82.8	88.9	96	77.8	88.9	92.6	96.3
T4	100.0	100.0	100.0	100.0	92.5	92.5	94.3	98.1	20.0	20.0	25.0	50.0	100.0	100.0	100.0	100.0	92.6	92.6	94.4	98.1
≤ T1 versus ≥ T2	100.0	97.9	97.9	100.0	42.9	85.7	57.1	85.7	92.2	97.9	93.9	97.9	100.0	85.7	80.0	85.7	92.6	96.3	92.6	94.4
≤ T2 versus ≥ T3	100.0	96.7	100	100	66.7	95.8	95.8	95.8	78.9	96.7	96.8	96.8	100.0	95..8	100	100	85.2	96.3	98.1	98.1

Table 3 Relation between pathology stage and ADC values

Variable	Pathology type				One-way ANOVA test	*P* value
	T1 (*n* = 7) mean ± SD	T2 (*n* = 17) mean ± SD	T3 (*n* = 29) mean ± SD	T4 (*n* = 1) mean ± SD		
Mean ADC value	1.04 ± 0.26	0.79 ± 0.28	0.80 ± 0.20	0.95 ± 0	2.11	0.11
Normal wall ADC	1.78 ± 0.36	1.62 ± 0.23	1.55 ± 0.49	1.97 ± 0.0	0.87	0.46
Urinary ADC	2.87 ± 0.24	2.57 ± 0.27	2.83 ± 0.37	2.97 ± 0.0	2.72	0.055

Figures 4, 5, 6 and 7 demonstrate the different examples of local T staging of the bladder tumors by multiparametric MRI and histopathology.

Discussion

Preoperative staging of urinary bladder carcinomas using TNM system is crucial in the management of bladder cancer which is determined mainly by stage and grade of tumor at diagnosis [1, 12].

TURBT is the current standard for determining the presence or absence of muscle invasion, provides an estimate of pathologic subtype and grade, and can be completely curative in some times if the entire tumor is resected [12, 13]. However, TURBT has been found to underestimate T stage in up to 40% of patients, is inaccurate at determining tumor grade in up to 15% of patients, and frequently needs to be repeated [3]. Furthermore, adherence to guidelines recommending repeat TURBT varies widely between urologists [14].

Improving MRI technology had led to introduction of mp-MRI (including high-resolution T2 WI, DW MRI, and DCE MRI) providing both anatomic and functional evaluation of the local staging and grading of bladder cancer with relatively high accuracy [6].

The overall T2 staging diagnostic accuracy in the current study was 72.3%, which is higher compared to previous similar studies. In the study conducted by Takeuchi et al. [14] on 52 patients with bladder tumor using 1.5-T MRI, they found that the overall diagnostic accuracy of T2WI in local T staging of bladder tumor was 67%. A study by Afifi et al. [15] using 1.5-T magnet, conducted on 50 patients with bladder cancer, showed T2 staging diagnostic accuracy of 52%. Another interesting study by Abou-El-Ghar et al. [16] using 1.5-T MRI conducted on larger number of patients (130 patients)

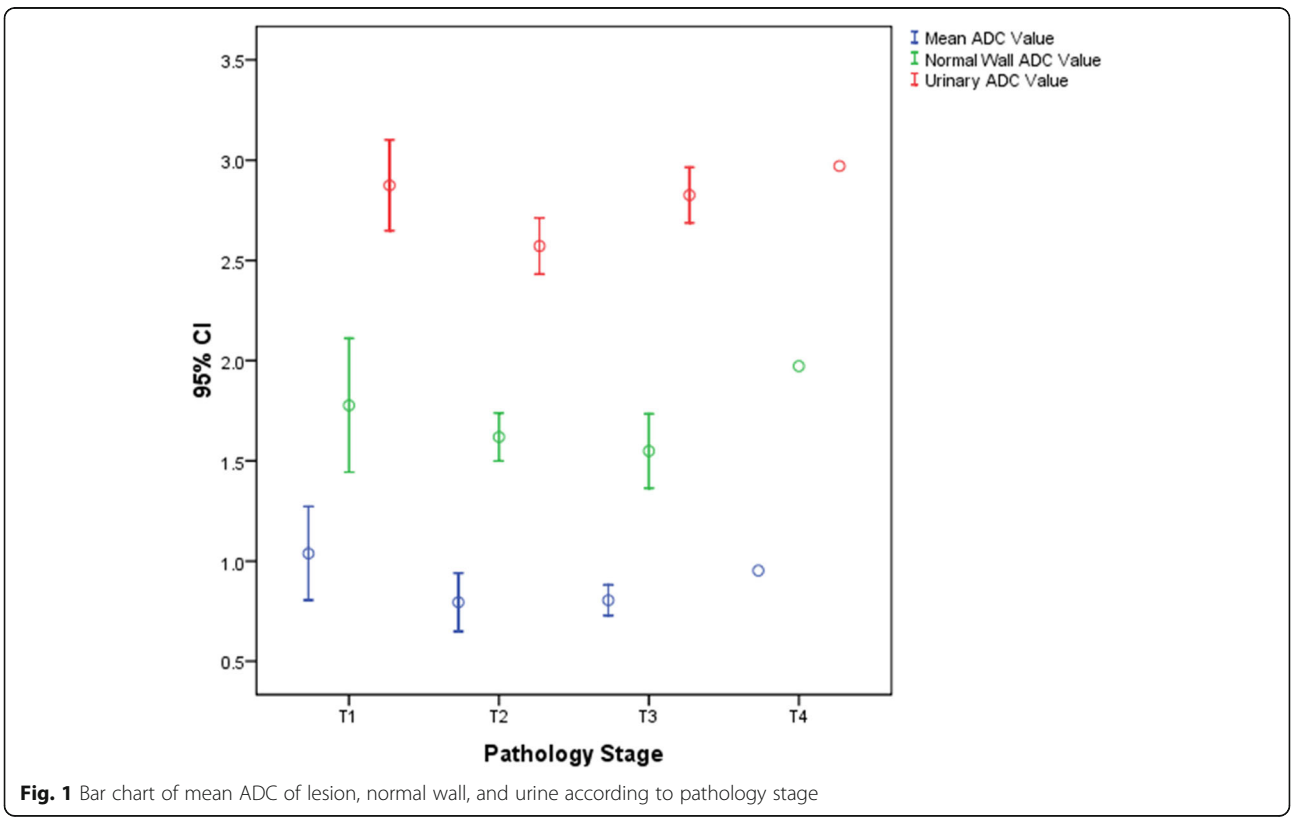

Fig. 1 Bar chart of mean ADC of lesion, normal wall, and urine according to pathology stage

Table 4 Mean ADC values according to tumor grades

Variable	Pathology type		*P* value
	High grade (*n* = 41) mean ± SD	Low grade (*n* = 13) mean ± SD	
Mean ADC value	0.73 ± 0.14	1.19 ± 0.15	< 0.001
Normal wall ADC	1.53 ± 0.42	2.58 ± 0.11	0.013
Urinary ADC	2.69 ± 0.36	2.36 ± 0.63	0.02

showed T2 staging diagnostic accuracy of 39.6%. The improved diagnostic accuracy of our study may be attributed to the use of 3-T MRI, as the most of the previous studies were done on 1.5-T magnet.

The current study revealed T2 diagnostic accuracy of 71% in differentiating superficial from invasive tumors. This was better than Takeuchi et al. [14] who reported a diagnostic accuracy of 79% and Barsoum et al. [17] who reported a diagnostic accuracy of 88%.

Our study revealed T2 diagnostic accuracies of 85.2% in differentiating organ-confined from non-organ-confined tumors. This was similar to Takeuchi et al. [14] who reported a diagnostic accuracy of 85% and less than Barsoum et al. [17] who reported a diagnostic accuracy of 94%.

In the current study, overall staging accuracy of DCE-MRI was 87% and overstaging was detected in 13% of patients. Our results were better than those reported by Afifi et al. [15] who reported accuracy of (74%) and overstaging of about 26%. In their study, Gupta et al. [6] detected less staging accuracy of DCE MRI (73.3%) and more overstaging (20%) compared to our results. Also, Takeuchi et al. [14] reported accuracies between 75 and 92% which is comparable to our results.

To our knowledge, the accuracy of dynamic contrast-enhanced MR images for differentiating between T1 or lower tumors and T2 or higher tumors has been reported to be 75–92% [14, 18, 19], and it was reported to be 75–92% for differentiating between T2 or lower tumors and T3 or higher tumors. The overall accuracy for diagnosing tumor stage has been reported to be 52–93% [14, 18].

Our study revealed a significant statistical correlation ($P < 0.001$) between grading, time-intensity curves, and corresponding histopathological grades. Grade 1 curve only identified in low-grade tumors (3.7%), grade 3 curve

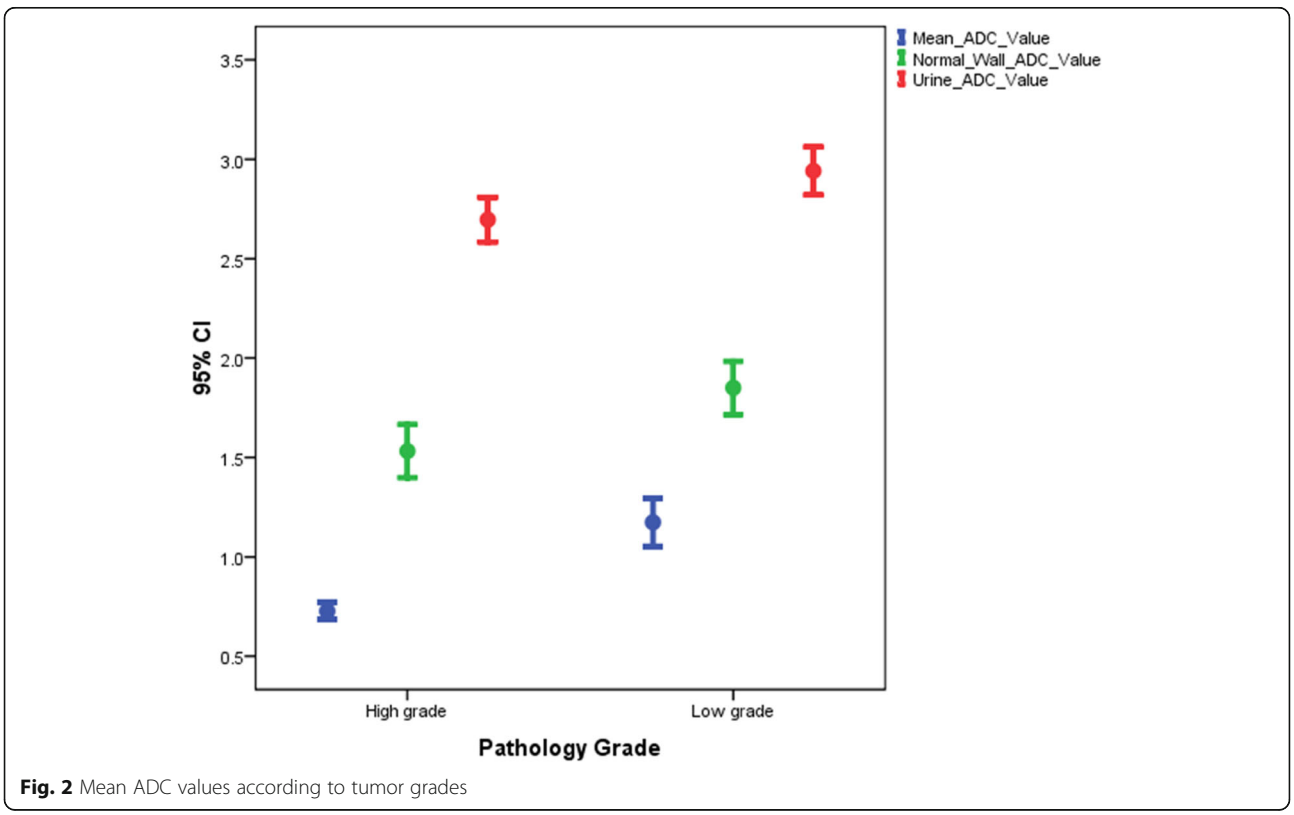

Fig. 2 Mean ADC values according to tumor grades

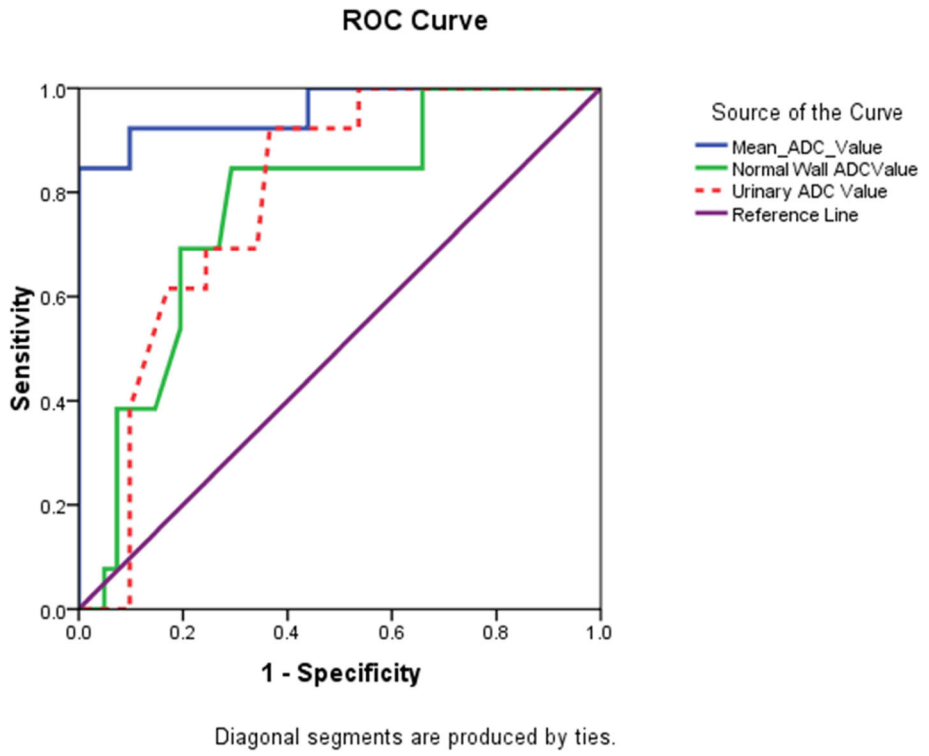

Fig. 3 ROC based on ADC values

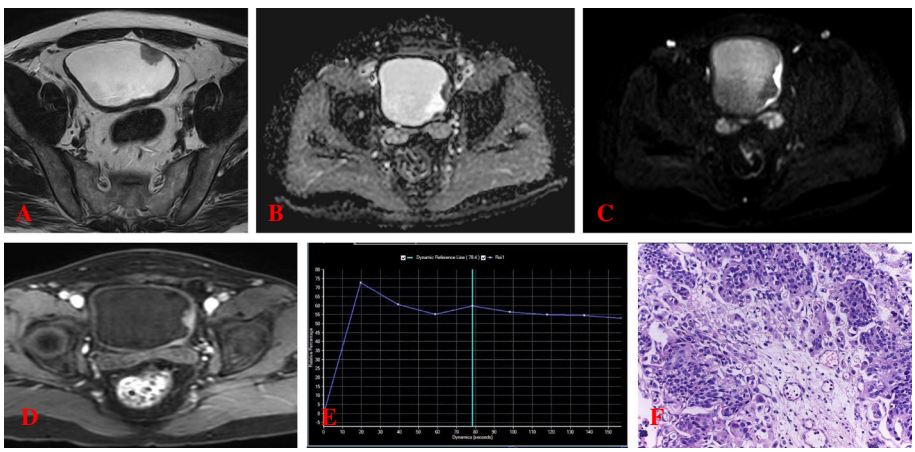

Fig. 4 A 57-year-old male patient presented with history of recurrent hematuria. Axial T2 WI (**a**) showed an intra-vesical soft tissue masses arising from left lateral and left postero-lateral bladder wall expressing intermediate signal intensity with no interruption of the hypointense underlying muscle layer. Axial ADC map (**b**) showed low SI of the lesion with ADC value = 0.8×10^{-3} mm^2/s, consistent with high-grade tumor. Axial DW-MRI (b1000) (**c**) showed restricted diffusion of the masses with intact underlying low SI muscle layer. Axial post contrast T1WI FAT-SAT (**d**) showed early enhancement of the masses with intact underlying muscle layer and preserved submucosal linear enhancement. Time-intensity curve (**e**) showed grade 3 curve with early enhancement and rapid washout. Multiparametric MRI features suggest high-grade stage T1 non-muscle-invasive urinary bladder carcinoma. Microscopic image of histopathology (**f**) demonstrated high-grade urothelial carcinoma which confirm the multiparametric MRI finding

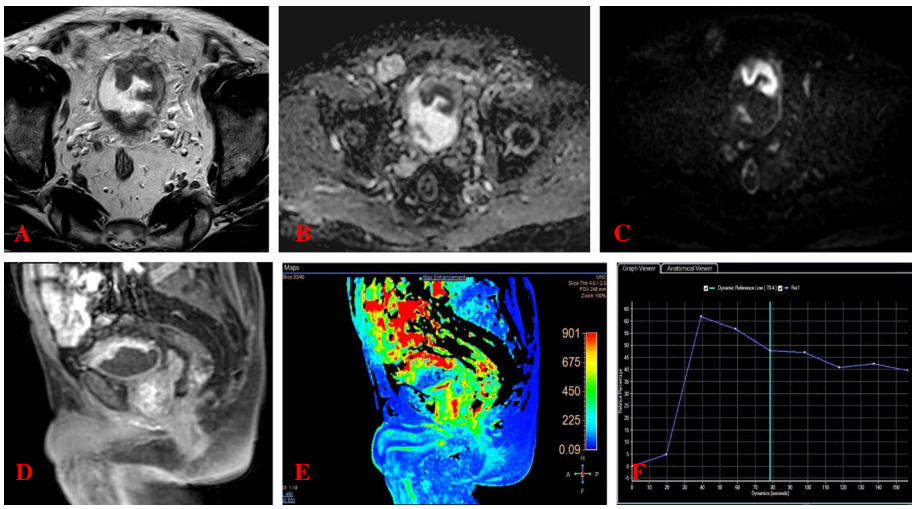

Fig. 5 A 64-year-old male patient presented with history of recurrent hematuria. Axial T2 WI (**a**) showed an intra-vesical soft tissue mass arising from bladder dome and left lateral wall expressing intermediate signal intensity with interruption of the hypointense underlying muscle layer and no obvious infiltration of the perivesical fat. Axial ADC map (**b**) showed low SI of the lesion with ADC value = 0.7 × 10^{-3} mm^2/s, consistent with high-grade tumor. Axial DW-MRI (b1000) (**c**) showed restricted diffusion of the mass with invasion of the muscle layer. Sagittal post contrast T1WI FAT-SAT image (**d**) showed early enhancement of the mass with focal involvement of underlying muscle layer. Perfusion image (**e**) and time-intensity curve (**f**) showed grade 3 curve with early enhancement and rapid washout. The patient underwent radical cystectomy, and the histopathology was high-grade adenocarcinoma; MP-MRI features suggest high-grade stage T2 muscle-invasive urinary bladder carcinoma, and histopathological assessment confirmed the diagnosis

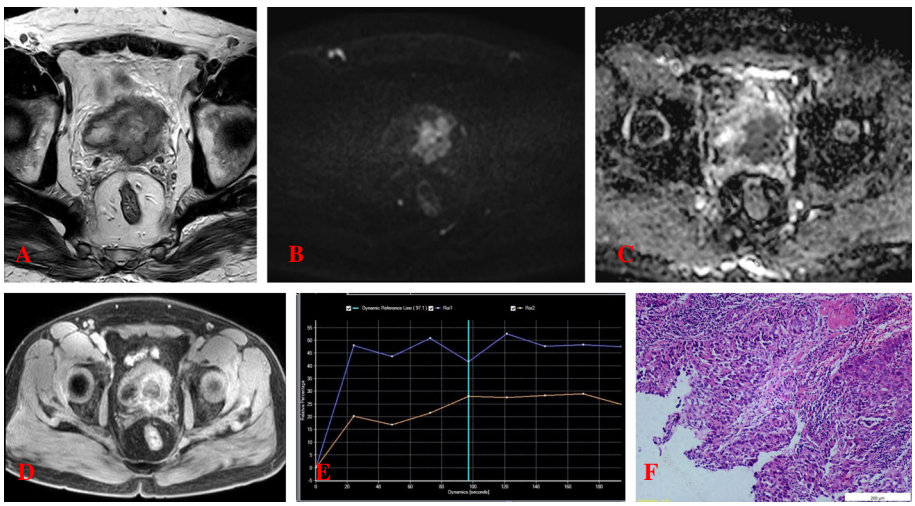

Fig 6 A 58-year-old male patient presented with history of recurrent hematuria and pelvic pain. Axial T2 WI (**a**) showed intra-vesical soft tissue mass arising from dome and high left posterolateral bladder wall expressing intermediate signal intensity with infiltration of the muscle layer and perivesical fat. Axial DW-MRI (b1000) (**b**) showed restricted diffusion of the mass with infiltration of the perivesical fat. Axial ADC map (**c**) showed low SI of the lesion with ADC value = 0.85 × 10–3 mm^2/s, consistent with high-grade tumor. Axial post contrast T1WI FAT-SAT (**d**) showed early heterogeneous enhancement of the mass with cystic degeneration and infiltration of the perivesical fat. Time-intensity curve (**e**) showed grade 3 curve with early enhancement and rapid washout. Multiparametric MRI features of low-grade stage T3 muscle-invasive urinary bladder carcinoma. Microscopic image of histopathology (**f**) demonstrated high-grade urothelial carcinoma which confirms the multiparametric MRI finding

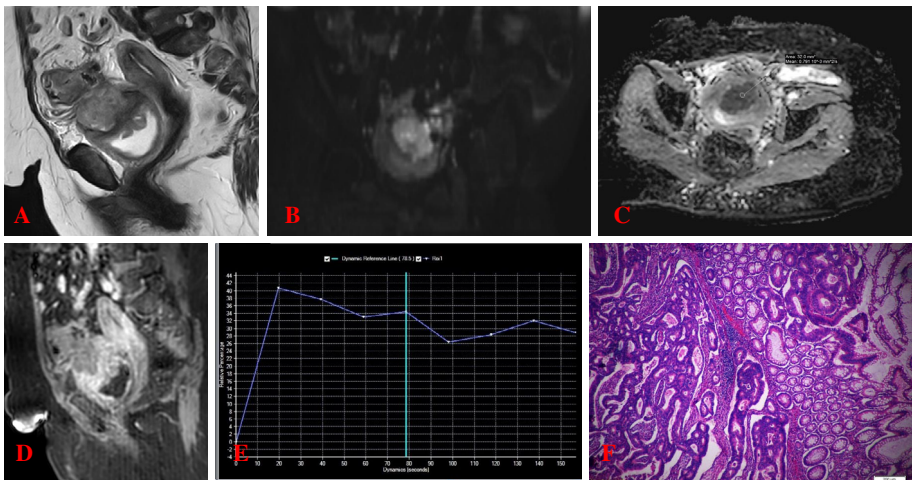

Fig. 7 A 69-year-old female patient presented with history of recurrent hematuria and burning micturition and notable changes of bowel habit with episodes of constipation alternating with diarrhea as well as bloody stool. Sagittal T2 WI (**a**) showed an intra-vesical soft tissue mass arising from bladder dome and high anterior wall expressing heterogeneous signal intensity with infiltration of the perivesical fat, anterior peritoneal reflection, and sigmoid colon. Coronal DW-MRI (b1000) (**b**) showed restricted diffusion of the masses with intact underlying low SI muscle layer. Axial ADC map (**c**) showed low SI of the lesion with ADC value = 0.79×10^{-3} mm^2/s, consistent with high-grade tumor. Axial post contrast T1WI FAT-SAT (**d**) showed heterogeneous enhancement of the mass which infiltrated the sigmoid colon with areas of cystic degeneration. Time-intensity curve (**e**) showed grade 3 curve with early enhancement and rapid washout. Multiparametric MRI features suggest high-grade stage T4a urinary bladder carcinoma. Microscopic image of histopathology (**f**) high-grade adenocarcinoma carcinoma which confirm the multiparametric MRI finding

mostly identified in high-grade tumors (75.9%), while grade 2 curve were more identified in low-grade (72.7%) than in high-grade carcinomas (27.3%). This was in agreement with Afifi et al. [15] and Gupta et al. [6] who showed significant correlation between time-intensity curves and tumors grading.

Quantitative analysis of the ADC values potentially reflects the histological grades of urothelial tumors. To our knowledge, DWI was superior to DCE-MRI and T2W-MRI in detection and local staging of urinary bladder cancers [13, 20].

The overall staging accuracy of DW-MRI in current study was 92.6% and overstaging was detected in 7.4% of patients. Our results are better than results reported by Gupta et al. [6] who detected less DWI staging accuracy (76.7%) and more overstaging (16.7%) and also Afifi et al. [15] who showed an overall staging accuracy of DW-MRI of 82% and overstaging in 18% of patients.

Our study revealed DWI diagnostic accuracies of 96.3% in differentiating both superficial from muscle-invasive and organ-confined from non-organ confined tumors. These results were higher than El-Assmy et al. [21] results who found the DWI staging accuracies of 63.6% and 69.6% in differentiating superficial from muscle-invasive and organ-confined from non-organ confined tumors, respectively. On other hand, our results were similar to Barsoum et al. [17] results who reported the accuracies of 96% and 98%, respectively.

In the current study, the correlation between the radiologic and pathologic stages was greater with the DWI (q = 0.766) than with the T2WI (0.527) or gadolinium-enhanced (0.758) which was in agreement with results reported by Watanabe et al. [22] and Gupta et al. [6]. Similar results also were detected in Afifi et al. [15] study who also found greater correlation between the radiologic and pathologic stages with the diffusion sequence (q = 0.679) than with the T2W (0.274) or gadolinium-enhanced (0.566).

By comparing multiparametric acquisition protocols, we found that the combination of T2-weighted, DWI, and DCE-MRI was most accurate for staging. Overall staging accuracy of mp-MRI in current study was 94.5% and overstaging was detected only in 5.9% of patients. These results were better than study of Afifi et al. [15] who reported mp-MRI overall staging accuracy of 88% and overstaging was detected only in 12% of their patients. Takeuchi et al. [14] also stated that theT2-WI diagnostic accuracy for the T stage was 67%, increased to be 88% for T2WI plus DWI, 79% for T2 WI plus contrast-enhanced images, and 92% for all three image types reaching the maximum accuracy using the combined multi-parametric assessment.

Our study revealed mp-MRI diagnostic accuracy of 94.4% in differentiating superficial from invasive tumors. This was better than van der Pol et al. [1] who reported diagnostic accuracy of 84 to 86% and Afifi et al. [15] who reported diagnostic accuracy of 88%.

Our study revealed mp-MRI diagnostic accuracy of 98.1% in differentiating organ-confined from non-organ-confined tumors. This was better than van der Pol et al. [1] who reported diagnostic accuracy of 81 to 83% and Afifi et al. [15] who reported diagnostic accuracy of 88%.

In this study, we found that the mean ADC value of the detected malignant bladder lesions was 0.813 ± 0.24 × 10^{-3} mm^2/s, which is significantly lower than that of urine (mean 2.71 ± 0.35) and that of normal bladder wall (mean 1.56 ± 0.41). This was similar to Afifi et al. [15] who reported mean ADC value in bladder cancers of 0.87 ± 0.26 × 10^{-3} mm^2/s, significantly lower than that of urine (mean 2.90 ± 0.25) and that of normal bladder wall (mean 1.57 ± 0.17). Our results also agreed with Kobayashi et al. [23] study.

In current study, we detected a cutoff ADC value of < 1.36 × 10^{-3} mm^2/s differentiating bladder carcinomas from normal bladder wall and a cutoff ADC value of 0.941 × 10^{-3} mm^2/s differentiating high-grade from low-grade carcinomas. Similar results were detected by Afifi et al. [15] who found that a cutoff ADC value of < 1.36 × 10^{-3} mm^2/s differentiating bladder carcinomas from normal bladder wall and a cutoff ADC value of < 1.012 × 10^{-3} mm^2/s differentiating high-grade from low-grade carcinomas.

On the other hand, Kobayashi et al. [23] stated a cutoff ADC value of 0.86 × 10^{-3} × 10^{-3} mm^2/s differentiating aggressive from low-grade disease which is lower than cutoff value detected in our study. Avcu et al. [20] stated a cutoff ADC value 1.545 × 10^{-3} mm^2/s differentiating malignant and benign bladder wall pathologies and a cutoff ADC value 1.135× × 10^{-3} mm^2/s differentiating high and low-grade carcinomas which is higher than our results.

We detected inverse correlation between bladder carcinomas ADC values and T stages, as ADC values were significantly lower in high stage tumors P T2 (mean 0.79 ± 0.28 × 10^{-3} mm^2/s) than the superficial tumorsT1 (mean 1.04 ± 0.26 × 10^{-3} mm^2/s). This was similar to Afifi et al. [15], who reported that the ADC values were significantly lower in high stage tumors P T2 (mean 0.69 ± 0.13 × 10^{-3} mm^2/s) than the superficial tumors T1 (mean 0.97 ± 0.26 × 10^{-3} mm^2/s). Similar to our results, Kobayashi et al. found that patients with higher T stages exhibited significantly lower ADC values ($P < 0.001$).

Our study had a number of limitations; the distribution of T stages was uneven, with a large number of T2 and T3 and a small number of T1 and T4 tumors; therefore, larger studies are warranted to more fully define the role of mpMRI in T staging of bladder tumors. Limitations of the current study included increased cost, time consumed by the technique especially including the cost of the contrast, and some patients were less cooperative with motion artifacts as the study mandates full UB. Finally, the radiologic-pathologic correlation was not perfect because the cut surfaces on surgical specimens were not always completely identical to those seen on MR images.

It is expected that utilization of mp-MRI for bladder cancer local T staging will increase as awareness of its accuracy in the urology community improves. Several recent meta-analyses assessing the topic of local staging of bladder cancer with mp-MRI confirm an increase in the potential benefits of performing mp-MRI [1].

Conclusions

Mp-MRI is an excellent tool for determining the different local T stages and the histological grades of urinary bladder cancers with high diagnostic accuracy. So, before cystoscopy and histopathological sampling, more accurate predictions can be made using Mp-MRI.

Abbreviations

MRI: Magnetic resonance imaging; mp-MRI: Multiparametric magnetic resonance imaging; DWI MRI: Diffusion-weighted imaging—magnetic resonance imaging; DCE-MRI: Dynamic contrast-enhanced—magnetic resonance imaging; ADC: Apparent diffusion coefficient; CIS: Carcinoma in situ; UBC: Urinary bladder carcinoma; TCC: Transitional cell carcinoma; SCC: Squamous cell carcinoma; TURBT: Transurethral resection of the bladder tumor; FOV: Field of view; T2W: T2-weighted; T1W: T1-weighted; FSE: Fast-spin-echo; MIBCs: Muscle-invasive bladder carcinomas; NMIBC: Non-muscle-invasive bladder carcinomas; SI: Signal intensity; ROI: Region of interest

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Authors' contributions

Contributed in the data collection: Dr. Hashim Frag and Dr. Basma Gad ElHaq. Data analysis and writing: Dr. Mohamed Badawy and Dr. Hashim Farg. Supervision: Prof. Mohamed Abou ElGhar, Prof. Ahmed Galal, and Prof. Mohamed Borg. The manuscript has been read and approved for submission by all named authors.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of the Faculty of Medicine at the Mansoura University in Egypt on 18 April 2017; reference number of approval 365. All patients included in this study gave written informed consent to participate in this research.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests

The authors declare that they have no competing interests.

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