Abdominal Radiology

Published online: 21 July 2018

Abdom Radiol (2019) 44:252–258
https://doi.org/10.1007/s00261-018-1696-8

Correlation of 3T multiparametric prostate MRI using prostate imaging reporting and data system (PIRADS) version 2 with biopsy as reference standard

Shobhit Mathur,[1] Martin E. O'Malley,[2] Sangeet Ghai,[1] Kartik Jhaveri,[2] Boraiah Sreeharsha,[2] Myles Margolis,[3] Lehang Zhong,[4] Hassan Maan,[1] and Ants Toi[3]

[1]Joint Department of Medical Imaging, Toronto General Hospital, University of Toronto, 585 University Ave., Toronto, ON M5G 2N2, Canada

[2]Joint Department of Medical Imaging, Princess Margaret Hospital, University of Toronto, 610 University Avenue, Toronto, ON M5G 2M9, Canada

[3]Joint Department of Medical Imaging, Mount Sinai Hospital, University of Toronto, 600 University Ave., Toronto, ON M5G 1X5, Canada

[4]Division of Biostatistics, Dalla Lana School of Public Health, University of Toronto, 155 College St, Toronto, ON M5T 3M7, Canada

Abstract

Objective: To correlate the findings on 3T multiparametric prostate MRI using PIRADS version 2 with prostate biopsy results as the standard of reference.
Materials and methods: 134 consecutive treatment naive patients (mean age 64 years, range 41–82 years) underwent MRI-directed prostate biopsy. MRI–TRUS fusion biopsy was used for 77 (77/134 = 57.5%) patients, cognitive fusion for 51 (51/134 = 38.0%) patients, and 6 patients (6/134 = 4.5%) without a target nodule had systematic biopsy only. Out of the 1676 biopsy sites, 237 (237/1676 = 14.1%) were positive on MRI for a PIRADS 3, 4, or 5 nodule. Fifty-eight (58/134, 43.3%) patients had clinically significant prostate cancer (csPCa). The findings on MRI using PIRADS version 2 were correlated with the biopsy results.
Results: The accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of PIRADS ≥ 3 for csPCa were 89%, 76.5%, 89.7%, 31.7%, and 98.4%, respectively. The detection rates of csPCa for PIRADS 3, 4, and 5 nodules were 6.1% (4/66), 33.3% (42/126), and 64.4% (29/45), respectively. MRI did not identify a nodule in 23/1676 (1.4%) biopsy sites that contained csPCa. The MRI reader, biopsy operator, method of fusion biopsy, and zonal location of prostate nodule did not significantly affect the odds of having a biopsy result positive for csPCa.
Conclusion: PIRADS ≥ 3 had high specificity and high negative predictive value for csPCa using biopsy results as the standard of reference. The presence of csPCa from a biopsy site was highly unlikely in the absence of a corresponding PIRADS ≥ 3 nodule.

Key words: Prostate MRI—PI-RADS—Prostate biopsy—Prostate cancer

Multiparametric prostate MRI is useful for the detection of clinically significant prostate cancer (csPCa) [1, 2]. In order to help guide and standardize image acquisition, interpretation and reporting of prostate MRI, the European Society of Urogenital Radiology introduced the Prostate Imaging Reporting and Data System (PIRADS) in 2012 [3]. In December 2014, using best available evidence and expert consensus opinion, the updated and simplified PIRADS version 2 (PIRADSv2) was introduced [4].

Several guidelines have emphasized the importance of quality assurance programs for prostate MRI [5, 6]. Quality assurance should include correlation of findings on MRI with pathology results. The most accurate way to correlate MRI findings with pathology results is with whole-mount specimens from radical prostatectomy. In clinical practice, however, this is neither universally available nor practical. In addition, when whole-mount specimens are used as the only standard of reference, the analysis could be biased toward patients with csPCa.

Correspondence to: Shobhit Mathur; *email:* shobhit.mathur@uhn.ca

The finding on prostate MRI of a PIRADS ≥ 4 nodule typically leads to a targeted biopsy. However, some authors have proposed a threshold of PIRADS ≥ 3, depending on clinical parameters [7, 8]. An MRI-directed biopsy may be performed with cognitive fusion, transrectal US–MRI fusion, or in-gantry MRI. Each of these biopsy methods has its own advantages and disadvantages related to procedure time, costs, and operator expertise [9]. In practice, the cognitive and transrectal US–MRI fusion biopsy methods have been most widely used and studied. Regardless of the method used, the biopsy results are then used to guide management and treatment decisions.

Although the recommendations for PIRADSv2 apply to 1.5T and 3T MRI scanners, most members of the PI-RADS Steering Committee prefer, use, and recommend 3T for prostate MRI [10].

The purpose of our study was to correlate the findings on 3T multiparametric prostate MRI using PIRADSv2 with the subsequent prostate biopsy results as the standard of reference.

Materials and methods

Patients

This single-center retrospective study was approved by our research ethics board. The requirement for informed consent was waived. An electronic search of our prostate biopsy center database was performed to identify patients that had a prostate biopsy between March 31, 2016 and November 30, 2016 and a corresponding prostate MRI performed at our institution up to 6 months before the biopsy date. During the study period, a total of 249 patients had a prostate biopsy; 90 patients were excluded from the study because they did not have a prostate MRI at our institution within 6 months of the biopsy, 16 patients were excluded because they were previously treated for prostate cancer, and 9 patients were excluded as the MRI study was performed on a 1.5T scanner. The final study group included 134 patients who were treatment-naïve for prostate cancer and had a prostate biopsy and corresponding prostate MRI performed on a 3T scanner within 6 months of the biopsy for correlation.

MRI protocol

Routine prostate MRI examinations were performed on a 3T scanner (Skyra, Siemens Healthcare) with an 18-channel phased array body coil. The following sequences were obtained: localizer; sagittal, axial, and coronal T2 weighted; axial T1 weighted; axial DWI (diffusion-weighted imaging); axial 3D-DCE (3 dimensional-dynamic contrast enhanced); and axial T1W post-contrast fat-saturated images. The major sequences are summarized in Table 1.

DWI included *b*-values of 100, 400, 800, 1600 s/mm^2 and a calculated *b*-value of 2000 s/mm^2. The calculated *b*-value was added to the protocol on June 1, 2016. For DCE imaging, 32 measurements were performed, with mean temporal resolution of 5.8 s. Immediately prior to imaging, 30 mg of hyoscine butylbromide was injected intravenously to suppress bowel peristalsis. For the contrast-enhanced images, Gadobutrol (Gadovist, Bayer Inc.) was injected intravenously (dose: 0.1 mL/kg) at the rate of 2 mL/s using a power injector (Medrad Spectris Solaris, Bayer Healthcare) followed by 30 mL of normal saline at the rate of 2 mL/s.

MRI interpretations

All prostate MRI examinations were interpreted by one of 6 Abdominal Imaging staff radiologists with 1–16 years of staff experience. The image interpretation and categorization of prostate nodules were determined using PIRADSv2 criteria. In March 2015, the staff radiologists made an internal agreement to adopt PIRADSv2 for reporting prostate MRI. In our practice, only nodules with a PIRADSv2 category ≥ 3 are routinely reported.

Prostate biopsy

All transrectal prostate biopsies were performed by 1 of 5 Abdominal Imaging staff radiologists with 6–30 years of staff experience with prostate imaging and intervention. For each patient, the prostate MRI images and report were reviewed immediately before biopsy. The method of prostate biopsy, cognitive fusion vs. MRI–TRUS fusion and type of prostate biopsy (targeted alone vs. targeted plus systematic), was determined by the preference of the referring urologist and the radiologist performing the biopsy. MRI–TRUS fusion biopsy was performed using the Artemis biopsy device (Eigen, Grass Valley, CA). Biopsy samples corresponding to each MRI nodule and each systematically sampled site were placed in individual containers labeled according to the anatomic location and sent to Pathology. In general, at least 2 biopsies were obtained from each nodule identified on MRI and 1 biopsy from each systematic site.

The biopsy samples were interpreted by a dedicated genitourinary pathologist at our institution using the Gleason classification system. The pathology results from each site were correlated with the MRI findings.

Prostate MRI and biopsy correlation

The date of the prostate biopsy, age of patient, PSA level, and indication for biopsy were recorded. The following components of the biopsy procedure reports were recorded: biopsy site (location), number of cores from each site, site of MRI nodule targeted for biopsy, biopsy operator, and method of biopsy (cognitive fusion or MRI–TRUS fusion). The date of MRI study, PIRADS

Table 1. MRI protocol

Parameter	T2 weighted imaging	Diffusion-weighted imaging	Dynamic contrast enhanced imaging
Orientation	Sagittal, axial, coronal	Axial	Axial
Repetition time (ms)	3530–5300	5100	247
Echo time (ms)	97–101	75	0.99
Flip angle (°)	150	150	13
Matrix	320 × 310	128 × 128	256 × 192
Field of view (cm)	20	20	25
Section thickness (mm)	3	3	3

scores with nodule sites and MRI reader were recorded from the corresponding MRI reports. The zonal location of the MRI lesion was categorized as PZ (peripheral zone), TZ (transition zone), combined PZ and TZ, or CZ (central zone). For prostate biopsies obtained with MRI–TRUS fusion, the estimated registration error is 3–4 mm [11–13]. For cognitive fusion, the registration error is likely to be greater. Therefore, any core biopsy containing csPCa from the target nodule or from the adjacent systematic site was considered a positive correlation.

Statistical analysis

A biopsy pathology result of either benign or Gleason Score (GS) 6 was considered *negative*, whereas a pathology result of cancer GS ≥ 7 (3 + 4 or 4 + 3) was considered *positive*. The MRI was considered *negative* if there was no nodule reported for a corresponding biopsy site. The MRI was considered *positive* if a PIRADS ≥ 3 nodule was reported for a corresponding biopsy site.

To evaluate the association of each PIRADS category with the biopsy results, a generalized linear mixed-effect logistic regression model was used with each patient as a random intercept. The effect of MRI reader, biopsy operator, biopsy method (cognitive vs. MRI–TRUS fusion), patient age, number of samples from each site, and number of biopsy positive csPCa sites within a prostate gland were tested on the model using both univariate and multivariate analysis. The analysis was performed without and with adjustment for the confounders (different biopsy samples from different sites and number of positive biopsy sites from each patient). Least-squares means was used to test if the zonal location of prostate nodules within a PIRADS category affected the probability of csPCa. Sensitivity, specificity, and positive and negative predictive values were also calculated. A p value less than 0.05 was considered statistically significant. Software R (version 3.4.2, R Foundation for Statistical Computing, Vienna, Austria) was used for statistical analysis.

Results

There were 134 men, aged 41–82 (mean 64; median 65) years with PSA levels ranging from 1 to 36 (mean 8.4; median 7.6) µg/mL. The mean time interval between MRI and subsequent biopsy was 69.9 days (range 0–182 days).

Indications for biopsy were rising PSA with previous negative biopsy (60/134 = 44.8%); active surveillance (56/134 = 41.8%); treatment planning in known prostate cancer (13/134 = 9.7%); and rising PSA (5/134 = 3.7%). Most patients (118/134 = 88.1%) underwent combined systematic and targeted biopsy, while 10 (7.5%) had a targeted biopsy only and 6 (4.5%) had a systematic biopsy only.

The total number of biopsy sites was 1676. The average number of biopsies obtained from each patient was 16.3 (median: 17; range 5–22). MRI–TRUS fusion biopsy was used for 77 (77/134 = 57.5%) patients and cognitive fusion was used for 51 (51/134 = 38.0%) patients. Six patients (6/134 = 4.5%) without a target nodule had systematic biopsy only using transrectal ultrasound.

Out of the 1676 biopsy sites, 237 (237/1676 = 14.1%) were positive on MRI (for PIRADS 3, 4 or 5 nodule) and 98 (98/1676 = 5.8%) were biopsy positive for csPCa. On a per nodule basis, the detection rates of csPCa for PIRADS 3, 4, and 5 were 6.1% (4/66), 33.3% (42/126), and 64.4% (29/45), respectively. Among the 134 patients, the highest PIRADS category was 3 in 23 (23/134 = 17.2%), 4 in 74 (74/134 = 55.2%), and 5 in 31 (31/134 = 23.1%) patients, respectively.

A total of 58 (58/134 = 43.3%) patients had csPCa, while the remainder did not have csPCa on biopsy. On a per patient basis, when considering the index lesion, for PIRADS categories 3, 4, and 5, 2/23 (8.7%), 33/74 (44.6%), and 21/31 (67.7%) patients had csPCa anywhere in the prostate gland, respectively. No MRI nodule was seen in 6 (6/134 = 4.5%) patients, out of which 2 had csPCa on systematic biopsy.

MRI did not identify a nodule in 23/1676 (1.4%) biopsy sites that contained csPCa (GS ≥ 7). These 23 biopsies were from 17 patients (2 patients each had two biopsy sites and 2 patients each had three biopsy sites that were falsely negative on MRI). Out of these 17 patients, 15 (15/17 = 88%) had a true-positive MRI nodule elsewhere in the prostate gland, and 2 patients had no corresponding nodule on MRI.

On analysis of all PIRADS ≥ 3 nodules on MRI, the accuracy, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were 89%, 76.5%, 89.7%, 31.7%, and 98.4%, respectively. On analysis of the PIRADS ≥ 4 nodules (i.e., if PIRADS 3 is considered a negative outcome on MRI), these values were 92.4%, 72.5%, 93.7%, 41.5%, and 98.2%, respectively. The number of biopsy samples from different sites and the number of positive biopsy samples from each patient had a significant effect ($p < 0.05$) on the odds of having a positive biopsy result (and hence were identified as confounders). However, the MRI reader, biopsy operator, patient age, and biopsy method (cognitive vs. MRI–TRUS fusion) had no significant effect ($p > 0.05$) on the odds of having a positive biopsy result. The odds ratio of csPCa with different PIRADS categories without and with adjustment for confounders is summarized in Table 2.

The zonal distribution of the 237 prostate nodules on MRI was PZ 128/237 (54%), TZ 81/237 (34.2%), PZ and TZ 22/237 (9.3%), and CZ 6/237 (2.5%). The zonal distribution of the 75 PIRADS ≥ 3 nodules positive for csPCa was PZ 40/75 (53.3%), TZ 19/75 (25.3%), PZ and TZ 14/75 (18.7%), and CZ 2/75 (2.7%). The zonal location of the nodule within PIRADS categories 3, 4, or 5 had no effect on the odds of having a positive biopsy result of csPCa. Representative images of nodules in the peripheral and transition zones are included in Figs. 1 and 2, respectively (Figs. 1, 2).

Discussion

In our study, PIRADS ≥ 3 had a high specificity and high negative predictive value for csPCa. The detection rate of csPCa increased with a higher PIRADS score: 6.1%, 33.3%, and 64.4% for PIRADS 3, 4, and 5, respectively. This is concordant with results from several prior studies [14–17]. When analyzed without adjusting for confounders, higher odds of csPCa were found with PIRADS 3, 4, and 5. However, after the adjustment, the odds of csPCA were not significantly increased with PIRADS 3, while the odds remained high for PIRADS 4 and PIRADS 5 categories (Table 2). Our results are useful for communicating to the referring urologist and the patient the rationale for proceeding with prostate biopsy when a PIRADS 4 or 5 nodule is present.

Only 4 of 66 (6.1%) PIRADS 3 lesions were found to be associated with csPCa in our study. Studies by Purysko et al. and Zhao et al. found higher cancer detection rates with PIRADS 3 of 14.3–20% and 26–35.1%, respectively [14, 15], while Liddell et al. and Mertan et al. found lower detection rates of 2.2% and 0%, respectively [16, 18]. These results are currently supportive of a tailored approach to the management of PIRADS 3 nodules depending on the clinical scenario (rather than the MRI findings alone). More recent studies have suggested that a high prostate-specific antigen density (PSAD), older age, and an abnormal digital rectal examination (DRE) are associated with an increased yield of csPCa in PIRADS 3 nodules [7, 8]. Future versions of PIRADS should attempt to modify the criteria or provide clearer guidance for PIRADS 3 nodules in order to reduce the number of false-positive biopsies.

In our study, we analyzed the data using each biopsy site as a separate observation. Using the threshold of PIRADS ≥ 3, the higher specificity (89.7%) and lower sensitivity (76.5%) in our study compared to other studies [14, 17, 19–21] are likely due to this different method of analysis. In several previous studies, only the dominant nodule of highest suspicion on MRI was used for analysis, potentially influencing the results [14, 19, 22]. The low PPV (31.7%) in our study compared to other studies [15, 17, 19] is also likely due to the same reason. When PIRADS ≥ 4 was used as the criteria for a positive MRI nodule in our study, the sensitivity decreased to 72.5% (compared to 76.5%) and the specificity increased to 93.7% (compared to 89.7%). Similar results for sensitivity have been shown by other studies using PIRADS ≥ 4 as the threshold. However, in other studies, the specificities have been shown to be lower compared to our study, again likely due to a different approach to analysis [17, 22, 23]. In a recent systematic review by Fütterer et al. [24], the sensitivity, specificity, and posi-

Table 2. Probability of cancer in PIRADS 3, 4 and 5 categories

	Total (% out of total biopsy sites, $n = 1676$)	Positive on biopsy for CS cancer (% out of MRI positive nodules in each category)	Without adjustment for covariates[a]			With adjustment for covariates[a]		
			Odds ratio	p value	CI (confidence interval) 95%	Odds ratio	p value	CI (confidence interval) 95%
PIRADS 3	66 (66/1676 = 3.9%)	4 (4/66 = 6.1%)	5.4	Less than 0.01	1.6–18.2	1.4	0.7	0.3–6.1
PIRADS 4	126 (126/1676 = 7.5%)	42 (42/126 = 33.3%)	54.6	Less than 0.01	25.4–117.5	4.6	0.005	1.6–13.1
PIRADS 5	45 (45/1676 = 2.7%)	29 (29/45 = 64.4%)	274.9	Less than 0.01	84.3–895.8	4.6	0.018	1.3–16.5

[a]Covariates which were adjusted: number of samples from each site and number of positive samples in each prostate

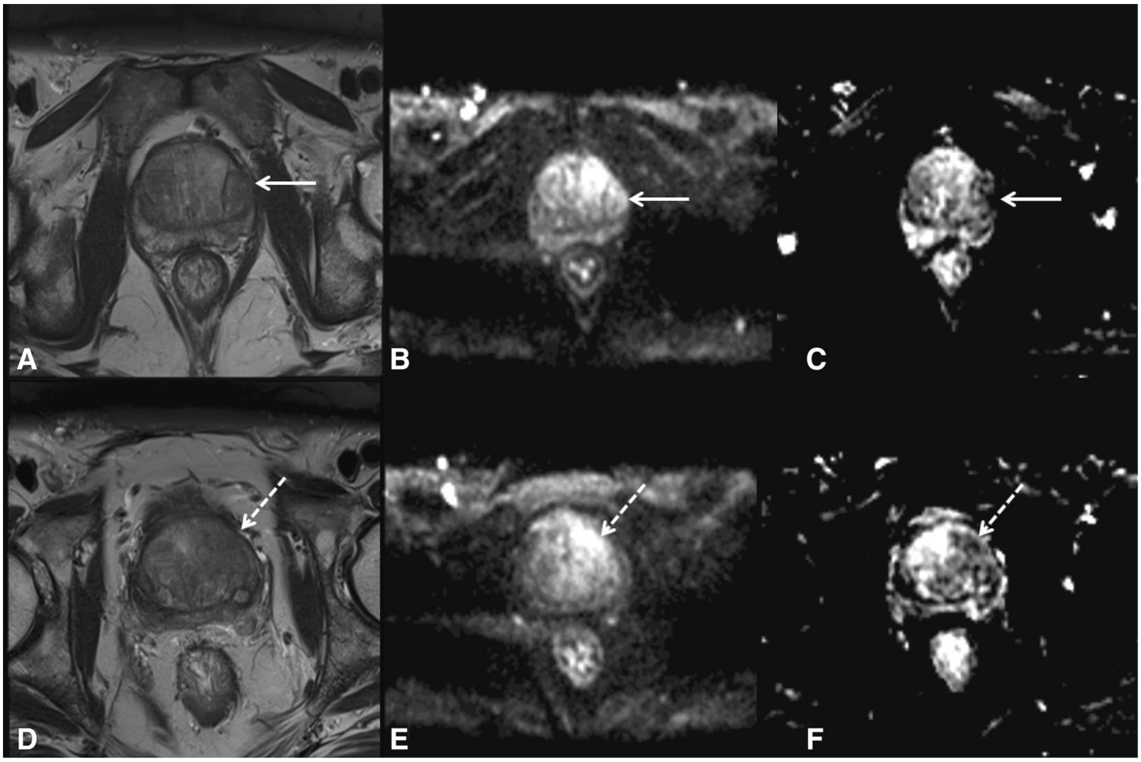

Fig. 1. True-positive PIRADS 4 and false-positive PIRADS 5 nodules in transition zone. A 69-year-old male with rising PSA (7.7 μg/mL) and previous negative biopsy. Axial T2 weighted image (**A**) shows an ill-defined, homogenous, hypointense area in left lateral transition zone in midgland measuring 1.2 cm with mildly high signal on high *b*-value DWI (**B**) and low ADC (**C**) and was categorized as PIRADS 4 nodule (arrow). A Gleason 7 (3 + 4) adenocarcinoma was found on subsequent MRI–TRUS fusion biopsy. Additional ill-defined, homogenous, T2 hypointense, 2.5-cm-sized nodule more superiorly in the left transition zone in midgland (**D**) with restricted diffusion (**E**, **F**) was categorized as PIRADS 5 nodule (dashed arrow). This was negative for cancer on MRI–TRUS fusion biopsy.

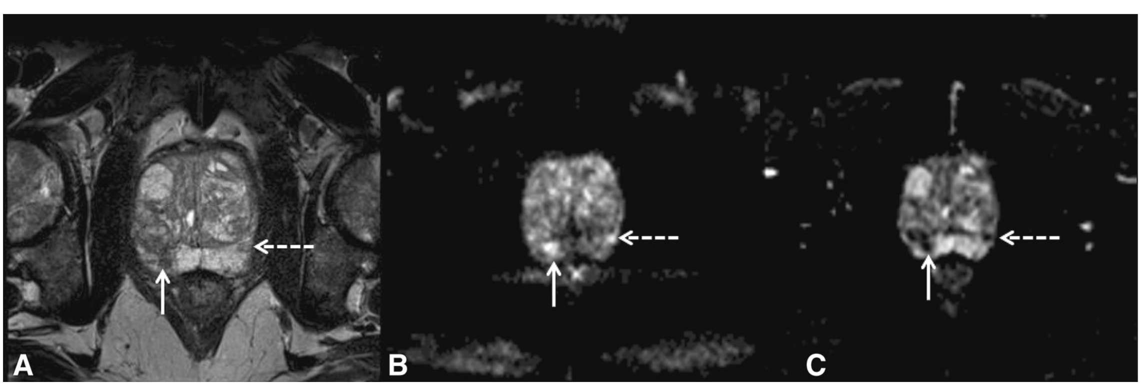

Fig. 2. True-positive PIRADS 4 and false-positive PIRADS 4 nodules in peripheral zone. A 60-year-old male on active surveillance (PSA: 3.9 μg/mL). Axial T2 weighted image (**A**) shows small hypointense nodules in right (arrow) and left (dashed arrow) peripheral zone which demonstrate high signal on high *b*-value DWI (**B**) and low ADC (**C**); both were categorized as PIRADS 4. On MRI–TRUS fusion biopsy, the right nodule was found to be Gleason 7 (3 + 4) adenocarcinoma, while the left nodule was a Gleason 6 (3 + 3) adenocarcinoma.

tive and negative predictive values for detection of csPCa by MRI ranged from 58 to 96%, 23 to 87%, 34 to 68%, and 63 to 98%, respectively.

The high NPV (98.4%) found in our study is concordant with previous publications [15, 17, 19, 24] that supports the potential role of MRI to screen for csPCa. In our study, MRI did not identify the presence of csPCa in 23 sites in 17 patients. However, in 15/17 (88%) of these patients, a true-positive MRI nodule was present elsewhere in the prostate gland. There were only 2 patients (2/134 = 1.5%) that had csPCa and no PIRADS ≥ 3 nodule. The high specificity along with the high NPV of MRI for csPCa in our study suggests that MRI could potentially be used to decide if patients with previous negative systematic biopsy could undergo a targeted biopsy only and a concurrent systematic biopsy may not be required. However, larger studies with long-term follow-up are required to confirm these results.

In our study, the method of fusion biopsy (cognitive vs. MRI–TRUS) did not affect the odds of csPCa from a target nodule which is in agreement with many prior studies [25, 26]. However, some studies have shown superior performance of MRI–TRUS fusion compared to cognitive fusion [27]. Also, the odds of csPCa were not affected by the MRI reader or biopsy operator. These results may be related to the level of experience of our radiologists with prostate biopsy and prostate MRI and may not necessarily apply to operators with less experience.

Some studies have found a better performance of PIRADSv2 for PZ lesions compared to TZ lesions [14, 17], particularly for PIRADS 3 nodules [17, 19]. In our study, the zonal location of the MRI lesion did not affect the probability of cancer in any of the PIRADS categories.

Our study is unique in that it attempted to account for PIRADSv2 categories assigned to different sites within the prostate gland. In addition, we identified and adjusted for confounding factors of different sample numbers from each site and the number of biopsy positive sites within each prostate gland. This was done to enhance the location-based assessment of MRI for predicting csPCa.

Our study has some limitations. This was a single-center, retrospective study, and is limited due to selection bias. It is possible that some patients had a prostate MRI at our institution and a subsequent biopsy elsewhere. However, this is unlikely as prostate MRI is a specialized service in our region and the vast majority of patients that have an MRI at our institution will also have a biopsy at the same institution. We used the original prospective prostate MRI reports of staff radiologists who were not blinded to the clinical information rather than a blinded single reader in an attempt to gain insight into our own practice and provide feedback to our radiologists. The approach and results of our study may serve as a useful reference for other practices that wish to implement a similar quality assurance initiative. We used the biopsy results as the standard of reference rather than whole-mount pathology specimens. In clinical practice, it is the outcome of the biopsy results that predominately influence patient management. In addition, not all patients with csPCa will ultimately be treated with radical prostatectomy.

Conclusion

PIRADS ≥ 3 on 3T MRI had high specificity and high negative predictive value for csPCa using biopsy results as the standard of reference. The presence of csPCa from a biopsy site was highly unlikely in the absence of a corresponding PIRADS ≥ 3 nodule.

Author contributions SM: Conceptualization, methodology, data acquisition/analysis, literature review, investigation, validation, writing. MEO and AT: Conceptualization, methodology, data acquisition, clinical studies, literature review, investigation, validation, writing, administration, supervision. SG, KJ, MM, and BS: Conceptualization, methodology, clinical studies, literature review, investigation, validation, writing. LZ: Methodology, literature review, literature review, investigation, data analysis, writing. HM: Conceptualization, methodology, data acquisition/analysis, literature review, investigation, writing.

Compliance with ethical standards

Funding None.

Conflict of interest None.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent Waived by institutional Research Ethics Board for this retrospective study.

References

1. Ahmed HU, El-Shater Bosaily A, Brown LC, et al. (2017) Diagnostic accuracy of multi-parametric MRI and TRUS biopsy in prostate cancer (PROMIS): a paired validating confirmatory study. Lancet 389:815–822. https://doi.org/10.1016/S0140-6736(16)32401-1
2. De Rooij M, Hamoen EHJ, Fütterer JJ, Barentsz JO, Rovers MM (2014) Accuracy of multiparametric MRI for prostate cancer detection: a meta-analysis. Am J Roentgenol 202:343–351. https://doi.org/10.2214/AJR.13.11046
3. Barentsz JO, Richenberg J, Clements R, et al. (2012) ESUR prostate MR guidelines 2012. Eur Radiol 22:746–757. https://doi.org/10.1007/s00330-011-2377-y
4. American College of Radiology (2015) MR prostate imaging reporting and data system version 2.0. ACR Webpage
5. Rosenkrantz AB, Verma S, Choyke P, et al. (2016) Prostate magnetic resonance imaging and magnetic resonance imaging targeted biopsy in patients with a prior negative biopsy: a consensus statement by AUA and SAR. J Urol 196:1613–1618. https://doi.org/10.1016/j.juro.2016.06.079
6. Salerno J, Finelli A, Morash C, et al. (2016) Multiparametric magnetic resonance imaging for pre-treatment local staging of prostate cancer: a Cancer Care Ontario clinical practice guideline. Can Urol Assoc J 10:332. https://doi.org/10.5489/cuaj.3823
7. Felker ER, Raman SS, Margolis DJ, et al. (2017) Risk stratification among men with prostate imaging reporting and data system version 2 category 3 transition zone lesions: is biopsy always necessary? Am J Roentgenol 209:1272–1277. https://doi.org/10.2214/AJR.17.18008
8. Sheridan AD, Nath SK, Syed JS, et al. (2017) Risk of clinically significant prostate cancer associated with prostate imaging reporting and data system category 3 (equivocal) lesions identified

on multiparametric prostate MRI. Am J Roentgenol . https://doi.org/10.2214/AJR.17.18516
9. Verma S, Choyke PL, Eberhardt SC, et al. (2017) The current state of MR imaging-targeted biopsy techniques for detection of prostate cancer. Radiology 285:343–356. https://doi.org/10.1148/radiol.2017161684
10. Weinreb JC, Barentsz JO, Choyke PL, et al. (2016) PI-RADS Prostate imaging—reporting and data system: 2015, version 2. Eur Urol 69:16–40. https://doi.org/10.1016/j.eururo.2015.08.052
11. Fedorov A, Khallaghi S, Sánchez CA, et al. (2015) Open-source image registration for MRI–TRUS fusion-guided prostate interventions. Int J Comput Assist Radiol Surg 10:925–934. https://doi.org/10.1007/s11548-015-1180-7
12. Sparks R, Bloch BN, Feleppa E, et al. (2015) Multiattribute probabilistic prostate elastic registration (MAPPER): application to fusion of ultrasound and magnetic resonance imaging. Med Phys 42:1153–1163. https://doi.org/10.1118/1.4905104
13. Martin PR, Cool DW, Romagnoli C, Fenster A, Ward AD (2014) Magnetic resonance imaging-targeted, 3D transrectal ultrasound-guided fusion biopsy for prostate cancer: quantifying the impact of needle delivery error on diagnosis. Med Phys 41:73504. https://doi.org/10.1118/1.4883838
14. Purysko AS, Bittencourt LK, Bullen JA, et al. (2017) Accuracy and interobserver agreement for prostate imaging reporting and data system, version 2, for the characterization of lesions identified on multiparametric MRI of the prostate. Am J Roentgenol 2:1–7. https://doi.org/10.2214/AJR.16.17289
15. Zhao C, Gao G, Fang D, et al. (2016) The efficiency of multiparametric magnetic resonance imaging (mpMRI) using PI-RADS version 2 in the diagnosis of clinically significant prostate cancer. Clin Imaging 40:885–888. https://doi.org/10.1016/j.clinimag.2016.04.010
16. Mertan FV, Greer MD, Shih JH, et al. (2016) Prospective evaluation of the prostate imaging reporting and data system version 2 for prostate cancer detection. J Urol 196:690–696. https://doi.org/10.1016/j.juro.2016.04.057
17. Kim SH, Choi MS, Kim MJ, Kim YH, Cho SH (2017) Validation of prostate imaging reporting and data system version 2 using an MRI–ultrasound fusion biopsy in prostate cancer diagnosis. Am J Roentgenol 209:800–805. https://doi.org/10.2214/AJR.16.17629
18. Liddell H, Jyoti R, Haxhimolla HZ (2014) Mp-MRI prostate characterised pirads 3 lesions are associated with a low risk of clinically significant prostate cancer-a retrospective review of 92 biopsied pirads 3 lesions. Curr Urol 8:96–100. https://doi.org/10.1159/000365697
19. Baldisserotto M, Neto EJD, Carvalhal G, et al. (2016) Validation of PI-RADS v. 2 for prostate cancer diagnosis with MRI at 3T using an external phased-array coil. J Magn Reson Imaging 44:1354–1359. https://doi.org/10.1002/jmri.25284
20. Rosenkrantz AB, Ginocchio LA, Cornfeld D, et al. (2016) Interobserver reproducibility of the PI-RADS version 2 Lexicon: a multicenter study of six experienced prostate radiologists. Radiology 280:793–804. https://doi.org/10.1148/radiol.2016152542
21. Woo S, Suh CH, Kim SY, Cho JY, Kim SH (2017) Diagnostic performance of prostate imaging reporting and data system version 2 for detection of prostate cancer: a systematic review and diagnostic meta-analysis. Eur Urol 72:177–188. https://doi.org/10.1016/j.eururo.2017.01.042
22. Park SY, Jung DC, Oh YT, et al. (2016) Prostate cancer: pI-RADS version 2 helps preoperatively predict clinically significant cancers. Radiology 280:108–116. https://doi.org/10.1148/radiol.16151133
23. Muller BG, Shih JH, Sankineni S, et al. (2015) Prostate cancer: interobserver agreement and accuracy with the revised prostate imaging reporting and data system at multiparametric MR imaging. Radiology 277:741–750. https://doi.org/10.1148/radiol.2015142818
24. Fütterer JJ, Briganti A, De Visschere P, et al. (2015) Can clinically significant prostate cancer be detected with multiparametric magnetic resonance imaging? A systematic review of the literature. Eur Urol 68:1045–1053. https://doi.org/10.1016/j.eururo.2015.01.013
25. Wysock JS, Rosenkrantz AB, Huang WC, et al. (2014) A prospective, blinded comparison of magnetic resonance (MR) imaging-ultrasound fusion and visual estimation in the performance of MR-targeted prostate biopsy: the profus trial. Eur Urol 66:343–351. https://doi.org/10.1016/j.eururo.2013.10.048
26. Puech P, Rouvière O, Renard-Penna R (2013) Prostate cancer diagnosis: multiparametric MR-targeted biopsy with cognitive and transrectal US–MR fusion guidance versus systematic biopsy. Radiology 268:461–469. https://doi.org/10.1148/radiol.13121501/-/DC1
27. Cool DW, Zhang X, Romagnoli C, et al. (2015) Evaluation of MRI–TRUS fusion versus cognitive registration accuracy for MRI-targeted, TRUS-guided prostate biopsy. Am J Roentgenol 204:83–91. https://doi.org/10.2214/AJR.14.12681